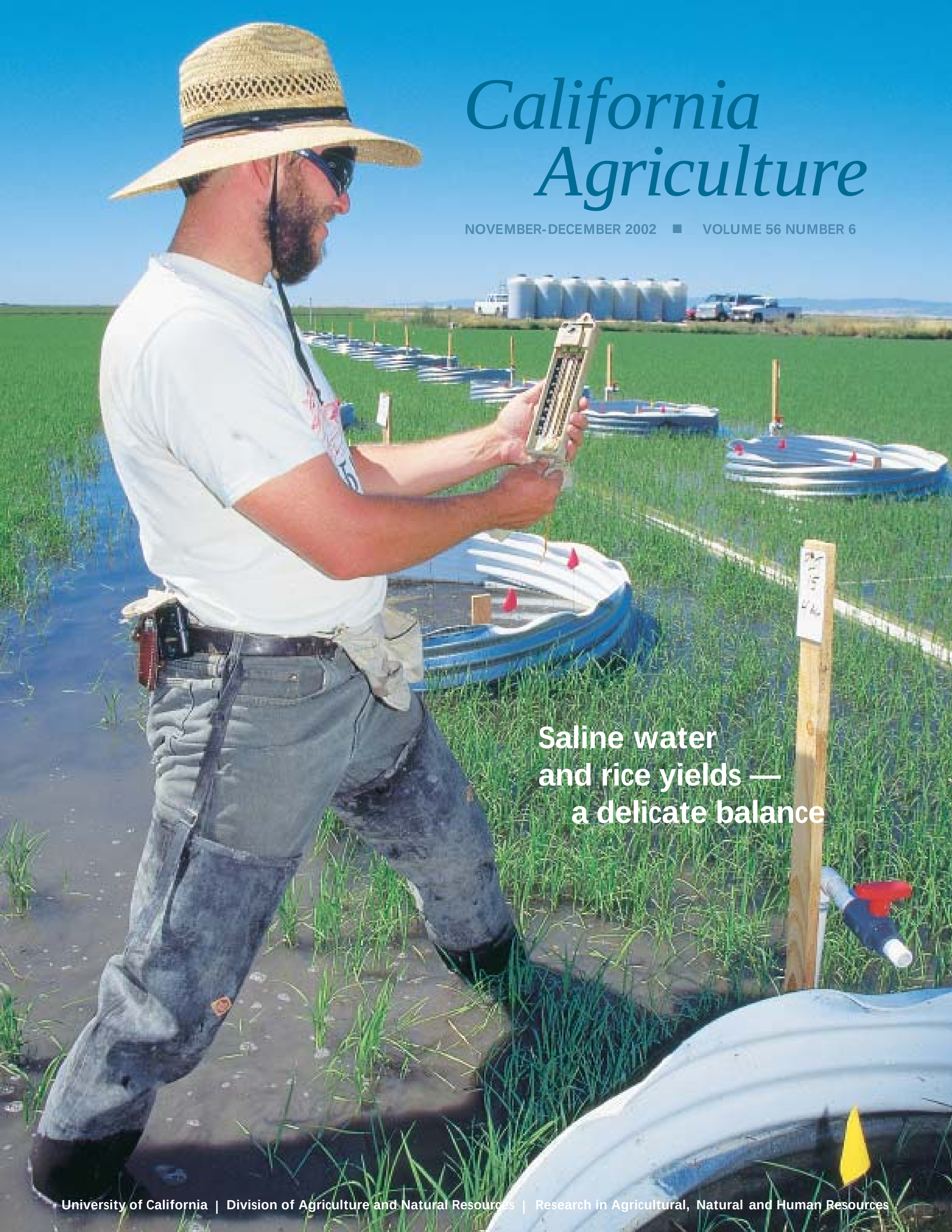
California Agriculture

NOVEMBER-DECEMBER 2002 ■ VOLUME 56 NUMBER 6



Saline water and rice yields — a delicate balance

Research budget cuts challenge ANR

W.R. GOMES
Vice President
Agriculture and Natural Resources

For more than a century, Californians have looked to UC for the scientific advances and practical research discoveries needed to maintain productive farms and ranches, a healthy environment, and a safe and nutritious food supply. In today's highly competitive, rapidly changing world this reliance on the University for science-based, cost-effective innovation is greater than ever.

Look at the critical issues facing Californians — agricultural sustainability, food safety and security, exotic pests and diseases, international trade and competitiveness, environmental quality, nutrition and public health — and you're likely to find UC scientists on the forefront of research and discovery.

However, our ability to continue to address these important issues, much less maintain the core research capacity necessary to anticipate and respond to the challenges of tomorrow, is at grave risk if current budget trends are not reversed. California's severe economic downturn — and a $24 billion budget shortfall in the state's coffers — resulted in significant cuts in research funding for UC in the fiscal 2002-03 state budget. This budget contains the largest single-year cut for research in University history — totaling $32 million, or 10% of state general funds committed to UC research.

The impact on the Division of Agriculture and Natural Resources (ANR) is especially dramatic, with nearly one-third of the research cut — equal to $10 million — to be absorbed by the Agricultural Experiment Station (AES). As the largest multicampus research unit in the UC system, the AES supports research activities on the Berkeley, Davis and Riverside campuses and statewide. More than 650 scientists from nearly 50 academic departments hold AES appointments, which fund core salaries and benefits and operational expenses. Around 85% of our state research funds are committed for these purposes.

Currently, we are making permanent cuts of $10 million to AES programs at the campus and systemwide levels (see p. 181). We do this with full knowledge that today's decisions will have lasting impacts well into the future.

At the campus level, the deans of the College of Natural Resources (Berkeley), College of Agricultural and Environmental Sciences (Davis), College of Natural and Agricultural Sciences (Riverside) and School of Veterinary Medicine (Davis) are taking about $8 million in cuts. The remaining $2 million will come from statewide operations under my office. These include the research and extension centers, statewide special programs and projects, and administrative support. Rather than make across-the-board cuts, we have decided to assess administration at a higher rate than programs with a strong research component.

As a result, Oakland-based and statewide administrative offices will sustain larger reductions, averaging 13%. Statewide special programs and projects (such as the Statewide Integrated Pest Management Project, Sustainable Agriculture Research and Education Program, Small Farms Center and Mosquito Research Program) will take cuts of around 4%. Some specific examples of other steps being taken in my office to meet the overall 10% cut include:

- All existing discretionary funds for new programs, "seed" efforts or unexpected issues will be eliminated.
- The number of issues of *California Agriculture* will be reduced from six to four in 2003, with substantial savings in printing costs and postage.
- *ANR Report*, our internal newsletter, will move from hard copy to an electronic format, with estimated annual savings of more than $15,000 and speedier delivery.

Despite the cost-cutting measures being implemented across the campuses and in my office, we know that reductions in state general funding for the AES will result in the loss of research faculty and staff. The cuts will also limit acquisition of new laboratory equipment and the upgrading of research facilities.

In the near-term the situation may become more difficult. There is speculation that UC and state agencies will face further midyear cuts, with additional budget reductions looming in 2003-04 if the state's economy doesn't rebound. To position ourselves for this contingency, we have instituted a hiring freeze on positions supported by state funds in my office. This freeze affects all new and vacant Cooperative Extension positions and all staff positions.

Cuts in state research funds beyond this year's 10% would be particularly difficult for our AES programs to absorb. Further cuts also don't make economic sense over the long run, as they would severely restrict our ability to meet new and evolving challenges. State research funds allow AES researchers to deal rapidly with emerging issues such as the outbreak of Pierce's disease in grapes, the spread of sudden oak death syndrome along the coast and the discovery of West Nile virus in Southern California. AES scientists also leverage state funds at greater than a 1:1 ratio, competing successfully for grants from government agencies and the private sector. It's a win-win for Californians.

The future promises more, not less, of these critical, often unforeseen problems, requiring immediate response. On the horizon are bioterrorism, new insect, plant and microbial diseases, economic hardships and dislocation that come with the loss of rural industries and jobs, and the increasing need for nutrition research that provides a foundation for better health and disease prevention. Will we be prepared?

One of our strengths in the Division is that our research capabilities span not only the agricultural sciences, but also human and natural resources. No other institution serves statewide needs in these areas with the same breadth and depth of world-class scientists, the same systematic know-how and the same sophistication in laboratory facilities. We are willing to share our part of the economic downturn, but if we are to survive and rebuild, we must keep basic capabilities intact.

California Agriculture

News and Peer-reviewed Research published bimonthly by the Division of Agriculture and Natural Resources, University of California
VOLUME 56, NUMBER 6

California Agriculture
1111 Franklin St., 6th floor
Oakland, CA 94607-5200
Phone: (510) 987-0044; Fax: (510) 465-2659
calag@ucop.edu
http://danr.ucop.edu/calag

Mailed at periodicals postage rates at Oakland, CA and at additional mailing offices. Postmaster: Send change of address "Form 3579" to California Agriculture at the above address. (ISSN 0008-0845)

RATES: Subscriptions free upon request in U.S.; $18/year outside the U.S. After publication, the single copy price is $4.00. Orders must be accompanied by payment. Payment may be by check or international money order in U.S. funds payable to UC Regents. MasterCard/Visa accepted; requests require signature and card expiration date. Please include complete address.

RESUBSCRIBE

LAST CHANCE

If you wish to continue receiving your free subscription to *California Agriculture*, you must return the postage-paid postcard on the wraparound cover, or go to htpp://danr.ucop.edu/calag and fill out the resubscribe form. To receive confirmation, include your e-mail.

COVER: With a production value of $138 million in 2001, rice is an important California field crop. Grown in flooded conditions, rice is also one of the crops considered most sensitive to salinity. In a series of field and greenhouse studies, scientists with UC and USDA determined that rice is significantly more sensitive to salinity than previous guidelines suggest. By carefully managing water in fields, particularly at growth stages when rice is most salt-sensitive, farmers can limit crop damage and optimize yields. *Above,* Former UC Davis post-graduate researcher Bill Thomas takes measurements in a grower's rice field, which was outfitted with large metal rings to study the impacts of various salinity levels in soil and water. *Photo by Jack Kelly Clark.*

News departments

Science briefs

180 The buzz on mosquito, malaria genetic codes

Centers to combat "agro-terror"

181 State budget calls for 10% research cut

UC offers online course for grape pest advisors

Research update

182 SOD pathogen hits coast redwoods, Douglas fir

183 Beahrs international program trains professionals in sustainable development

Research articles

184 Water management practices can affect salinity in rice fields
Scardaci et al.

Extensive sampling in rice fields showed that salinity can increase during water holding periods and as irrigation water flows from top to bottom basins.

189 Rice is more sensitive to salinity than previously thought
Grattan et al.

Field and greenhouse studies determined a new salinity threshold level above which salt stress occurs, reducing rice yields.

196 California mealybugs can spread grapevine leafroll disease
Golino et al.

Using new technology and recently developed techniques, the authors confirmed for the first time that grape and obscure mealybug are grapevine virus vectors**.**

202 Proper harvest timing can improve returns for intermountain alfalfa
Orloff, Putnam, Blank

A decision model will help alfalfa growers choose optimal cutting times, in order to quantify the yield-quality trade-off and its effect on return.

Jessica Glikshtern has joined the *California Agriculture* staff as our new publications assistant. Jessica comes to us from Macromedia where she worked as a an editor/copywriter. Prior to that, Jessica spent 2 years as a marketing coordinator at Novo, a San Francisco Internet firm. While studying rhetoric at UC Berkeley, Jessica worked as an editorial assistant for a travel guide with Greenline Publications.

Lobsang Wangdu

The buzz on mosquito, malaria genetic codes

In October announcements, two international teams of scientists reported sequencing the entire genomes of the malaria-carrying mosquito, and the malarial parasite itself. These breakthroughs will provide powerful tools to scientists struggling against malaria, which afflicts 500 million people worldwide and causes up to 2.7 million deaths annually (more than 90% in sub-Saharan Africa).

The simultaneous publications included a *Science* article detailing the genome of the mosquito *Anopheles gambiae* and a *Nature* article detailing the genome of the parasite *Plasmodium falciparum*. The *Science* article listed 123 authors, including three at UC Riverside; the *Nature* article listed 44 authors.

Jack Kelly Clark

Sequencing of the mosquito genome could help to prevent malaria, which kills 2.7 million people annually. However, the scientific community was urged to use caution when pursuing genetic modification of insects.

"The economic cost to affected nations is immense," says Peter Atkinson, co-author and UC Riverside associate professor of entomology. "No vaccine has been developed for malaria. Understanding the genetic makeup of the mosquito that transmits malaria will help with the design of new strategies to fight this disease."

In addition to Atkinson, postdoctoral researcher Peter Arensburger and graduate student Lisa Friedli are co-authors of the *Science* paper, analyzing the genome for one class of transposable elements.

In the same issue of *Science*, UC Davis medical entomologist Thomas Scott and colleagues called upon the scientific community to use caution in applying this new knowledge to genetic modification of mosquitoes. With the release of the genetic sequences, they noted, scientists are now better able to explore the use of genetically modified, disease-resistant mosquitoes. Such mosquitoes could be used to breed with, and largely replace, their disease-causing counterparts in the wild.

If this new strategy is to succeed, however, the very basic ecology and population biology of mosquitoes needs to be better understood, Scott and colleagues wrote.

The October disclosures also came on the heels of a September announcement that the National Institutes of Health had awarded a 10-year, $4.3 million research grant to Alexander Raikhel, UC Riverside entomology professor. The grant will support continuing investigation into the genetic and molecular mechanisms regulating egg development and maturation in mosquitoes. The research has implications for the prevention of deadly, mosquito-transmitted diseases, including malaria, West Nile virus and dengue fever.

Centers to combat "agro-terror"

UC Davis recently received two major grant awards to help combat "agro-terror" by protecting crop plants and food from contamination, disease, pests or pathogens, whether introduced accidentally or by terrorist acts.

A $900,000 homeland security grant from the U.S. Department of Agriculture (USDA) will provide the initial funding for a new Western Center for Plant Disease and Pest Surveillance and Detection at UC Davis, coordinated by the College of Agricultural and Environmental Sciences. "Establishing an effective network for monitoring, detecting and diagnosing plant pests and diseases will be a challenging but vital task," says center director Richard Bostock, chair of the UC Davis plant pathology department.

And a new $5 million center located at UC Davis, the Western Institute for Food Safety and Security, will facilitate a partnership between UC, the California Department of Food and Agriculture and the California Department of Health Services. "Our food supply is increasingly subject to contamination from both biological and chemical sources; and now we have the new threat of intentional contamination of food through bioterrorism," says Jerry Gillespie, institute director and UC Davis veterinary pathologist.

In September, a National Research Council report concluded that the United States is vulnerable to agricultural bioterrorism and needs a comprehensive defense plan. "Biological agents that could be used to harm crops or livestock are widely available and pose a major threat to U.S. agriculture," NRC committee chair Harley Moon of Iowa State University said. (The committee began its study prior to the September 11 attacks and the subsequent anthrax outbreak.) Over the past year, the federal government has allocated an additional $328 million to USDA for homeland security programs to protect the food supply, including $43 million for research to states and land-grant universities.

The plant-disease and pest network will concentrate on linking personnel, information systems and databases at diagnostic laboratories throughout the western region to better track the health of crops or the progression of a disease or insect outbreak.

The food safety institute's mission will be to develop the capability to identify food-borne hazards more rapidly and accurately, as well as methods to prevent natural and intentional food contamination. One area of emphasis will be the development of rapid diagnostic tests for disease-causing microbes such as *Salmonella*, deadly strains of *E. coli*, *Cryptosporidium*, anthrax and foreign foodborne diseases such as "mad cow disease."

State budget calls for 10% research cut

With a 10% permanent reduction in state financial support for University research, the state's fiscal 2002-03 budget calls for a $32 million cut in UC's organized research funding (see p. 178). The across-the-board cut was among several targeted reductions specified for the University. Overall, the state is providing $3.2 billion for UC's operating budget in 2002-03, about 3% less than last year.

The cut in organized research affects programs throughout the University, including those conducted by the Agricultural Experiment Station (AES) at the Berkeley, Davis and Riverside campuses. Also included are AES funds managed through the Office of the Vice President in the Division of Agriculture and Natural Resources (ANR).

The Division's senior administrators expect the impact of this budget reduction to be substantial and long-lasting. "State agencies have been asked to plan for a 20% reduction in funding for 2003-04," says W.R. Gomes, ANR vice president. "The University budget and that of ANR will no doubt sustain further reductions, beyond those taken in 2003-04. The extent of these reductions is unpredictable at this time."

This cut is "relatively harsher" for the Division than it might seem at first blush, notes ANR associate vice president Henry Vaux Jr., because "we have never recovered financially from the severe budget cuts of the early 1990s." Like Gomes, Vaux doesn't expect the fiscal situation to improve soon. "The bottom line is we anticipate that there are going to be even larger cuts next year — and the reserves that helped buffer the impact of this year's cuts are gone," he says.

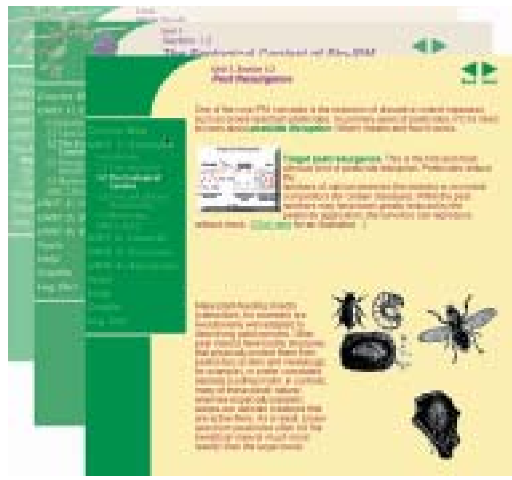
UC offers online course for grape pest advisors

Faced with increasingly stringent environmental regulations — including more rigorous state licensing requirements that go into effect Jan. 1, 2003 — pest control advisors (PCAs) for grapes can now obtain important information in a new online course developed by the UC Davis-based Sustainable Agriculture Research and Education Program (SAREP).

"Ecological Pest Management in Grapes" is the first online course of its kind in California, and perhaps the nation, that is completely Web-based and has undergone scientific peer-review, says Chris Geiger, California Department of Pesticide Regulation (DPR) entomologist. Geiger, formerly of SAREP, created the course with SAREP education coordinator David Chaney, in consultation with an advisory committee of UC scientists and grape PCAs. "As environmental regulations become tighter and older pesticides are removed from the market or heavily restricted, many growers are modifying their production systems to include more ecologically based approaches to controlling pests," Chaney says.

Pest management professionals can play a key role in this transition process, providing clients with information on the biology of pests and natural enemies, sampling programs, decision support tools and knowledge of softer, less disruptive pest control materials.

By making use of up-to-date educational technologies, the self-guided course offers a highly interactive educational experience. It includes inquiry-based, problem-solving simulations, and interactive self-tests.



Grape pest advisors have a new educational tool — the first online course that has been peer reviewed by UC scientists. "Because it's on the Web, students can progress at their own pace," says Chris Geiger of the California Department of Pesticide Regulation, who co-developed the program.

The course covers the biology of specific organisms in the grape ecosystem, field diagnosis and monitoring techniques and summaries of the best available decision-making tools and management options. Graded multiple-choice exams are taken online, and are used to determine the number of continuing education credits students receive.

The course advisory committee included: Jenny Broome, SAREP associate director; Clifford Ohmart, Lodi-Woodbridge Winegrape Commission; Kent Daane, UC Berkeley Extension assistant specialist; Rhonda Smith, viticulture farm advisor, UCCE Sonoma County; Mary Louise Flint, publications director, UC Integrated Pest Management Program; Larry Whitted, PCA; and George Leavitt, viticulture farm advisor, UCCE Madera County.

For more information, go to: www.sarep.ucdavis. edu/ courses/grapes.

— Compiled from UC and other news sources

Research update

Garbelotto/Rizzo

While the pathogen that causes sudden oak death has been detected in redwood saplings, UC scientists do not yet have evidence that the funguslike disease is killing adult redwood trees.

SOD pathogen hits coast redwoods, Douglas fir

California's prized coastal redwoods and Douglas firs are infected with the same pathogen that causes sudden oak death (SOD), the deadly disease that has killed tens of thousands of oaks along the northern coast of the state, UC scientists reported in September.

Researchers from UC Berkeley and UC Davis have isolated living cultures of *Phytophthora ramorum* from the branches and needles of coast redwood and Douglas fir saplings that had shown signs of infection. This highly contagious, funguslike disease has now been found in 17 tree species, 16 of which are found in California including madrone, bay laurel and buckeye.

Collaborators UC Davis plant pathologist David Rizzo and UC Berkeley ecosystem scientist Matteo Garbelotto have confirmed its presence in 12 California counties (see map). The disease was first discovered in Marin County oaks 7 years ago.

Garbelotto and Rizzo first announced the discovery of *P. ramorum* DNA in redwoods earlier this year, but couldn't confirm that the pathogen was causing infection until living cultures of it were successfully grown from the field samples.

While the findings may have grave implications for the majestic California redwoods and Douglas fir forests that extend into British Columbia, the researchers have yet to find disease symptoms or death from the pathogen in large, mature redwoods or Douglas fir.

"Although *P. ramorum* infects redwood saplings and may kill redwood sprouts growing at the base of stumps and adult trees, we don't have any evidence at present that it is killing adult trees," Garbelotto says. "It will take years to know if that is possible."

Each species affected by the disease shows different symptoms, Garbelotto says. In the case of redwoods, the preliminary data suggests the pathogen will infect redwood needles and twigs, as well as portions of the wood. On Douglas fir saplings, the disease causes a tip wilting of both the branches and the terminal shoot.

"It seems that some species are able to tolerate the pathogen better than others," Rizzo says. "We see a whole range of symptoms in the field, from extensive cankers on the trunks of oaks to minor spots on the leaves of the buckeye."

California's coastal redwood and Douglas fir trees are ecologically and economically vital to the state, particularly to the timber, nursery, landscape and construction industries. After the scientists' disclosure, the California Department of Food and Agriculture and USDA Animal and Plant Health Inspection Service (APHIS) immediately added these trees to the official list of susceptible species, making them subject to evolving quarantine regulations. The agencies have regulated movement of redwood and Douglas fir seedlings, needles, twigs and branches less than 1 inch in diameter, from the 12 counties in the official "zone of infestation."

The researchers also conducted DNA tests on diseased sprouts growing from the bases of mature redwood trees in Marin, Alameda, Sonoma, Santa Cruz and Monterey counties. Repeated positive DNA identification strongly suggests the presence of the pathogen in the sampled trees, indicating infection on redwoods may be widespread. Symptomatic and infected Douglas firs, however, have been found only at a single location in Sonoma County to date.

The results were published online in October in the journal *Plant Disease.* A complete presentation of the data, with analysis by the scientists, will appear in an upcoming issue of *California Agriculture.*

— *Janet White*

The 12 counties where the SOD pathogen has been detected are Humboldt, Mendocino, Sonoma, Marin, Napa, Solano, Contra Costa, Alameda, San Mateo, Santa Clara, Santa Cruz and Monterey.

Beahrs international program trains professionals in sustainable development

A workshop on global warming and carbon sequestration offered recently by the Beahrs Environmental Leadership Program in Berkeley could fundamentally change the way Charles Yamoah of Ghana approaches the problem of soil degradation in Africa.

"Organic carbon is more productive than fertilizer alone," says Yamoah, most recently a soil scientist with the International Fertilizer Development Center. "Those are the techniques we need to use in Africa to keep the land productive."

Based at UC Berkeley's Center for Sustainable Resource Development in the College of Natural Resources, the Beahrs program was founded in 2000 with seed money from Carolyn and Richard Beahrs, UC Berkeley alumni now based in New York City. "They were interested in putting science to work in solving global environmental problems and promoting interdisciplinary approaches and leadership," says Robin Marsh, co-director of the program with David Zilberman, UC Berkeley agricultural economist.

The heart of the program is a 3-week intensive summer certificate course in sustainable environmental management, which seeks to provide high-level training for mid-career academics and environmental professionals from around the world; facilitate cross-learning among global peers; and offer opportunities for UC faculty to learn from the "on-the-ground" experiences of participants. About 75 people completed the course in 2001 and 2002.

The majority of course participants develop a "leadership change contract," which outlines how they will implement the new ideas they have acquired. Furthermore, a new small grants initiative, funded by the Goldman Fund and Packard Foundation, will provide $5,000 to $10,000 grants to assist participants with implementing their plans together with UC Berkeley collaborators.

For example, Yamoah and Oscar Arruda d'Alva, executive director of the Instituto Sertao in Brazil, began discussions this summer about joining forces to develop community-based programs for combating desertification. "The program has taken me out of my reality and enabled me to make contact with other people working on environmental issues," Arruda says. Likewise, participants from Kenya and Uganda teamed up with a fellow program alumnus from Finland to form a nonprofit foundation that will fight poverty in East Africa.

The Beahrs Environmental Leadership Program brings environmental professionals from around the world to UC Berkeley for a 3-week summer course. Participants are encouraged to form ongoing, collaborative working relationships with each other and UC faculty.

In addition to workshops and panel discussions, the 2002 course included field tours of sustainable winegrowing techniques in Napa Valley and the Agroecology Center at UC Santa Cruz, as well as a 4-day case study of community forestry and participatory forest research in Trinity and Plumas counties. "The Beahrs program provides an international showcase for the Division's world-class research and extension programs," Zilberman says.

The program has developed several mechanisms to facilitate ongoing contacts among participants, including mentored fellowships with UC faculty, a Web-based alumni network, an information clearinghouse and alumni newsletters. A pilot Beahrs "satellite center" is under way in the Philippines in conjunction with the Southeast Asian Graduate Research Center in Agriculture (SEARCA), which will offer environmental management training workshops in Asia and encourage collaborative research with UC Berkeley faculty.

For more information, go to:
http://cnr.Berkeley.edu/BeahrsELP

Over the next 3 to 5 years, Marsh says the Beahrs program would like to raise an endowment, update and expand the course curriculum, strengthen its leadership component via partnership with the UC Berkeley Haas School of Business, and further develop the alumni network. Perhaps the most critical outcome will be the connections that participants make with each other and the joint projects that result.

"I will always cherish this network. I will stay in touch with them," says Beahrs program graduate J.K. Ladha of India, UC Davis adjunct professor and soil scientist with the International Rice Research Institute. "I have a strong feeling that they will become environmental leaders in their countries."

— Janet Byron

RESEARCH ARTICLE

Water management practices can affect salinity in rice fields

Steven C. Scardaci
Michael C. Shannon
Stephen R. Grattan
Austine U. Eke
Stacey R. Roberts
S. Goldman-Smith
James E. Hill

Water management practices in California rice production can affect salinity in the field. This is particularly important because rice is one of the most sensitive crops to salinity. We extensively monitored salinity patterns in dozens of rice fields in Colusa and Glenn counties, in order to determine how salinity varies from basin to basin and to compare salinity patterns under different irrigation systems. We found that the fields most vulnerable to salinity damage were those with higher soil salinity and using irrigation water sources initially high in salinity, particularly nondistrict sources that are combinations of well and drain water. Long water holding periods, while effective in reducing pesticide concentrations in rice fields, can contribute to salinity increases in bottom basins. Salinity can increase with either conventional or static irrigation management systems, but the salinity pattern in the field will be different.

Grown in flooded conditions, rice is one of the most sensitive crops to salinity. In California, rice is generally grown in a series of basins, with water running from upper to lower basins before draining out. The authors found that salinity stress and yield reductions tend to increase from upper basins, *above,* to bottom basins, *below*.

More than 470,000 acres of rice were planted in California in 2001, with a production value of $138 million (according to the California Agricultural Statistics Service). Rice is different from the state's other important field crops in that it is grown in basins under continuously flooded conditions. Rice has a unique anatomical feature called *aerenchyma* (large internal air spaces), which provide oxygen to roots, allowing the plant to thrive under flooded conditions. Most weed species cannot survive in this environment.

Unlike other crops, rice is seeded directly into saturated fields by aircraft, providing a uniform stand. Historically, most rice has been grown using a conventional "flow-through" system where irrigation water flows sequentially through a series of basins starting at the top and ending at the bottom. Weirs between basins control water depth and flow, and excess water in the bottom basin spills into a drainage ditch.

Water management practices in California rice production have changed substantially since the 1970s and early 1980s, when water was held in the field for short periods of several days. In the early 1970s, water quality studies in California indicated that the salinity of rice-field outflows averaged about 30% higher than inflow water in 14 fields (Henderson et al. 1974). In five fields from Colusa and Glenn counties, the salinity of outflow water averaged about 60% more than inflow water. By the early 1990s, rice growers were holding water in basins for up to 30 days (May to early June) after a pesticide application (Lee et al. 1993). These holding periods were the primary means of reducing pesticide residues and were required by the state Department of Pesticide Regulation to fulfill the Central Valley Regional Water Quality Control Plan. Rice growers adopted closed systems, which recirculate water within basins, or constructed static water basins, in which water flows into a single basin without an outflow. They also developed gravity systems, in which drainage water from the bottom basin bypasses the drain by redirecting it to the top basin of another series of lower-elevation basins.

During the late 1980s and early 1990s California experienced a long-term drought, resulting in further tailwater outflow restrictions and a no-spill policy, which prohibited the discharge of field water from bottom basins into waterways after June 30 or July 15 (1992 to 1994) in some rice-growing areas. In the early 1990s some rice growers noticed problems with stand establishment in parts of their fields. They suggested that salinity problems might develop with the longer water holding periods and / or in closed irrigation systems. The late-season no-spill policy was discontinued in 1995, and other less restrictive modifications have been made since.

Rice is sensitive to salinity, particularly during the early seedling (Maas 1990) and pollination stages (Khatun and Flowers 1995). Salinity stress during these periods may reduce rice growth and / or yield. In rice, salinity during the seedling stage causes a reduction in stand density and seedling biomass (Shannon et al. 1998). During pollination salinity may cause panicle blanking (sterile florets) or sterility, leading to a reduction in grain yield. Rice is more tolerant of salinity at other growth stages, and salinity stress during these periods has less impact on yield (see Grattan et al., p. 189).

We initiated salinity investigations in the early 1990s to determine if salinity was adversely affecting rice production in California and to determine impacts on yield. Different irrigation systems that limit the discharge of field water into waterways were monitored to evaluate the distribution of salinity within particular fields.

Irrigation water salinity

Thirteen irrigation district and nondistrict water sources in Colusa and Glenn counties were monitored for salinity in June, July and August from 1993 through 1995. District water comes directly from an irrigation agency such as the Glenn-Colusa Irrigation District, while nondistrict water provides a mix of river water, well water and / or recaptured drain water. Data indicated that most irrigation waters had low mean summertime salinity levels. For example, the electrical conductivity of the inflow water (EC_w) — which goes up as water salinity increases — was less than 0.7 deciSiemens / meter (dS / m), but some sources had moderate levels of 0.7 to 1.47 dS / m (fig. 1). (DeciSiemens per meter is a measure of the electrical conductance of the water supply, which is related to its saltiness.)

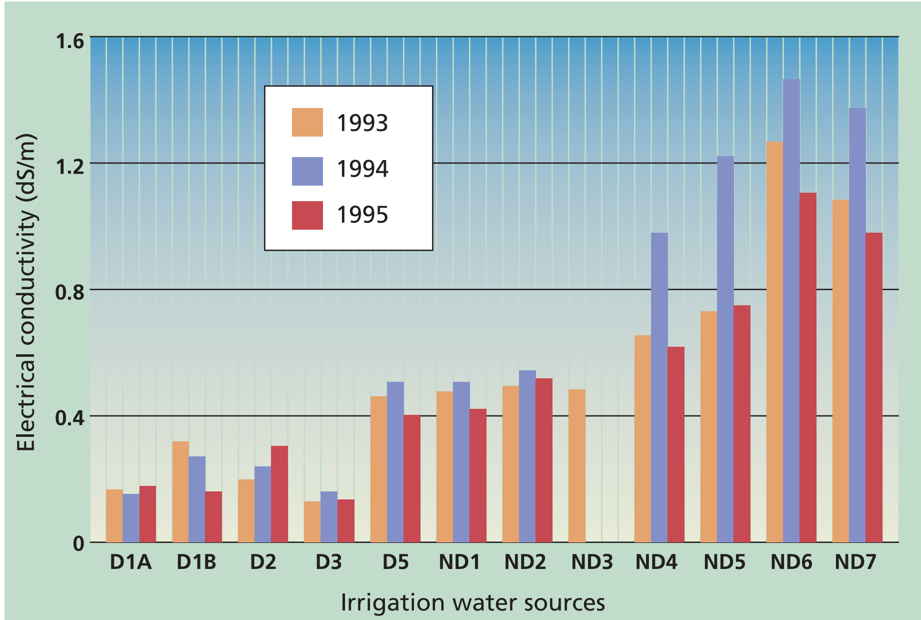


Fig. 1. Electrical conductivity among district (D) and nondistrict (ND) irrigation water sources in Glenn and Colusa counties. (Readers may e-mail srgratton@ucdavis.edu for identities of district and nondistrict irrigation water sources.)

Irrigation districts that divert water from the Sacramento River had the lowest mean summertime salinity levels (0.13 to 0.31 dS / m). Other district and nondistrict sources had low but slightly higher mean summertime salinity levels (0.40 to 0.54 dS / m). Nondistrict water sources that used a mixture of drain and well water had higher mean salinity levels (0.62 to 1.47 dS / m). Drain water from nonrice field sources may have also affected water quality at some sites.

The mean summertime EC_w for all irrigation water sources was highest in 1994 and lowest in 1993 and 1995. For example, the mean salinity level in the Colusa Basin Drain at the Davis Weir was 1.22 dS / m in 1994, but only 0.73 and 0.75 dS / m in 1993 and 1995, respectively. The higher salinity levels in 1994 (compared to 1995) can likely be attributed to higher cumulative evapotranspiration (ET) and lower rainfall during the summer (June to August) months, in addition to stricter water conservation practices.

Field salinity monitoring

We also monitored 27 rice fields that used conventional, recirculating and gravity irrigation systems for salinity in Colusa and Glenn counties, annually from 1993 to 1995. Management of these fields varied considerably, as has been previously described (Hill et al. 1995). Salinity of the water was monitored at the inlet, top and bottom basins of each field in June, July and August. The June sample time was during or close to the water holding period in many of the fields studied. Soil salinity was also monitored in these fields at the same times but was not initiated until midway through the 1993 season. Some fields utilized recirculating, gravity or static systems to manage water during the water holding period while others held water for the required holding period or season-long. Yield data was collected in 1994 and 1995 from 3.3-feet-by-3.3-feet (1 square meter) plots near the salinity monitoring locations in each of the top and bottom basins.

Mean bottom-basin water salinity levels were significantly higher than those in top basins, while EC of the inlet water was often the same as EC of the field water (EC_{fw}) in the top basin (fig. 2). Fields with low EC_{fw} levels showed little difference between top and bottom basins.

Data for June is presented because the water salinity levels were higher and the differences between the top and bottom basins were greater during or after the water holding period. The salinity level and relative differences between top and bottom basins de-

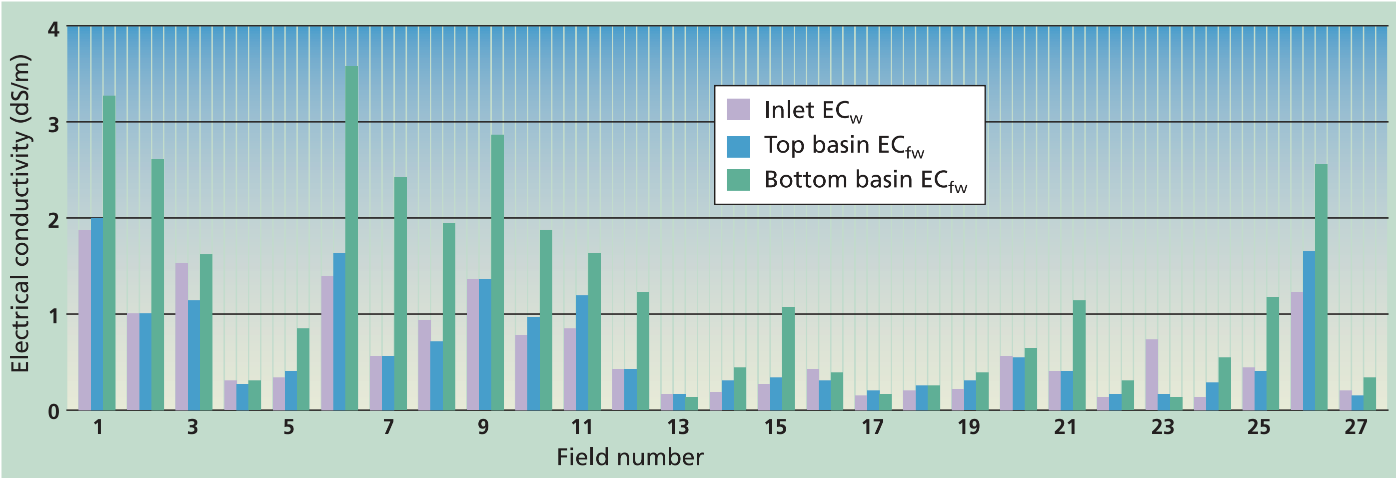


Fig. 2. Electrical conductivity of water at field inlet (EC_w) and in field water (EC_{fw}) in top and bottom basins from 27 rice fields in Colusa and Glenn counties, June 1995.

clined later in the season after water flow and depths increased. Similar results were observed with soil EC (data not shown). From 1993 through 1995, the mean EC_{fw} for June was 0.70 dS / m in the top basins and 1.28 dS / m in the bottom basins of all fields monitored. Similar patterns were found in 1994. In fields with higher salinity levels, rice stand establishment was affected more in bottom basins than top basins.

In 1994, during the June sample, field water and soil salinity levels correlated significantly in both top and bottom basins ($r^2 = 0.52$ and $r^2 = 0.70$, respectively). The relationship between EC_{fw} and the average root-zone salinity (EC_e) varied between top and bottom basins and at different times during the season.

In 1995, water salinity was monitored more frequently in several fields, two with high salinity and one with lower salinity. Salinity data was similar in both fields with the highest salinity, indicating that EC_{fw} was highest during the water holding period, particularly in bottom basins. Conversely, the low salinity field, which held water season-long, had low salinity levels all season (0.1 to 0.2 dS / m).

In one of the high-salinity fields, the EC of inlet water (EC_w) was similar to that in the top basin, regardless of time after flooding (fig. 3). During the water holding period, water salinity levels in the bottom basin increased rapidly, which we attribute to a combination of no outflow, reduced inflow rates and evapoconcentration of salts. This suggests salinity can be a serious problem in some fields during the water holding period. However, adding fresh water (lower EC) to the bottom basin toward the end of the holding period increased the field's water level and reduced salinity, indicating that monitoring and management can help moderate a salinity problem. In bottom basins of some fields, salinity increases made it difficult for some growers to hold water without experiencing stand problems and yield losses.

Multiyear analysis of yield data indicates a significant decrease in grain in bottom basins compared to top basins (9,700 versus 10,300 pounds / acre). Single-year analysis indicates that top and bottom basin yields were significantly different in 1994 but not in 1995 (10,960 versus 9,880 pounds / acre, respectively). The absence of yield decline in 1995 was probably due to lower EC levels in some irrigation water sources, lower cumulative ET during the season and lower salinity levels in a number of rice fields. Grattan et al. (see p. 189) subsequently conducted controlled studies to better understand and quantify the relationship between salinity, crop performance and yield.

Max Spyres

Appropriate water management in fields can help to reduce salinity damage and produce a healthier rice crop. This normal rice, *above,* was irrigated with water at 0.6 dS/m, well below the threshold for salinity stress.

Impact of irrigation systems

In 1997, extensive sampling was conducted in six rice fields to compare different irrigation systems and determine what influence they have on salinity patterns in the field. In the conventional system, water flows in series from basin to basin while in the static system water is independently delivered to each basin from a supply / drain ditch perpendicular to the basins. Flap-gated pipes prevent water mixing between basins. Seventeen locations were monitored in each of an upper, middle and lower basin in each field (51 samples per field). At all locations, field water salinity was measured throughout the season and soil salinity was measured at harvest. At two sites, soil salinity was measured at midseason and yields at harvest.

These studies confirmed that water

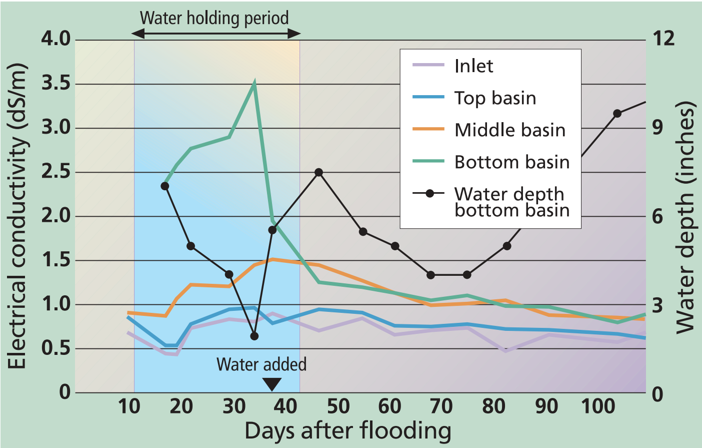


Fig. 3. Electrical conductivity of rice field water at the inlet, top, middle and bottom basins from a salt-affected field intensively monitored in 1995. The water holding period can substantially increase salinity in the bottom basin.

salinity increases in bottom or lower basins to some degree in most fields during the water holding period (data not shown). They also showed that different irrigation systems influence field water salinity patterns (fig. 4A-B). In conventional systems salinity levels increased from top to lower basins. In static systems each basin was irrigated independently, and salinity levels among basins varied somewhat but were not significantly different. However, in both systems salinity increased with distance from the water inlet. The soil salinity and water flow patterns may contribute to spatial variation between and among basins in the static irrigation systems. After the water holding period, differences among and within basins declined sharply. EC_{fw} levels increased during the water holding period, but decreased later when irrigation water was again added to the field.

In the static system, the measured peak EC_{fw} occurred at the middle of the water holding period — water was added just prior to the late sample time, most likely lowering the EC level. Although not illustrated in figure 4, data from earlier studies showed increases in late-season EC_{fw} levels in static and other closed-basin systems. The mean EC_e (51 samples) for all basins was 3.1 dS/m in the conventional and 1.7 dS/m in the static system.

Yield data from the 1997 field study was inconsistent. EC_{fw} at one location, which ranged from less than 1 dS/m to greater than 4.0 dS/m at the end of the water holding period, was negatively correlated with reduced stand ($r = –0.38$, mean water holding period EC_{fw} versus stand density), but not to yield ($r = 0.29$). At this site, poor weed control in the top basin had likely affected yield more than salinity in the bottom basin, thereby reducing the salinity-yield correlation. At a second location with lower salinity levels but a similar salinity range, stands ($r = –0.22$) and yields ($r = –0.30$) were negatively correlated with EC_{fw} during the water holding period.

Coping with salinity

Rice growers have made great strides in reducing pesticide loads into rivers by holding water on fields longer and using various alternative irrigation systems. At the same time, increased soil and water salinity levels, particularly in bottom basins, have been associated with reduced rice stands and yield. Higher salinity in bottom basins

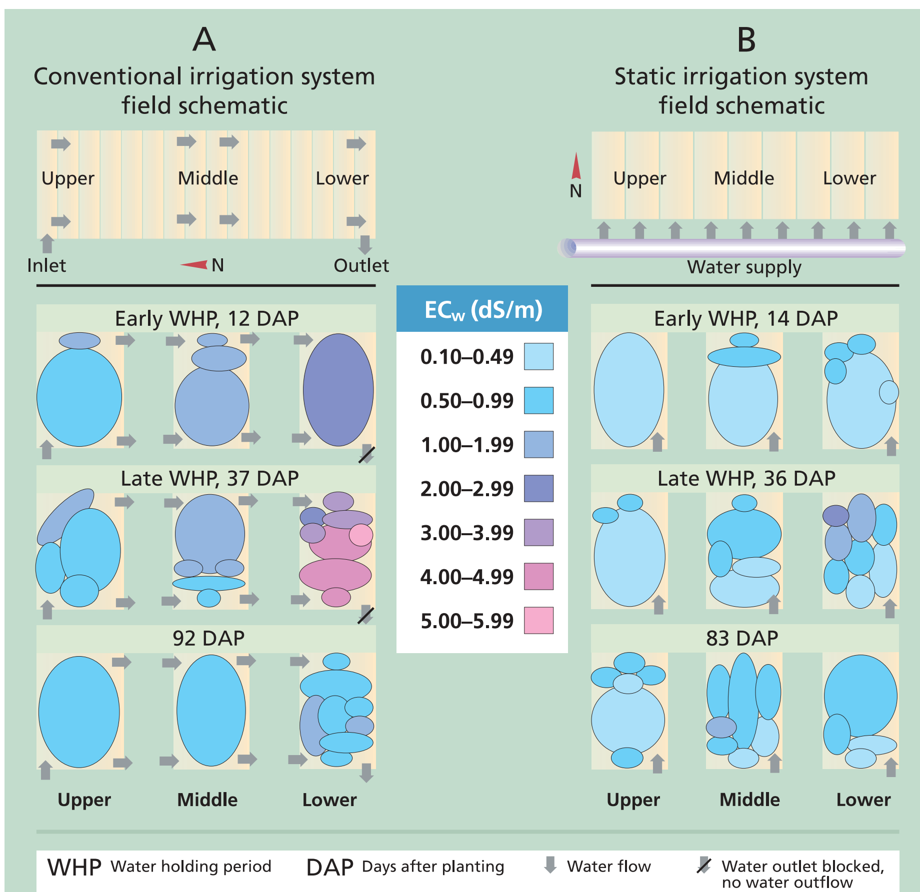


Fig. 4. Field-water electrical conductivity patterns in rice fields with (A) conventional and (B) static irrigation systems, at three monitoring times after planting.

Max Spyres

Above, **Rice grown in water at 6.8 dS/m, two to three times the threshold for salinity damage, shows severe leaf necrosis. In basins where salinity is a problem, growers can adopt mitigations such as adding fresh water or recirculating water among basins.**

apparently is not a new phenomenon: in the early 1970s, when water holding was only required for several days, salinity in outflow water was also higher than in inflow water. However, the current longer holding times appear to increase the problem in salinity-prone areas. Salinity problems appear to be exacerbated in areas irrigated with non-district water from drain or well water sources with higher salinity levels.

When our studies were conducted, most district irrigation water on the west side of the Sacramento Valley was low in salinity (< 0.70 dS / m), while some nondistrict water had salinity levels between 0.70 and 1.5 dS / m. The mean summertime salinity level in the Colusa Basin Drain at the Davis Weir was highest in 1994 (1.2 dS / m) when tail-water outflow restrictions were in effect in portions of the Colusa Basin. They were also high during the 1976–1977 drought, when water availability was limited (GCID 1997). These findings indicate that the quality of nondistrict water sources may be adversely affected under conditions of low water availability or restricted flow.

Salinity levels increased in bottom basins particularly during the early season when water holding periods of more than 30 days were in effect. In some fields where salinity was excessive, grain yield was significantly reduced. In contrast, water can be held for the same period in fields low in salinity without affecting yields.

The type of irrigation system and pattern of water flow greatly influenced salinity patterns in fields. In conventional and static systems, salinity levels increased as the distance from the water inlet increased. Salinity was highest in these areas during the early-season water holding period. Water depths in rice fields are typically raised to about 8 inches at 60 to 70 days after planting to protect the developing pollen from cold nighttime temperatures. Raising water at this time dilutes salts in the field water, countering the increased salinity resulting from evapoconcentration. This is important as it helps to moderate and control early-season salinity problems and minimize late-season problems during pollination.

Previous salt-tolerance guidelines indicated that rice yields are not adversely affected until EC_e (root-zone salinity) exceeds 3.0 dS / m or when EC_w (inlet water salinity) exceeds 2.0 dS / m (Ayers and Westcot 1985). However, an independent field study (see p. 189) indicates that rice growth and / or grain yield are reduced when the mean seasonal EC_{fw} (field water salinity) exceeds 1.9 dS / m. Since EC_{fw} increases from top to bottom basins in conventional systems and within basins in static systems, EC_w should be substantially lower than this threshold to maintain a mean seasonal EC_{fw} below 1.9 dS / m.

Rice growers should monitor salinity periodically in fields and basins where salinity may be problematic. When salinity is a problem, modifications may be needed, such as adding fresh water to salt-affected basins or perhaps recirculating water among basins to reduce the salinity in the lower basin. UC Cooperative Extension can offer valuable assistance to growers in diagnosing salinity problems and better managing rice farms.

---

*S.C. Scardaci is former Farm Advisor, UC Cooperative Extension, Colusa County, UC Davis; M.C. Shannon is Research Geneticist, USDA-ARS George E. Brown, Jr. Salinity Laboratory, Riverside; S.R. Grattan is Plant-water Relations Specialist, Department of Land, Air and Water Resources, UC Davis; and A.U. Eke and S.R. Roberts are former Staff Research Associates, S. Goldman-Smith is former Post Graduate Researcher, and J.E. Hill is Agronomist, Department of Agronomy and Range Science, UC Davis. *We would like to acknowledge the late Max Spyres, former Colusa County rice grower, for his pioneering work in identifying salinity as a problem in local rice fields and for his preliminary studies on the problem. Max's encouragement was instrumental in conducting this work. We also thank the numerous rice growers whose cooperation made this work possible. This project was partially funded through the USDA Presidential Water Quality Initiative: The Sacramento River Rice Water Quality Demonstration Project, number 94-EWQD-9520.*

References

Ayers RS, Westcot DW. 1985. Water quality for agriculture. FAO Irrigation and Drainage paper No 20 (rev. 1). FAO United Nations, Rome, Italy. 174 p.

[GCID] Glenn-Colusa Irrigation District. 1997. Water Measurement Report. Willows, CA.

Henderson DW, Tanji KK, Biggar JW, et al. 1974. Water Quality in Rice Fields. Water Science and Engineering Papers 4008, Dept. of Water Science and Engineering (now Land, Air and Water Resources), UC Davis.

Hill JE, Scardaci SC, Roberts SR, et al. 1995. Rice irrigation systems for tailwater management. UC DANR Pub 21490 (revised). 14 p.

Khatun S, Flowers TJ. 1995. Effects of salinity on seed set in rice. Plant Cell Environ 18:61–7.

Lee MJ, Ross LJ, Wang RG. 1993. Integrating environmental toxicology and monitoring in the development and maintenance of a water quality program: California's rice herbicide scenario (Ch. 18). In: Jolley FL, Wang RGM (eds.). *Effective and Safe Waste Management: Interfacing Sciences and Engineering with Monitoring and Risk Analysis.* Ann Arbor, MI: Lewis.

Maas EV. 1990. Crop salt tolerance. In: Tanji KK (ed.). *Agricultural Salinity Assessment and Management Manual.* ASCE Manuals & Reports on Engineering Practices No 71. New York. p 262–304.

Shannon MC, Rhoades JD, Draper JH, et al. 1998. Assessment of salt tolerance in rice cultivars in response to salinity problems in California. Crop Sci 38:394–8.

Rice is more sensitive to salinity than previously thought

Salinity has reduced rice yields on some farms in Colusa and Glenn counties. Research using large metallic rings, *above*, indicates that current salinity guidelines for rice may need updating.

Stephen R. Grattan
Linghe Zeng
Michael C. Shannon
Stacy R. Roberts

Field studies conducted by UC and under controlled greenhouse conditions by the U.S. Department of Agriculture's Agricultural Research Service indicate that rice is more sensitive to salinity than current guidelines suggest. This information is particularly important to rice growers who have experienced salinity problems after holding water on fields for longer time periods to reduce pesticide loading into the Sacramento River. Our field experiments show that an average seasonal salinity of the field water in excess of 1.9 deciSiemens per meter (dS/m) can reduce grain yields; current guidelines indicate that salinity affects rice yield at or above 3.0 dS/m. Salinity had a negative impact on a number of yield components including stand establishment; panicles, tillers and spikelets per plant; floret sterility; individual grain size; and even delayed heading. The emergence and early seedling growth stages were most sensitive to salinity, as was the three-leaf to panicle-initiation stages. Irrigation management practices should be adopted to minimize salinity during these critical growth stages.

Research by UC and the U.S. Department of Agriculture's Agricultural Research Service (USDA-ARS) suggests that salinity has reduced rice yields on several farms in Colusa and Glenn counties over the past decade. Scardaci et al. (see p. 184) found that salinity monitoring in various fields indicated that the electrical conductivity (EC) of the soil and field water in bottom basins was significantly higher than in top basins. An indicator of the salinity hazard, EC increases in direct proportion to the salt concentration in the water. (EC units are reported in deciSiemens per meter [dS/m] or millimhos per centimeter [mmhos/cm]; both units are numerically equivalent.) Salinity reduced crop yields in the lower basins of a number of fields.

The literature indicates that rice is sensitive to salinity, particularly during the seedling stage (Maas and Hoffman 1977). Current guidelines (Maas and Grattan 1999; Hanson et al. 1999) indicate that rice yields decrease 12% for every unit (dS/m) increase in EC_e (average root-zone EC of saturated soil extract) above 3.0 dS/m.

Salinity guidelines were first developed by Maas and Hoffman (1977), who suggested that the salt tolerance of a crop is best described by plotting relative yield as a continuous function of soil salinity. Their guidelines for rice were based largely on laboratory research conducted between 1959 and 1972 on obsolete cultivars. The guidelines have since been used internationally (Ayers and Westcot 1985) and appear as the standard in current literature (Maas and Grattan 1999) and current grower manuals (Hanson et al. 1999). Newer revisions include guidelines for new crops and adjustments to old guidelines where new research has since emerged. However, until now no new research has been conducted on field-grown rice to verify or modify these guidelines.

Scardaci et al. (p. 184) suggest that the salinity problems observed in grower fields over the past decade were aggravated by water management practices designed to reduce pesticide concentrations in the Sacramento River. The water quality of the river has been improved substantially since the early 1990s by holding water in pesticide-treated fields for extended periods of up to 30 days and using closed irrigation systems, such as static basins or those that recirculate the water through a series of basins. However, these practices, while decreasing pesticide concentrations in the receiving river, increased the potential for field salin-

UC scientists install the rings into a grower's field to the depth of the plow pan, about 4 to 6 inches. Rice was then sown and cultivated in the fields as usual by growers, while researchers flooded the rings with water at various salinity levels.

ization. While salinity of the soil and field water in top basins was about the same as the irrigation water source, the salinity of lower basins was substantially higher. This difference indicates that salt concentrations in the lower basins are increasing by evapoconcentration.

In light of these findings, we conducted controlled salinity studies at the USDA-ARS George E. Brown, Jr. Salinity Laboratory in Riverside and in a Colusa County rice field. The objective was to quantify the relationship between salinity, seedling survival, stress timing, crop growth, grain yield, and how yield is partitioned into these components. This research was also used to verify or modify current salinity guidelines for California-grown rice.

Field study with metallic rings

A controlled field study was conducted in 1996 and 1997 in the Colusa County grower's field using metallic rings. In 1996, the field was planted to an early rice variety, M-103, while in 1997 it was planted to M-202. In 1996 aluminum-ring basins (8-foot diameter) were used, and in 1997 galvanized rings were made by cutting a 5-foot-diameter culvert pipe into 2-foot sections. The rings were installed in the soil to the depth of the plow pan (the high-density layer below the plowed zone) — about 4 to 6 inches. Each ring was flooded using irrigation waters that varied in salinity.

Rice growth and plant development within the rings were fairly uniform and there were no visual border effects. That is, plants directly next to the ring walls were stunted as much as others within the ring. Those directly outside the ring were no different from plants in the field, suggesting that the effective rooting system of rice is shallow, reportedly in the surface 4 inches of soil (Pearson 1959).

In 1997, but not 1996, plots were presalinized prior to seeding. This was done to test the influence of salinity on seedling emergence and overall stand establishment.

Rice is grown in flooded fields, at levels that can vary throughout the season. Saline irrigation water was prepared in 1,000-gallon tanks. Ring-plots were flooded using prepared irrigation waters that varied in salinity, with targeted EC values of 0.4 (control / grower water), 1.0, 2.0, 4.0, 6.0, 8.0 and 10.0 dS / m. Saline irrigation water was prepared by adding known quantities of various salts in proportions that produced water close to the same ionic composition as that in rice-growing areas currently affected by salinity. Sodium chloride (NaCl), calcium chloride ($CaCl_2$), magnesium sulfate ($MgSO_4$) and sodium sulfate (Na_2SO_4) were added in a molar ratio of 10:1:2:1. These seven salinity treatments were replicated four times (three times in 1996) in a randomized block design. Plots were monitored two to three times weekly for EC and water depth. The water depth within the rings was close to that of the field water. Water of either an equal or lower salinity was added several times each week to the plots to maintain water levels and EC values as close as possible to the targeted level.

Seeds were sown directly into the rings and surrounding fields by airplane as is standard practice in the region. Plant growth and development were measured at various times throughout the season. Among parameters measured were seedling and tiller density (number per area), tillers per plant, timing of panicle initiation, heading date, floret sterility, plant biomass and grain yield at the end of the season. As rice develops, it produces tillers (grasslike sprouts) from the main stem. Panicles (reproductive organs bearing seeds) begin to develop on the tillers and the main stem about 25 days before heading, when 50% of plants have at least one visible panicle. The rice plant is at the booting stage when the panicles begin to swell and are visible at the base of the leaf sheath. Next the flowering stage occurs with the formation of spikelets, which, if fertile, produce seeds.

The data is presented based on the seasonal, time-weighted average EC of field water (EC_{fw}) in each ring (0.4 to 12.0 dS / m). Soil samples were also collected at different times throughout the season. In 1997, there was a linear relationship between salinity in

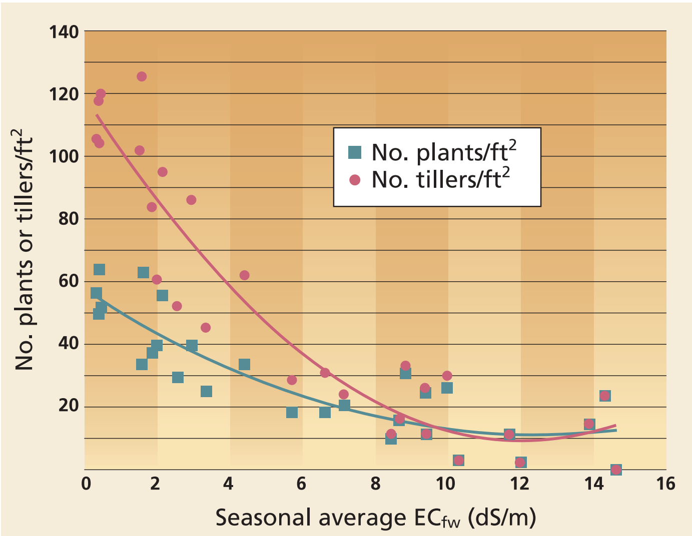


Fig. 1. Effect of increased salinity on plant and tiller density in Colusa County field study.

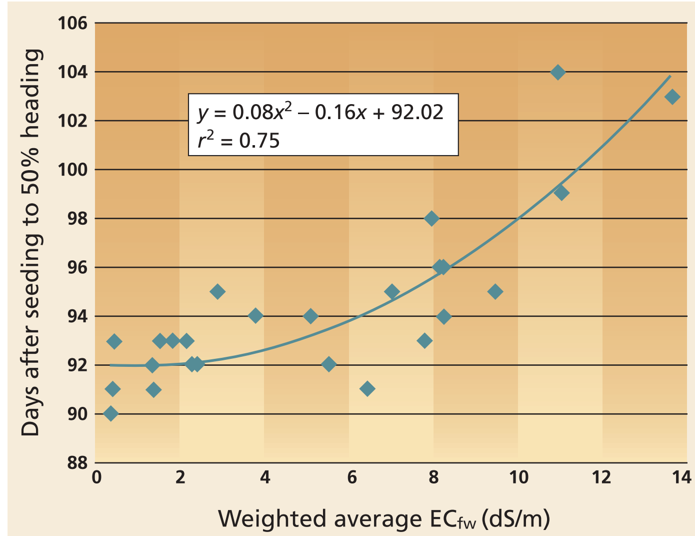


Fig. 2. Effect of salinity on rice heading in Colusa County field study. Weighted average is based on 62 days after seeding.

the top 3 inches of soil taken at the end of the season and average field water salinity ($EC_e = 1.17 \times EC_{fw} + 1.2$, $r^2 = 0.88$). Samples from the standing water and underlying mud or soil all produced high correlation coefficients with plant variables where standing water in relation to biomass gave the highest correlation ($r = -0.86$)(Shannon et al. 1998).

Jack Kelly Clark

Salinity levels were measured by monitoring the electrical conductivity of the irrigation water; conductivity increases with salinity. Former UC Davis post-graduate researcher Bill Thomas takes measurements in the field.

Effects of salt stress in field

At 28 days after seeding, visual observations showed severely salt-stressed seedlings that were smaller, had fewer tillers, less root mass, and shorter, thinner, chlorotic leaves compared to nonsalinized control plants. Moreover, the data indicate salinity had a profound influence on plant and tiller density (number per area) (fig. 1). Reductions in plant and tiller density followed a quadratic function ($r^2 = 0.76$ and 0.89, respectively). At an EC of 3.0 dS / m, the currently published salinity threshold for rice yield, plant and tiller densities were reduced by one-third and 40%, respectively, compared to nonsalinized controls (EC = 0.4 dS / m). This data supports the claim that rice is very sensitive during the seedling and early development stages.

At 28 days after seeding, salinity reduced the number of tillers per plant in a linear fashion ($r^2 = 0.72$) with increasing salinity (Grattan et al., unpublished data). We also found a relatively good second-order relationship ($r^2 = 0.75$) between salinity and days after seeding to 50% heading (fig. 2). At 10.0 dS / m salinity, it took plants roughly 6 additional days to reach 50% heading compared to nonsaline controls. Data collected in 1996 also showed delayed panicle initiation by salinity.

Biomass data collected at harvest indicated that salinity had profound effects on shoot and root growth as well as panicle yield. As with nearly all crops, salinity reduced shoot growth more than root growth. In 1997, salinity reduced straw yield in direct proportion to grain yield (data not shown), therefore at no effect on the harvest index (the fraction of total shoot biomass comprised of grain). This was not the case in 1996 when salinity reduced the harvest index.

The discrepancy in harvest index between years can be partly explained by salinity's differential response to sterility. In 1996, salinity increased the percentage of sterile florets in a given panicle such that percent sterility increased with increasing salinity. The number of filled grains per panicle equaled –3.41 EC plus 52.3 ($r^2 = 0.74$). Results in 1996 agreed well with results from greenhouse studies conducted in the United Kingdom. While salinity increases sterility in rice, little is known about the underlying cause (Khatun and Flowers 1995). Greenhouse studies from the United Kingdom showed that salinity delayed flowering, and reduced productive tiller number, fertile florets per panicle, weight per grain and overall grain yield (Khatun et al. 1995). In our 1997 study, however, salinity had little influence on percent sterility (data not shown).

Left to right, **Increasing salinity of 0.3 to 12.0 dS/m clearly stunts rice growth and reduces yields.**

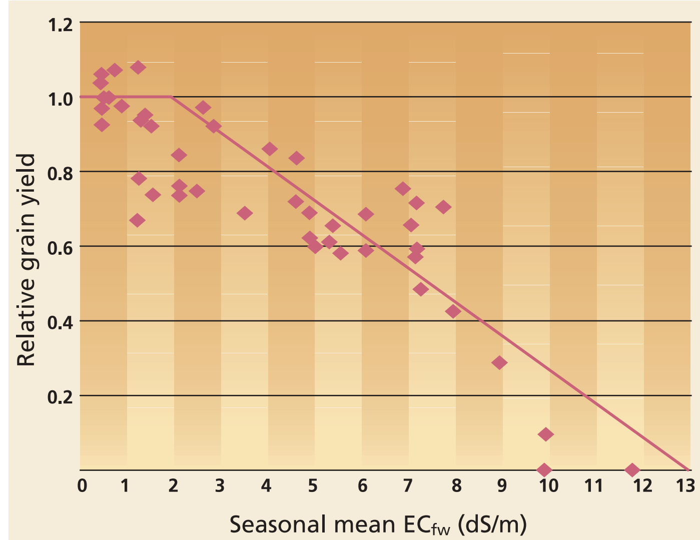


Fig. 3. Based on field study results from 1996 and 1997, rice grain yield decreased as salinity in field water increased above 1.9 dS/m.

The grain yield reduction in 1997 by salinity was attributed to both the reduction of panicles per area and individual seed size. In 1996, reduction in grain size and perhaps an increase in the number of sterile florets were the primary causes for yield reduction under saline conditions. In both years, strong linear relationships were found between increasing salinity and decreasing seed size. For example, with decreasing 1,000-kernel weight (the weight of a thousand kernels of rice), r^2 was 0.94 and 0.79 for 1996 and 1997, respectively, even though this effect was small.

New salinity coefficients for rice

In order to determine the appropriate salt-tolerance guidelines for Sacramento Valley–grown rice, grain yield data for 1996 and 1997 was converted to a relative basis, combined and plotted (fig. 3). A piecewise linear model (Maas and Hoffman 1977) was used to calculate the salinity threshold and percent slope of the regression. This method uses a number of least-squares iterations until the best-fit threshold and slope are found. A threshold of 1.9 dS / m and slope of 9.1% best fit the combined data set. Yield data at salinities less than 1.9 dS / m was considered insignificantly different and the yield maximum was determined as the average. The yield potential of rice based on salinity of the field water can be estimated using the following formula:

$$\% \text{ yield} = 100 - 9.1\ (EC_{fw} - 1.9)$$

where EC_{fw} is the seasonal, time-weighted average salinity in the field water.

These data indicate that the actual salinity threshold (1.9 dS / m) for rice grown in the Sacramento Valley is less than current guidelines indicate (3.0 dS / m), suggesting that rice is adversely affected by salinity at a lower level. (Because rice is grown under flooded conditions and the majority of active roots are within the top 4 to 6 inches of the soil profile, much of which is unconsolidated mud, we assumed that EC_e is equivalent to EC_{fw}.) However, percent slope is not as large (steep) as in the current guidelines. This indicates that the reduction in yield with increasing salinity above the threshold does not drop off as rapidly as current guidelines suggest. Nevertheless, C_{50} values are comparable between our findings and those using the current guidelines. The C_{50} value is the average salinity level (EC) resulting in a 50% yield reduction. The C_{50} value for our data is 7.4 dS / m; the value from the Maas and Grattan (1999) guidelines is 7.2 dS / m.

There are obvious advantages to conducting salinity experiments in the field, but not all variables (such as climate) can be readily controlled. Moreover, it is difficult to create transient salinity conditions in order to identify growth stages of rice that are particularly sensitive. These, however, can be readily controlled in the greenhouse.

Greenhouse studies in sand tanks

A series of follow-up greenhouse studies was conducted at the USDA-ARS George E. Brown, Jr. Salinity Laboratory in Riverside from 1997 through 1999. These studies were designed to investigate the influence of salinity on rice seedling growth, plant stand and grain yield under controlled conditions, as well as to determine salinity sensitivity at different growth stages.

The experiments were conducted in sand tanks (48-by-24-by-18-inches deep). Seeds were presoaked, sown directly in the sand and established with a nutrient solution. The water level was controlled between 0.4 to 0.8 inches (1 to 2 centimeters) the first week, and 2.0 to 3.1 inches (5 to 8 centimeters) thereafter. Salts (mixtures of sodium chloride and calcium chloride at 2:1 or 5:1 on a molar ratio) were added to the solutions either 5 days after seeding or at a later growth stage, depending upon the particular experiment. Final treatment salinities varied between 0.9 to 1.1 dS / m (nonsalinized control) up to 12.0 dS / m for the highest treatment.

In one series of experiments, seven salinity treatments were tested in a ran-

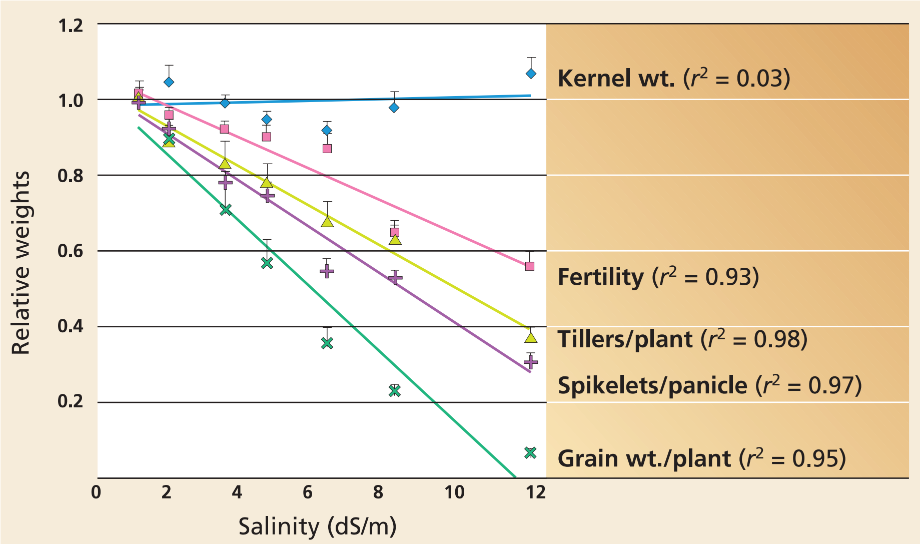


Fig. 4. In greenhouse studies, salinity reduced various yield components differently.

In controlled laboratory studies conducted at the USDA George E. Brown, Jr. Salinity Laboratory in Riverside, salinity-stressed rice developed white tips.

domized block design with five or six replicates. Rice seedlings (M-202) were harvested at incremental times ranging from 11 to 25 days after seeding. Harvested shoots were separated into various components and dried. Data in relation to duration of salinity exposure was expressed as cumulative thermal time (degree-days) or days after seeding.

Another study was conducted to test the sensitivity of rice (M-103 and M-202) to salinity at different growth stages. In these experiments, three salinity treatments (1.8, 3.2 and 4.6 dS / m) were tested along with five salt-stress-timing treatments: salinized on the day of seeding, one-leaf, three-leaf, panicle-initiation and booting stages. Salt stress was relieved after 20 days in each timing treatment.

Seedling survival and growth

In the first series of experiments, salinity dramatically reduced seedling survival (Zeng and Shannon 2000a, data not shown). The relationship between seedling survival and salinity in the greenhouse study was similar to seedling density per area versus salinity in the field-ring study, although the impact was not as great. In the greenhouse study, seedling survival was reduced about 20% at 3.0 dS / m, whereas plant density was reduced by one-third in the ring study at a similar salinity level.

Salinity also significantly reduced seedling growth (Zeng and Shannon 2000a, data not shown). Seedling growth of rice is dependent on both salt concentration and time of exposure. At lower salinities, longer exposure times were needed to produce measurable effects. For example, in one experiment, 3.2 dS / m significantly reduced seedling biomass at 17 days after seeding or 788°F degree-days (420°C degree-days) whereas 1.9 dS / m significantly reduced seedling biomass at 20 days after seeding or 923°F degree-days (495°C degree-days). Both the greenhouse and field studies confirm that rice is very sensitive to salinity during early seedling growth and that EC levels in

Researchers studied the impacts of salinity on yield, in conjunction with other factors such as seeding rates, salinity timing and water depths. In this study, the control was compared with a low-salt treatment.

TABLE 1. Effects of salt stress over time on grain yield and other crop factors

Salt stress initiated*	Seed weight (g) per plant	Seed weight (g) per panicle	Spikelet (no./panicle)	Tiller (no./plant)
Day of seeding	5.1bc	1.5bc	76ab	3.8c
First-leaf stage	5.7ab	1.6ab	83a	4.1c
Third-leaf stage	3.9d	1.2c	72b	3.7c
Panicle initiation	4.5cd	1.2c	63c	5.5a
Booting stage	6.4a	1.8a	83a	4.8b

* Salt-stress duration was constant for each timing treatment and was relieved 20 days after initiation of stress. Rice cultivar is M-202 and data was combined across salt levels. Column means followed by the same letter are not significantly different at 0.01 probability level. Source: Zeng et al. 2001.

TABLE 2. Impact of increased seeding rates on grain yield (data combined across salt levels)

Seeding density (seeds/m²)	400	600	720
Grain yield (g/m²)	429a*	434a	467a
Panicle density (no./m²)	512b	628a	669a
Plant stand (no./m²)	249c	358b	452a
Seed wt. per plant (g)	1.41a	1.03b	0.91b
Fertility (%)	71.1a	66.3ab	64.1b

* Means followed by the same letter in each row are not significantly different at 0.01 probability level.
Source: Zeng and Shannon 2000b.

standing water as low as 1.9 dS/m may affect growth and development.

Yield components and stress timing

Rice grain weight per plant decreased linearly with increased salinity, but salinity affected the various yield components differently (fig. 4). Seed size was relatively unaffected (1,000-kernel weight) at any of the salinity levels tested, but there was a profound reduction in fertility (such as, increased sterility), tillers per plant and spikelets per panicle.

Grain yield data (grain weight per plant) from the greenhouse experiment conducted in 1997 using M-202 was used to calculate the C_{50} value by the model developed by van Genuchten and Hoffman (1984). The C_{50} value from our data is over one-third less than that calculated with the original data and model used to develop the current guidelines. Statistical analyses of our greenhouse data confirmed those finding from the field, again suggesting that the salinity threshold value for rice is lower than current guidelines indicate.

Stress timing had a large influence on the overall sensitivity of rice to salinity (table 1)(Zeng et al. 2001). The reductions in spikelets per panicle, seed weight per panicle and tillers per plant were greatest when plants were stressed between the three-leaf and panicle-initiation stages. An approximate 20-day interval between these developmental stages was the most sensitive. Spikelet number per panicle was also significantly reduced by salinity imposed between panicle-initiation and early booting stages. However, tillering was not sensitive to salinity imposed during this period and, therefore, the overall impact on grain yield was less.

Seeding rates and water depth

Changes in certain management practices such as seeding rates (number of seeds per area) and depth of standing water may affect the salt sensitivity of rice plants. Understanding the influence of such changes is necessary to develop management strategies for ameliorating yield losses in salt-stressed rice. Another series of greenhouse studies was conducted at the USDA-ARS Salinity Laboratory during 1998 and 1999 to investigate these possibilities.

One study was conducted at three seeding densities — 400, 600 and 720 seeds per square meter (equivalent to 100, 150 and 180 kilograms per hectare, respectively), and three salt levels — 1.0 (control), 3.9 and 6.5 dS/m. Plants were grown in sand cultures as described above. The results indicate that salinity sensitivity increased with increasing seeding density (Zeng and Shannon 2000b). Grain weight per plant decreased and sterility increased with increasing seeding density (table 2). Although high seeding density also increased plant stand and panicle density, these increases were offset by reduced seed weight per plant and increased sterility. As a result, final grain yield was not significantly increased at high seeding density. Therefore, there is no evidence to suggest the economic feasibility of increasing seeding rates to overcome yield losses under salt-stressed conditions.

Another study was performed to determine the responses of rice growth and yield to different water depths using saline irrigation water. Plants were grown at seven water depths ranging from 1.7 to 7.9 inches (4 to 20 centimeters) under different salinities (0.9 to 6.0 dS/m). The results indicated a negative correlation between water depth and plant growth under salt stress (data not shown). Rice seedling establishment and grain yield decreased with increasing water depth during irrigation with saline water. Under moderate salinity, and without competition from weeds, plants grew better in shallow water (approximately 4 inches) than deep water (more than 4 inches).

Implications for rice growing

The field and greenhouse research reported here indicates that rice production in the Sacramento Valley is more sensitive to salinity than current guidelines indicate. Data suggests that California rice varieties M-103 and M-202, grown under Sacramento Valley conditions, have a salinity threshold of 1.9 dS/m rather than 3.0 dS/m, and that the yield-decline slope is 9.1% rather than 12%. These findings are important for policy decisions regarding water quality standards and water allocation requirements. These quantitative studies suggest that rice will not be affected by salinity provided that the seasonal mean EC of the field water is maintained below 1.9 dS/m. Care should also be taken to ensure that fields do not have inherently high soil-salinity levels.

Identification of salt-sensitive growth stages is important for managing irrigation water and controlling salinity. The field studies indicate that rice stand establishment is very sensitive to salinity. In addition, the greenhouse stress-timing studies indicate that a 20-day period between the three-leaf and panicle-initiation stage was most sensitive to salinity in terms of seed yield. This suggests salinity levels can increase in rice fields to moderate levels above the threshold without compromising grain yield, provided this occurs only for short periods after the booting stage.

The development of appropriate management practices is critical for optimizing rice performance under saline or potentially saline conditions. Our studies demonstrate that yields cannot be improved under salt-stressed conditions by increasing the seeding rate. Moreover, high field-water levels are more growth limiting than shallow water levels. Therefore, rice growers facing salinity problems should adopt irrigation management strategies that maintain low levels of salinity stress during early seedling development and between the three-leaf and panicle-initiation stages, while minimizing high field water levels. Growers should also be aware, however, that salinity levels could increase in shallow water (such as, with a large surface area and small volume of water) quite rapidly under highly evaporative conditions.

At the same time, such water management practices must ensure that sufficient times are allowed for the pesticides to break down naturally, such as recirculating the water among basins before discharging into public waterways. There may be some cases where it is impossible to hold water for extended periods (to promote pesticide degradation) and avoid salinity problems at the same time. In such cases it is possible state agencies may issue permits for fields where water salinity levels exceed a certain salinity (such as 2 dS/m), allowing the emergency release of field water.

In both the greenhouse, *above,* and in the field, rice was more sensitive to salinity than has been previously observed. The combined data from both series of studies indicates a rice salinity threshold of 1.9 dS/m rather than 3.0 dS/m. Timing is important: Rice growers should attempt to reduce salinity stress during the early seedling stage and between the three-leaf and panicle-initiation stages.

S.R. Grattan is Plant-water Relations Specialist, Department of Land, Air and Water Resources, UC Davis; L. Zeng and M.C. Shannon are Research Geneticists, USDA-ARS George E. Brown, Jr. Salinity Laboratory; and S.R. Roberts is former Staff Research Associate, Department of Agronomy and Range Science, UC Davis.
We thank Jim Poss at the USDA-ARS Salinity Laboratory for applying the slope-threshold model on the yield data from the field in order to develop the salinity coefficients. The field study was partially funded by the California Rice Research Board, project number RP-8.

References

Ayers RS, Westcot DW. 1985. Water quality for agriculture. FAO Irrigation and Drainage paper No 20 (rev. 1). FAO United Nations, Rome, Italy. 174 p.

Hanson B, Grattan SR, Fulton A. 1999. Agricultural salinity and drainage. UC DANR Pub 3375. 160 p.

Khatun S, Flowers TJ. 1995. Effects of salinity on seed set in rice. Plant Cell Environ 18:61–7.

Khatun S. Rizzo CA, Flowers TJ. 1995. Genotypic variation in the effect of salinity on fertility on rice. Plant Soil 173:239–50.

Maas EV, Grattan SR. 1999. Crop yields as affected by salinity. In: Skaggs RW, van Schilfgaarde J (eds.). *Agricultural Drainage.* Agron Monogr 38. ASA, CSSA, SSA, Madison, WI. p 55–108.

Maas EV, Hoffman GJ. 1977. Crop salt tolerance – current assessment. J Irrig Drain Div, ASCE 103 (IR2):115–34.

Pearson GA. 1959. Factors influencing salinity of submerged soils and growth of Caloro rice. Soil Sci 87:198–206.

Shannon MC, Rhoades JD, Draper JH, et al. 1998. Assessment of salt tolerance in rice cultivars in response to salinity problems in California. Crop Sci 38:394–8.

van Genuchten MTh, Hoffman GJ. 1984. Analysis of crop salt tolerance data. In: Shainberg I, Shalhevet J (eds.). *Soil Salinity under Irrigation.* Ecological Studies (Vol 51). Berlin, Germany: Springer-Verlag. p 258–71.

Zeng L, Shannon MC. 2000a. Salinity effects on seedling growth and yield components of rice. Crop Sci 40:996–1003.

Zeng L, Shannon MC. 2000b. Effects of salinity on grain yield and yield components of rice at different seedling densities. Agron J 92:418–23.

Zeng L, Shannon MC, Lesch SM. 2001. Timing of salinity stress affects rice growth and yield components. Agri Water Management 48:191–206.

RESEARCH ARTICLE

California mealybugs can spread grapevine leafroll disease

The most obvious symptom of grapevine leafroll disease, which is common in grape-growing regions worldwide, is reddening and curling of leaves in the fall on dark-fruited varieties.

Deborah A. Golino
Susan T. Sim
Raymond Gill
Adib Rowhani

UC Davis's Foundation Plant Materials Service (FPMS) maintains the disease-tested, professionally identified collection of grape scion and rootstock varieties, which is the core of the California Grapevine Registration and Certification Program. In 1992, newly developed serological testing techniques revealed the presence of grapevine leafroll–associated viruses (GLRaVs) in previously healthy vines in an older foundation propagating block, indicating active and recent virus spread. FPMS responded by increasing isolation distances and implementing a comprehensive virus screening program using the new methodology. The critical problem was the lack of information on leafroll virus epidemiology. When the distribution of infected plants in the old vineyard was mapped, new infections were frequently adjacent to known diseased grapevines. This study examined the ability of mealybugs, a putative leafroll vector, to transmit this group of viruses. We were able to confirm that four species found in California — obscure, longtailed, citrus and grape mealybug — can transmit GLRaV-3 isolates. This is the first experimental evidence of grapevine leafroll virus transmission by obscure and grape mealybug. In addition, we report for the first time that GLRaV-5 can be transmitted by longtailed mealybug.

Grapevine leafroll disease occurs in all the major grape-growing regions of the world, causing reductions in productivity and quality of both wine and table grapes. The most obvious symptom of the disease occurs in the autumn in dark-fruited varieties, which develop a strong red leaf color. In lighter fruited varieties, a general chlorosis will develop. Often, leaf margins turn under and roll downward, hence the disease name "leafroll." Growers are most concerned with reduced berry yields, delayed maturity and poor pigmentation. Some studies estimate yield losses of as much as 30% to 40%. In addition, the disease agent has been implicated in certain types of graft incompatibility and young vine failure. The most successful approach to controlling leafroll disease in grapevines has been the use of disease-tested grapevine nursery stock produced through the California Grapevine Registration and Certification Program, a program administered by the California Department of Food and Agriculture.

The Foundation Plant Materials Service (FPMS) clean stock program for grapes was one of the first in the world, created during the 1950s (Alley and Golino 2000). The program was originally managed under the assumption that grapevine leafroll viruses spread only by grafting healthy stock with infected stock and did not spread naturally in vineyards (Goheen 1989). This was based on many years of observation by scientists that leafroll disease had been rarely recorded to spread between vines in California vineyards. Hence, healthy and diseased vines were planted in the same location in many of the older blocks.

In 1992, the first evidence of leafroll disease was discovered in the Foundation vineyard at UC Davis (Rowhani and Golino 1995) using the recently developed leafroll virus serological test, an enzyme-linked immunoabsorbent assay (ELISA)(Gonsalves 2000). It became clear that more research was needed on how and when leafroll was spread between grapevines. Previously, scientists had observed the natural spread of leafroll disease and had implicated mealybugs as putative vectors (Teliz et al. 1989; Tanne et al. 1989; Engelbrecht and Kasdorf 1990; Habili et al. 1995; Jordon et al. 1993). It was possible that this was a mechanism for spread in California vineyards as well.

We began experiments to determine whether the species of mealybug found in California vineyards could transmit domestic isolates of leafroll under experimental conditions. Four species of mealybug that are found commonly in California vineyards were selected: longtailed mealybug, *Pseudococcus longispinus* (Targioni-Tozzetti); obscure mealybug, *Pseudococcus viburni* (Signoret); grape mealybug, *Pseudococcus maritimus* (Ehrhorn); and citrus mealybug, *Planococcus citri* (Risso). Two of these four species of mealybug already had been reported to have vector potential: longtailed mealybug was reported to transmit leafroll disease agents in 1989 (Tanne et al. 1989) and citrus mealybug was reported to transmit grapevine virus A (Rosciglione and Castellano 1985). Neither obscure nor grape mealybug had yet been shown to transmit leafroll disease agents or any of the other grapevine closteroviruses. They were strong candidates for testing since they are widespread on grapevines in California.

Establishing mealybug populations

All mealybug species were identified by co-author Gill, pseudococcid taxonomist. Obscure and longtailed mealybug were collected from a vineyard in San Luis Obispo, with the help of UC farm advisor Mary Bianchi. Kent Daane, UC Berkeley extension assistant specialist, supplied the citrus mealybug. For all these cultures, single females were isolated and allowed to reproduce, assuring that the established culture contained only a single species. This was essential because mealybug species are often found as mixed populations, as was the case in our San Luis Obispo collection. Mealybug cultures were maintained for several years on sprouted organic potatoes in quart glass jars. They were then covered with 16XX silk-screen cloth secured with a lid band to which a caulk seal had been applied, and maintained at room temperature under fluorescent lights with a 14-hour day length and 8-hour dark period. We found that populations readily adapted to experiments on grape plants if they were reared on that host for at least a generation or so. As needed, populations were moved from potatoes to grapevines caged in greenhouses.

Grape mealybug was collected from a vineyard in Napa Valley. This species cannot be raised reliably in the laboratory; therefore, field-collected insects were used for the experiments. This population was checked to ensure that they were initially free of virus when collected from the field by screening on healthy plants and ELISA-testing of the mealybugs.

Leafroll from virus collection

Reference sources of leafroll and other grape virus diseases were established in the UC Davis grapevine virus collection (Golino 1992). This collection is essential to our studies since many grape viruses cannot easily be purified,

Most mealybug cultures were maintained on sprouted, organic potatoes in glass mason jars with silk-screen fabric covers.

Four species of mealybug that are commonly found in California vineyards were selected for experiments on transmission of leafroll diseases: *top to bottom,* longtailed mealybug (female) and nymph with long, taillike filaments; obscure mealybug; grape mealybug, which is commonly found on grape berries, as shown; and citrus mealybug, with characteristic short, wedge-shaped filaments.

TABLE 1. Virus accession number, and viruses detected in acquisition-access plants and test plants (after mealybug inoculation)

Accession no.*	Viruses† detected in acquisition-access parent plant by ELISA and/or PCR	Virus detected in inoculated test plant
LR101	GLRaV-3, GRSPaV	GLRaV-3
LR102	GLRaV-1, GLRaV-2, GLRaV-5, GVB, GRSPaV	GLRaV-5
LR106	GLRaV-4, GRSPaV	None
LR109	GLRaV-2, GLRaV-3, GFkV , GRSPaV, GVC	GLRaV-3
LR114	GLRaV-1, GLRaV-2, GVB, GRSPaV	None
CB100	GLRaV-2, GVB	None
CB116	GLRaV-3, GVA, GVB, GVD	GLRaV-3
Healthy	None	None

* Each acquisition-access plant was ELISA-tested before use. Test plants were ELISA-tested a minimum of four times at 3, 6 and 12 months after inoculation and after the test plant had gone through at least one dormancy period. A subset of plants that tested ELISA-positive was planted in a vineyard for long-term observation and PCR-testing.

† GLRaVs = grapevine leafroll–associated viruses (1–7); GVA, GVB, GVD = grapevine viruses A, B, D; GFkV = grapevine fleck virus; GRSPaV = grapevine rupestris stem pitting–associated virus.

stored or transmitted to smaller, easy-to-grow plants. Leafroll disease is associated with a group of closely related viruses, all in the closterovirus group, known as grapevine leafroll–associated viruses (GLRaV), which are numbered sequentially in the order of their discovery (GLRaV-1 through -7). For our experiments, we selected the most common GLRaVs found in California, GLRaV-1, -2, -3 and -4. GLRaV-2, -3 and -4 were from infected *Vitis vinifera* cv. Thompson Seedless vines in the UC Davis grapevine clonal virus collection. GLRaV-1 was from infected *V. vinifera* cv. Pinot Noir vines in a commercial vineyard. We also tested an accession of grapevine infected with corky bark disease, another serious viral disease that some researchers believe may be mealybug transmitted. All but one of the virus accessions used were infected by more than one virus, a situation recently found to be so common in grapevines that it is difficult to find single infection sources of these viruses. At the time these experiments were initiated, the techniques available to characterize the virus profiles were still under development and it was not possible to determine whether the vines had single isolates of these diseases. We report here the results of recently completed molecular and biological screening of these virus sources (table 1).

Dormant cuttings approximately 18 inches long of each source vine were stored at 34°F until needed. Canes were rooted and then grown in a greenhouse until they were about 2 to 3 feet tall, ELISA-tested and used for acquisition feeding. Acquisition feeding plants also were propagated by tissue culture. Approximately 0.25-inch-long nodes were cut from vines in the field, grown in tissue culture, and then transplanted to the greenhouse and grown to about 3 feet tall. All plants were ELISA-tested to ensure they were infected with virus.

Virus detection

The virus source plants were tested for grapevine viruses by methods including herbaceous host indicators, woody indexing, ELISA and reverse transcriptase-polymerase chain reaction (RT-PCR or PCR). Virus detection technology advanced significantly throughout the duration of these experiments, greatly improving our ability to detect and differentiate between the grapevine viruses. When our work was initiated in 1992, all virus sources were tested with herbaceous and woody indicator tests, the most reliable biological tests available at that time (Martelli 1993). By the conclusion of the project in 2001, both ELISA and PCR tests were used to better characterize our virus sources.

Herbaceous indexing involves a mechanical inoculation of susceptible herbaceous plants in the greenhouse. Woody indexing is accomplished by chip-budding virus-infected sources on susceptible cuttings of indicator grape selections and planting them in the field for 2 years of observation. Both types of tests are very sensitive in detecting the presence or absence of the disease, but do not identify the specific virus causing symptoms on the indexing host. For example, the woody index on *V. vinifera* cv. Cabernet Franc will determine if leafroll disease is present but does not tell which virus is causing the disease. Another major limitation of the woody indicator test is the 2 years required for completion.

A special type of ELISA called $F(ab')_2$ was used to detect virus infection in test and virus acquisition plants (Rowhani 1992). A test was considered positive if the sample had an optical density of at least three times above the healthy control and was over 0.1. Plants were observed for symptoms and tested by ELISA a minimum of three times over a 2-year period. Plants that tested ELISA-positive were established in a vineyard to document disease development.

All GLRaV source vines were screened using PCR and / or ELISA for GLRaV-1, -2, -3, -4, -5 and -7; grapevine viruses A (GVA), B (GVB) and D (GVD); grapevine fleck virus (GFkV); grapevine fanleaf virus (GFLV); tomato ringspot virus (ToRSV); arabis mosaic virus (ArMV); grapevine rupestris stem pitting–associated virus (GRSPaV); and grapevine rootstock stem lesion–associated virus (GRSLaV). PCR reactions were performed using a simplified RT-PCR technique optimized for grapevine tissue (Rowhani et al. 2000). With this new technology, it became clear that many of our virus sources were infected with more than one virus.

Testing for disease transmission

Mealybugs are difficult insects to manipulate for vector experiments. In our initial work, we found that even when individual adults — each about the size of a pinhead — were handled gently using fine brushes, transfer between plants often resulted in death of the individual, likely caused by damage to their fragile feeding stylet. We did extensive experimentation with acquisition-access feeding, transferring mealybugs to infected grapevines by a number of different techniques, and subsequently developed a simple and effective procedure that allowed us to screen each species for its ability to transmit the various GLRaVs. Leaf pieces were cut from one plant and placed on another. The adult insects did not move, even as the leaf dried, and they eventually died; however, the nymphal stages would move to the new plant and start feeding. A standard period of 14 days was established for acquisition and transmission based on this work. Crawlers (first instar mealybugs) were used for the acquisition-access feeding on virus-infected plants, then moved with leaf pieces to healthy test plants for possible transmission of the viruses.

Bulk transmission tests were performed to determine if a mealybug species could transmit a given virus type. Mixed stages of mealybug were established on virus-infected grape plants, using the method described above. The plants were placed in individual box cages, and caged plants of each virus were placed in separate walk-in cages in a greenhouse kept at 85°F, with a 14-hour photo period. Mealybugs fed for an acquisition-access period of 2 weeks. One-node cuttings of healthy Cabernet Franc were used as inoculation test plants. Leaves of the virus-infected, mealybug-infested plants were cut into sections and arranged on test plants to allow inoculative mealybugs to crawl off as the leaf dried. Approximately 10 to 20 mealybugs were observed feeding on each test plant. The inoculation access feeding period was 2 weeks, after which plants were sprayed with the insecticide chlorpyrifos (Dursban 2E) to kill the mealybugs. Mealybugs from healthy grapes and test plants with no mealybugs were used as controls, ensuring that our insect cultures were not inoculative and that spread had not occurred by some other means under our experimental conditions.

In most tests, at least 30 plants were exposed to mealybugs that had fed on a virus-infected plant, 10 plants were exposed to mealybugs that fed on a healthy grape plant and 10 plants had no mealybug feeding. The single exception was the tests conducted with grape mealybug, which had only 10 inoculated plants, five healthy and five with no mealybug control plants. Because of the difficulty in obtaining sufficient numbers of grape mealybug, it was not tested with GLRaV-1 and -4 sources.

The authors developed a unique method for transferring mealybugs, which involved placing leaf cuttings from virus-infected plants onto healthy 'Cabernet Franc' plants so that insects were not harmed by direct handling.

We also performed tests to determine the minimum period necessary for mealybug to acquire the virus. For these experiments we used a fine brush to transfer longtailed mealybug to a grape plant infected with LR109. The mealybugs were allowed to feed for either 3, 6, 24, 48 or 72 hours, or 2 weeks. Fifteen to 20 insects then were transferred to each of the 10 test plants for each acquisition time period, and allowed to feed for 2 weeks to transmit the virus to the test plants.

To determine the minimum period necessary for virus transmission, longtailed mealybug that had been reared on an LR109-infected grape plant (and therefore were highly inoculative) were transferred on a fine brush in groups of 15 to 20 insects to each of 10 test plants. After allowing them to feed for a specified length of time, they were sprayed with insecticide. Time periods tested were 24, 48 and 72 hours, and 7, 14 and 21 days.

Indicator grape test plants

Dormant, healthy cuttings of Cabernet Franc were used for GLRaV transmission tests. Cabernet Franc is highly susceptible to leafroll disease and shows very strong symptoms of infection; it is frequently used as a biological indicator for the disease. One-node cuttings of dormant canes were rooted in sand on warm mats and transplanted to 4-inch pots. Plants were inoculated when they were approximately 6 inches tall with three to four leaves. They were transplanted to gallon pots after 1 month and held in an insect-proof greenhouse and screen house for testing. All plants were periodically cut back during the growing season. They were pruned to two buds during at least one dormant season.

Test plants were ELISA-tested a minimum of four times at 3, 6 and 12 months after inoculation and, a final time, after the test plant had gone through at least one dormancy period. Some of the inoculated plants that became infected were planted in a vineyard for further testing. Woody indexing showed them all to be positive for leafroll disease on Cabernet Franc

The authors determined that all four mealybug species can transmit grapevine leafroll disease via feeding. *Above,* 'Cabernet Franc' vines developed severe leafroll systems after infected longtailed mealybug fed on them.

TABLE 2. Summary of virus transmission tests by California mealybugs

Virus accession no.	Avg. % infection*	Range (%)†	No. plants tested‡	No. exp.§
Longtailed mealybug				
LR101	37	21–60	80	4
LR102	<1	0–10	120	4
LR106	0	NA ¶	70	3
LR109	35	10–55	100	4
LR114	0	NA	110	3
CB100	0	NA	175	6
CB116	nt #	nt	nt	NA
Healthy	0	NA	125	NA
Control (none)	0	NA	125	NA
Obscure mealybug				
LR101	0	NA	85	3
LR102	0	NA	70	2
LR106	0	NA	45	3
LR109	19	0–33	65	2
LR114	0	NA	35	2
CB100	0	NA	30	2
CB116	nt	nt	nt	NA
Healthy	0	NA	85	NA
Control (none)	0	NA	85	NA
Grape mealybug				
LR101	nt	nt	nt	nt
LR102	0	NA	25	2
LR106	nt	nt	nt	nt
LR109	41	17–66	23	2
LR114	nt	nt	nt	nt
CB100	nt	nt	nt	nt
CB116	90	NA	10	1
Healthy	0	NA	13	5
Control (none)	0	NA	18	5
Citrus mealybug				
LR101	0	NA	40	2
LR102	0	NA	40	2
LR106	0	NA	80	4
LR109	5	NA	40	2
LR114	0	NA	40	2
CB100	nt	nt	nt	nt
CB116	nt	nt	nt	nt
Healthy	0	NA	40	12
Control (none)	0	NA	40	12

* Average percent of plants positive for virus infection after inoculation using mealybugs.
† Range of transmission percentages over different experiments.
‡ Number of plants inoculated and tested.
§ Number of experiments used with each mealybug and virus combination.
¶ NA = not applicable.
# nt = not tested.

and negative for other diseases on the indicators St. George, LN-33 and Kober 5BB. They were also retested by PCR for the other grapevine viruses.

Mealybug spreads leafroll viruses

We were able to determine that four California species of mealybug — obscure, longtailed, citrus and grape — can transmit California GLRaV-3 isolates (table 2). These experiments demonstrated for the first time that obscure and grape mealybug are capable of transmitting GLRaV-3 viruses. We can confirm previous reports of the ability of longtailed and citrus mealybug (Cabaleiro and Segura 1997) to transmit GLRaV-3 and establish that our experimental populations from California vineyards are competent vectors. Only one other apparent virus transmission was recorded: two Cabernet Franc vines fed upon by longtailed mealybug developed severe leafroll symptoms and PCR-testing revealed the presence of GLRaV-5. This is the first record of GLRaV-5 transmission by any vector.

Extensive screening of the test plants was unable to detect transmission of any other grapevine leafroll–associated viruses, even when inoculum sources were infected with multiple virus types. Only GLRaV-3 and GLRaV-5 were transmitted by the mealybug species and, to the limits of our detection ability, none of the other viruses present in the original virus sources were transmitted. Apparently, the mealybug acted as a filter and created single infections of GLRaV-3 and GLRaV-5. This is likely due to the specificity of virus and insect interactions of each leafroll virus type. Mealybug may never transmit other leafroll viruses, although it is difficult to draw conclusions from negative data of this nature.

The single infections we have created will prove valuable for future research. Much of the work on the effects of these viruses has been done with multiple infections, making it hard to determine the effect of individual viruses; these new single infections will allow research on individual viruses.

This work was conducted using laboratory populations established from a single vineyard for each of the mealybug species. In the case of grape mealybug, all the insects came from just a few vines. We would expect there to be population variation related to vector efficiency and specificity within the mealybug species. Furthermore, it was only possible to test a limited number of virus strains and types. We have demonstrated that it is possible for transmission to occur, but cannot yet comment on the variation in vector potential beyond these laboratory populations. Additional work with diverse collections is needed to generalize more broadly about the transmission biology of California populations of these species.

During our work, reports have been published confirming transmission of GLRaV-3 by the soft scale *Pulvinaria vitis* (Linnaeus). We now also know that GLRaV-1 is transmitted by two species of soft scale insects, but not mealybug (Martelli 2000). These two soft scale species, *Parthenolecanium corni* (Bouché) and *Neopulvinaria innumerabilis* (Rathvon), are found in California.

Our tests to determine a minimum virus-acquisition feeding period for longtailed mealybug were inconclusive; no virus transmission was observed at the shorter intervals. We believe this may have been due to the necessity of handling the fragile individual mealybugs twice to complete the experiments. The tests to determine minimum virus-transmission feeding period by this species were more successful. Virus transmission occurred within 24 hours, the shortest period we tested, indicating that the minimum acquisition-feeding period is less than 1 day.

Our results clearly indicate that the obscure, longtailed, citrus or grape mealybug could have been responsible for the spread of GLRaV-3 observed at the foundation vineyard. A rigorous search in the old foundation vineyard did discover limited numbers of grape mealybug. This does not prove that mealybug was the cause of leafroll spread in the collection, but does indicate a possibility since they are present in the area.

Strategies for the future

Based on these results, it is clear that the species of mealybug found in California vineyards are capable of transmitting at least two of the viruses that cause leafroll disease, GLRaV-3 and GLRaV-5. Although documented cases of field transmission are rare, it is essential that vines in the California Grapevine Registration and Certification Program be protected from natural disease spread, both at the FPMS vineyard and at commercial nurseries producing certified stock. To ensure maximum protection of nursery stock, we recommend the implementation of greater isolation of registered plants from any potential virus source plants and control of mealybug populations in these plantings. By combining these practices with regular monitoring of registered vines and the new laboratory tests, it will be possible to produce a high-quality grapevine stock free of target viruses.

D.A. Golino is Cooperative Extension Plant Pathology Specialist, S.T. Sim is Staff Research Associate, and A. Rowhani is Plant Pathology Specialist, Department of Plant Pathology, UC Davis; and R. Gill is Senior Insect Biosystematist, Plant Pest Diagnostic Center, California Department of Food and Agriculture. *The authors thank Mary Bianchi, San Luis Obispo Farm Advisor, for assistance in locating mealybug populations; Kent Daane, UC Berkeley Extension Assistant Specialist, for populations of citrus mealybug and advice on insect rearing strategies; Glen Friebertshauser, Agrianalysis, for GLRaV-1–infected cuttings; and Estelle Devevre and Jorge Jimenez for excellent technical assistance. We gratefully acknowledge financial support provided by the American Vineyard Foundation, the California Table Grape Commission, and the Fruit and Nut Tree and Grapevine Industry Advisory Board. Portions of this work have been previously published as abstracts.*

References

Alley L, Golino D. 2000. The origins of the grape program at Foundation Plant Materials Service. Proc 50th Annu Am Soc Enol Viticulture meeting, Seattle, WA. Am J Enol Vitic 51:222–30.

Cabaleiro C, Segura A. 1997. Field transmission of grapevine leafroll associated virus 3 (GLRaV-3) by the mealybug *Planococcus citri*. Plant Dis 81:283–7.

Engelbrecht DJ, Kasdorf GGF. 1990. Field spread of corky bark, fleck, leafroll and Shiraz decline diseases and associated viruses in South African grapevines. Phytolactica 22:347–54.

Goheen A. 1989. Virus diseases and vine selection. Am J Enol Vitic 40:67–72.

Golino D. 1992. The Davis grapevine virus collection. Am J Enol Vitic 43:200–5.

Gonsalves D. 2000. Progress towards understanding the genomic organization and expression of grapevine closteroviruses. Proc 13th International Committee on Study of Virus and Virus-like Diseases of Grapevine, Adelaide, Australia. p 6–7.

Habili N, Fazeli DF, Ewart A, et al. 1995. Natural spread and molecular analysis of grapevine leafroll–associated virus 3 in Australia. Phytopathol 85:1418–22.

Jordan D, Peterson C, Morgan L, Segaran A. 1993. Spread of grapevine leafroll and its associated virus in New Zealand vineyards. Proc 12th International Committee on Study of Virus and Virus-like Diseases of Grapevine, Montreauz, Switzerland. p 113–4.

Martelli GP. 1993. *Graft-transmissible Diseases of Grapevines: Handbook for Detection and Diagnosis.* UN FAO, Rome, Italy. 262 p.

Martelli GP. 2000. Major graft-transmissible diseases of grapevines: Nature, diagnosis and sanitation. Proc 50th Annu Am Soc Enol Viticulture meeting, Seattle, WA. Am J Enol Vitic 51:231–6.

Rosciglione B, Castellano MA. 1985. Further evidence that mealybugs can transmit grapevine virus A (GVA) to herbaceous hosts. Phytopath Medit 24:186–8.

Rowhani A. 1992. Use of $F(ab')_2$ antibody fragment in ELISA for the detection of grapevine viruses. Am J Enol Vitic 43:38–40.

Rowhani A, Biardi L, Johnson R, et al. 2000. Simplified sample preparation method and one-tube RT-PCR for grapevine viruses. Proc 13th International Committee on Study of Virus and Virus-like Diseases of the Grapevine, Adelaide, Australia. p 148.

Rowhani A, Golino D. 1995. ELISA test reveals new information about leafroll disease. Cal Ag 49(1):26–9.

Tanne E, Ben-Dov Y, Raccah B. 1989. Transmission of closterovirus-like particles by mealybugs (Pseudococcidea) in Israel. Phytoparasitica 17(1):64.

Teliz D, Gonsalves D, Hu JS, Hummer DJ. 1989. Detection of grapevine leafroll associated closteroviruses in recently infected tissue in New York and spread of the disease in Mexico. Phytoparasitica 17(1):68–9.

RESEARCH ARTICLE

Proper harvest timing can improve returns for intermountain alfalfa

Alfalfa hay is a major California crop, primarily due to the strength of the state's dairy industry. The optimal cutting timing for alfalfa — whether to maximize forage quality (earlier harvest) or yield (later harvest) — is a fundamental concern for growers, including at Prather Ranch, *above,* near Mt. Shasta.

Steve B. Orloff
Daniel H. Putnam
Steve C. Blank

Harvest timing has a profound effect on the yield and forage quality of alfalfa hay. Early harvest results in low yield but high forage quality and price, while delayed harvest increases yield but reduces forage quality and price. Since gross revenue is a function of both yield and price, it is important for growers to select the optimum cutting schedule. We quantified a biological relationship among yield, forage quality and day of harvest, using the results from 2 years of field studies at locations in the intermountain alfalfa production region of California. An economic analysis, including a decision model, was developed to enable producers to assess current market conditions and seasonal effects, and in turn select the most profitable harvest timing. Our analysis demonstrated that no single harvest strategy is always best. The most profitable approach depends on the rate of change in yield and quality for that season and the current price differential between the quality market classes for alfalfa hay.

The optimal cutting schedule for alfalfa hay is a fundamental concern for alfalfa growers and has been the subject of research for decades (Marble 1980). Alfalfa maturity at harvest affects both the yield and quality of the harvested product. Forage quality has a significant influence on price per ton, while yield and price determine the return per unit of land area. Since yield and quality are typically inversely related, determining the most profitable cutting schedule can be a challenge for growers.

The demand for alfalfa hay comes from two basic groups, dairy producers and all other users (Konyar and Knapp 1986). California's $4.6 billion dairy industry is the state's primary alfalfa consumer. Alfalfa is an integral component of rations for milking cows and cannot be easily replaced by other feeds. The forage quality or digestibility of alfalfa hay in the dairy ration directly affects milk output per cow. Dairy producers demand alfalfa with high digestibility and protein, and low fiber — particularly for top-producing cows — and they pay extra for this class of hay.

Other users do not need such high-quality hay, and are generally unwilling to pay premium prices. Some classes of livestock, such as beef and nonlactating dairy cows, perform well when rations are balanced with lower quality hay. Horse owners also have quality considerations but their purchasing habits are more visual and physical (for example, they avoid feeds with weeds, mold and / or dust). For this economic analysis, horse demand is included with producers of beef and other kinds of livestock.

For marketing purposes, the forage quality of alfalfa is most commonly expressed in terms of total digestible nutrients (TDN), which is calculated from a lab fiber value (acid detergent fiber [ADF]). While 52% TDN was considered adequate during the 1970s, the market threshold steadily rose during the 1980s and 1990s. Dairy producers now seek 55%, 56% or even 57% TDN alfalfa hay. (TDN is calculated using the California equation, TDN% = 82.38 – [0.7515 × ADF%] and expressed on a 90% dry matter basis.)

Quality affects market value

Forage quality, which determines price, is a continuum with a range of values from high to low. However, there are distinct alfalfa-hay quality designations now recognized by the U.S. Department of Agriculture (USDA) for categorizing hay prices: Supreme (> 55.9 TDN, < 27 ADF, [category created in 1999]), Premium (54.5–55.9 TDN, 27–29 ADF), Good

(52.5–54.5 TDN, 29–32 ADF) and Fair (50.5–52.5 TDN; 32–35 ADF). Dairy-quality hay is most frequently associated with the Supreme and Premium grades, and less frequently, with the Good grade; these categories receive significantly higher prices in California than Fair or Low. While the alfalfa market is not as volatile as that for other higher value commodities, the fluctuations are great enough to influence whether alfalfa as a crop option is profitable or not.

From 1992 to 2001, the average annual price for the top category of alfalfa hay from Northern California varied from $89.62 to $136.53 per ton (fig. 1). In addition to price, the quality differential varies significantly from year to year. The price differential — the percentage change between highest category hay (Premium or Supreme) and Fair hay — ranged from 24.4% to 74.3% (expressed as a percent of the lower value) over the same 10-year period.

Yield-quality relationship

Alfalfa yield and quality are inversely related. Harvesting alfalfa at an immature growth stage will result in high forage quality but low yield. Conversely, delaying cutting until a more mature growth stage will result in higher yield but poorer, often unacceptable, forage quality. This presents a dilemma for the alfalfa grower who desires both high yield and high forage quality. Furthermore, little information has been available to assist growers in deciding whether total revenues or profits are maximized with a short or long cutting schedule. This research was undertaken to quantify the yield-quality trade-off in alfalfa and provide tools to determine optimum cutting schedules for the intermountain regions of the western United States.

Field trials were conducted during the first and second alfalfa growth periods, in two high-mountain valleys of Siskiyou County: Scott Valley (elevation 2,700 feet) and Butte Valley (elevation 4,200 feet). Two alfalfa varieties were chosen to represent a range of varieties common to the intermountain region. 'Blazer XL', the more dormant variety, has a fall dormancy rating of 3, and 'Archer' has a fall dormancy rating of 5. The fall dormancy rating is based on alfalfa plant height in fall — lower numbers indicate a more dormant variety.

Alfalfa was harvested every 2 to 3 days, throughout first and second growth periods (late spring and summer, respectively) in 1996 and 1997. A completely randomized design with four replications was used. The first harvest was at the late vegetative pre-bud stage; the last harvest was at full bloom. A different area of each field, with a uniform first-cutting harvest date, was selected for the second-cutting harvests. The total number of harvests per growth period averaged 12, ranging from 9 to 14 depending on the cutting and the location.

Forage yield was measured using a sickle mower from a 3-feet-by-15-feet area of each plot at each harvest date. Each plot was subsampled with eight to 10 randomly selected handfuls of standing crop to determine moisture content and forage quality. Acid detergent fiber (ADF), neutral detergent fiber (NDF) and crude protein (CP) were measured at each harvest using near infrared spectroscopy (NIRS) analysis (NDF and CP data not shown).

Weather conditions during the springs of 1996 and 1997 were very different. Spring 1996 was cool and alfalfa development was delayed approximately 10 days to 2 weeks later than in spring 1997. This illustrates the problem with using a calendar date to time alfalfa harvests. Plant maturity, height and / or other measurements more accurately determine optimal harvest timing. For example, alfalfa harvests at the higher elevation area, Butte Valley, averaged 16 days later than in Scott Valley.

In this study, the location, variety, cutting and year all had significant effects on alfalfa yield and quality changes over time. Location and variety effects, while statistically significant, were small. Our intent was to quantify changes in yield and quality with time rather than to compare varieties or regions, which were included to develop a robust relationship that would hold true across a range of growing conditions in the intermountain region. This relationship would likely differ in areas with widely divergent varieties or growing conditions than those tested.

Quantifying yield, quality changes

As alfalfa matured from the late vegetative pre-bud stage to full bloom, the daily increase in yield per acre for the first cutting was 80 pounds dry matter, averaged over 2 years, two varieties and two locations (fig. 2). In other words, each day delay in the first-cutting harvest resulted in an 80-pound increase in yield. The rate of yield increase was greater for the second cutting, with each day delay resulting in a 112-pound increase in yield.

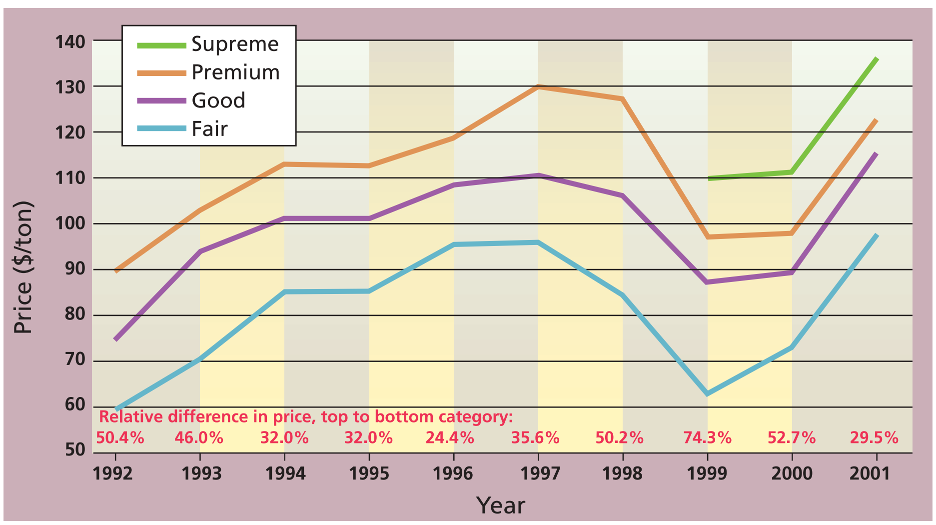


Fig. 1. Average price of alfalfa hay per ton as a function of forage quality for the past 10 years in intermountain regions of California. Percentage is the difference between top and bottom USDA categories, as a percent of the Fair category. (See text for definition of hay quality categories.) The Supreme quality category was added in 1999 (it was combined with Premium in previous years). Source: USDA Market News, Moses Lake, WA.

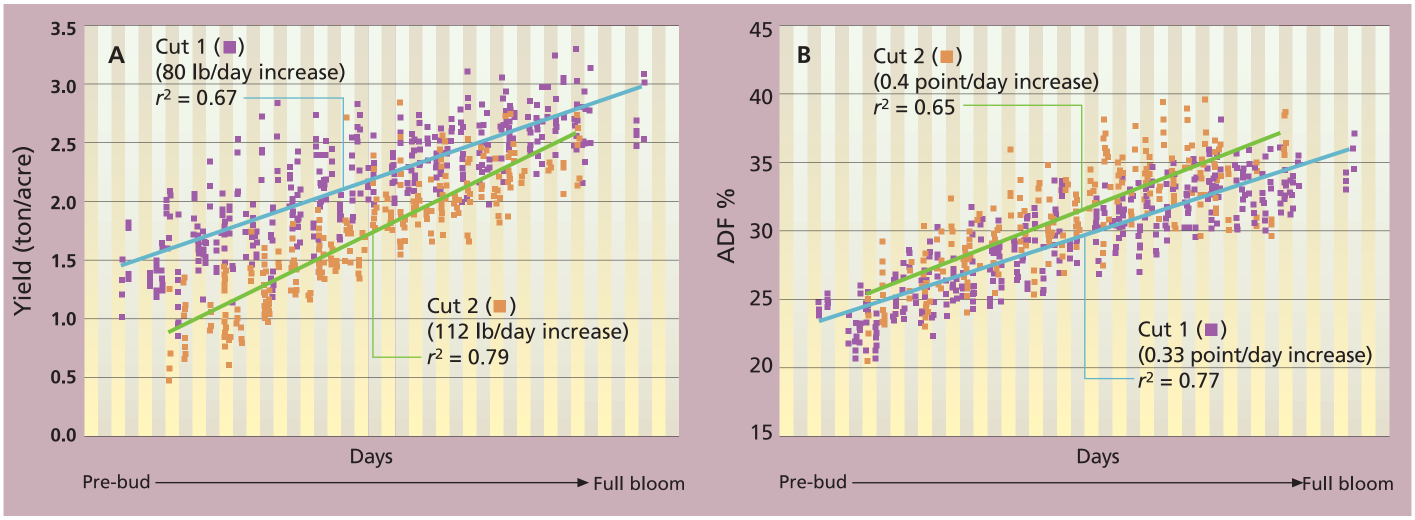


Fig. 2. Relationship between (A) alfalfa yield and (B) acid detergent fiber content (ADF, 100% dry matter), and time of harvest from pre-bud to full bloom for first and second cuttings (over two intermountain locations, 2 years and two varieties). Each vertical column represents 1 day. Lines represent linear regression averaged across locations, varieties and years.

As expected, forage quality declined as the alfalfa matured. During the first growth period, the ADF concentration increased an average of 0.33 percentage points per day. This equates to a loss of 0.22 percentage points of TDN (calculated as a linear function of the ADF value) per day (fig. 2). The increase in NDF per day was very similar to ADF, 0.30 percentage points per day. CP dropped 0.20 percentage points per day on average across locations, varieties and years.

Forage quality declined even more rapidly during the second growth period. The ADF content increased an average of 0.40 percentage points per day on the second cutting. This increase in ADF equates to a 0.27 percentage point loss in TDN per day delay. The NDF concentration increased 0.38 percentage points per day. The average drop in CP on second cutting was 0.34 percentage points per day, declining at a rate 75% more rapid than during the first growth period.

Identifying the optimal cutting schedule for alfalfa hay involves choosing between different price and yield combinations. First, there is the choice of the *timing* of each cutting, recognizing that delaying a cutting increases the yield but lowers forage quality and thereby price. Second, is the choice of *how many* cuttings to make during the growing season. The first choice affects the second — choosing longer time periods between cuttings may reduce the total number of cuttings that are feasible in one season. The optimal harvest solution requires an analysis and integration of both the yield-quality tradeoff and market prices for the different hay quality categories.

During an alfalfa growth period, choosing the best time to cut simply involves identifying when yield and price result in the highest revenue per acre. Although other strategic considerations (such as long-term stand life, machinery costs, overall system viability) ultimately come into play, the basic economic decision begins with the yield-quality trade-off.

Harvest decision equation

We developed a decision-making tool to compare gross returns for two different cutting times during a growth period (Blank et al. 2001). The breakeven point for two cutting options occurs when their revenues are equal. It is assumed that costs for both cutting options are basically the same (there will be slight differences due to yield, such as twine usage and time to harvest, but these are minor). Two alternative harvest times can be evaluated by comparing the product of the yield and the price for the two timings. Time 1 is when the yield still generates dairy-quality hay (Supreme or Premium), and time 2 is when yield has increased enough to exactly offset the lower price that will be received for the lower (Good or Fair) quality hay. The equation used to express the breakeven point in terms of price (P) and yield (Y) for two cutting times is as follows:

$$P_1 \times Y_1 = P_2 \times Y_2$$

Manipulating this equation provides a decision rule to aid producers in deciding whether to cut at time 1 (for quality) or at time 2 (for yield). Expressed as a breakeven point, the relationship between price and yield is:

$$\underset{\text{in price}}{\overset{\text{Relative}}{\text{difference}}} \quad \frac{P_1 - P_2}{P_2} = \frac{Y_2 - Y_1}{Y_1} \quad \underset{\text{in yield}}{\overset{\text{Relative}}{\text{difference}}}$$

If the price differential equals the yield differential, both cutting times would result in equal revenues. However, if the price differential (relative change in price from higher quality to lower quality) is greater than the yield differential (relative change in yield between the two cutting times), it is better to cut for quality. Conversely, if the yield differential is greater than the price differential it is better to cut for yield.

Applying the decision rule

An example will help illustrate how to apply this decision-making equation. In 2000, an alfalfa grower in the intermountain area of Northern California wants to know whether it is better to aim for Supreme alfalfa or to delay harvest and produce Premium. The grower uses subjective judgment or the Intermountain Alfalfa Quality Stick (Orloff and Putnam 2001) to estimate that

Based on field studies conducted in Butte Valley, *left,* and Scott Valley, *right,* researchers developed a decision model to help growers maximize profits by adjusting their cutting schedules.

his alfalfa field is likely to test about 57 TDN (within the Supreme category) at a particular time. If this is the grower's first cutting he may obtain approximately 1.6 tons per acre, according to the yield-quality relationship (fig. 2). The grower must decide whether to cut for quality and capture the Supreme price in fig. 1 (P_1 = \$111.39) with a yield (Y_1) of 1.6 tons, or wait until the yield increases enough to at least offset the lower price. To calculate the higher yield needed at time 2 to offset the lower price, the grower substitutes the current Supreme price into the equation as P_1 and the current Premium price as P_2. Assuming that the market offers the average 2000 price for hay (fig. 1), P_2 is \$98.13. Calculating the left-hand side of the equation gives a price differential of 13.5%. This means that to offset the 13.5% drop in expected price at time 2, the yield differential (increase) must be at least 13.5% of the current available yield. Thus, yield at time 2 must be at least 1.8 tons / acre (0.2 tons / acre higher) to generate the same total revenue as cutting now for Supreme quality. Alfalfa yield increases approximately 80 pounds per day for the first cutting in the intermountain region (fig. 1). A simple calculation reveals that delaying cutting 5 or more days will cause the yield to exceed 1.8 tons / acre, so the grower is better off waiting to harvest and producing Premium rather than Supreme hay. ADF increases approximately 0.33 percentage points per day in spring so a 5-day delay would result in a 1.65 percentage point increase in ADF, well within the Premium category.

The price differences between hay quality categories vary widely from year to year due to a number of complex supply and demand factors. The Northern California price differentials ranged from 24.4% to 74.3% over a 10-year period (fig. 1). The decision to cut for quality or yield depends upon the magnitude of this price difference.

Considering how much prices have varied over the past decade, no single strategy was always best. This point is illustrated by the 1996 and 1999 data, which represent extremes in the market price differentials. In 1996, the price differential was only 24.4% between Premium and Fair. Using the decision rule for our intermountain grower results in a decision to cut for yield (Fair quality) on both the first and second cutting (considering Premium-Good and Good-Fair comparisons). On the other

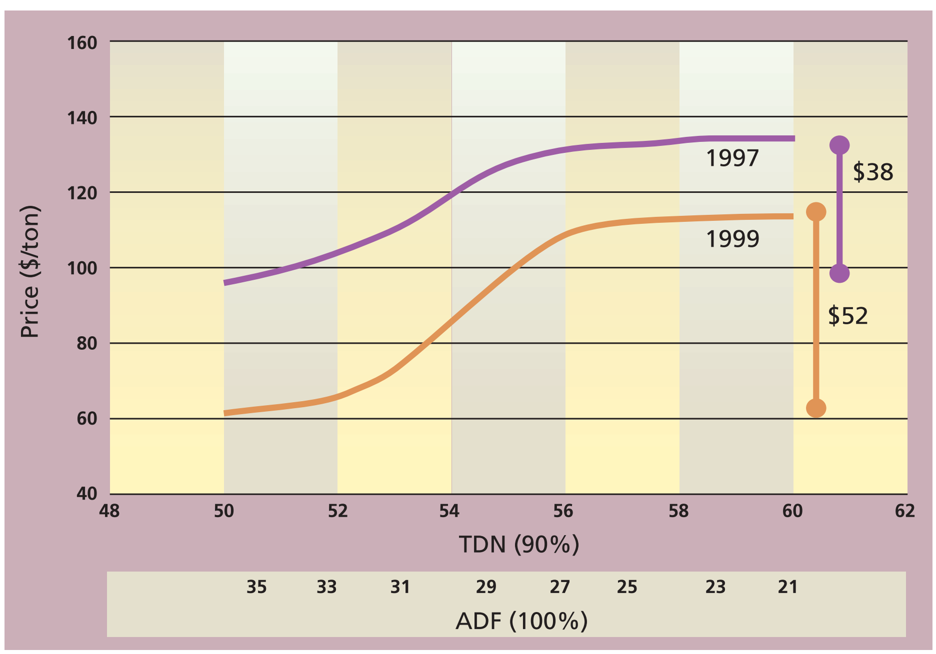


Fig. 3. Idealized relationship between forage quality (ADF, TDN) and alfalfa price (\$/ton) for high-price (1997) and low-price (1999) years. ADF is acid detergent fiber (100% dry matter) and TDN is total digestible nutrients (California equation, 90% dry matter).

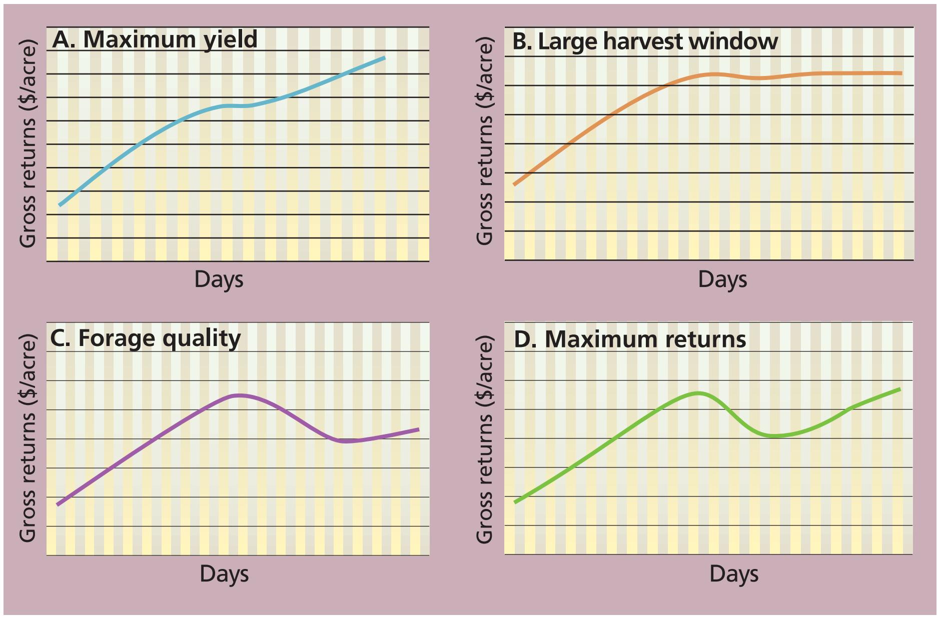


Fig. 4. Four typical outcomes of harvest timing on gross returns, based on field data and hypothetical quality-price relationships. These result from changes in the price difference between higher and lower quality hay under various market conditions. (A) Maximum yield produces the greatest returns; (B) with a large harvest window, yield and quality equalize after a certain point; (C) high forage quality produces the greatest return, then profitability rapidly declines; and (D) two optimum points of return — quality, followed by yield. Each vertical column represents 1 day.

hand, in 1999 the wide price differentials lead to decisions to cut earlier for higher quality on both cuttings.

Idealized price curves

The four categories used by USDA to characterize the alfalfa market contain a range of forage quality values. To analyze potential returns, a continuous sequence of forage quality values along with corresponding prices is needed. We developed idealized price curves for two distinct price years to show the change in price for each incremental change in TDN or ADF (fig. 3). These curves represent a high-price year (1997) with a relatively small Premium-to-Fair price differential and a low-price year (1999) with a large Premium-to-Fair price differential. The curves were based partly on real data from 1997 and 1999, and on discussions with growers and hay brokers about market behavior.

Reflecting the behavior of the California market, there are three distinct segments to the price curves. For TDN values of 56% and above there is very little change in price for each incremental change in TDN. Similarly, there is little drop in price associated with each change in TDN at the low-quality end of the curves. However, at the center portion of the curves, when alfalfa hay goes from 56 to 54 or 53 TDN, there is a precipitous drop in price. This is characteristic of the commonly observed "dairy hay" cutoff perceived by the market. Under current market conditions and perceptions, alfalfa above 55% to 56% TDN (below 27 to 28 ADF) is considered dairy quality, while hay lots below this level of quality are used for dry cows and other nondairy classes of animals.

Timing effects on gross returns

We also calculated gross grower returns within a growth period. The yield (ton /acre), with its corresponding forage quality, was simply multiplied by the associated price from the price curves in fig. 3.

Projections under different price relationships suggest four likely outcomes for gross returns (fig. 4A-D). With all outcomes it was not profitable to cut very early for extremely high-quality alfalfa, greater than about 58 TDN (less than about 24 ADF). The price premiums received never compensated for the lower yields obtained that early in the growth cycle. The first possible outcome (fig. 4A) is where maximum yield always optimizes returns. In this case the price premium obtained for dairy-quality alfalfa is so low that the effect of increasing yield overrides any effect of forage quality on price. This scenario occurs most frequently in high-price years.

The second outcome (fig. 4B) affords a large harvesting window. The drop in price associated with a reduction in forage quality is equally offset by an increase in yield, so returns remain relatively constant after a certain time in the growth cycle.

In the third outcome (fig. 4C), gross returns are maximized by producing alfalfa with high forage quality just at or above the cutoff for dairy-quality alfalfa. The grower must cut for quality and capture the Premium price, or risk loosing profitability. Any increase in yield after that point is insufficient to compensate for the large price drop.

In the last outcome (fig. 4D) there are two potential points of maximum return. Returns peak first when alfalfa is cut for quality. After that point, a slight increase in yield is insufficient to compensate for the large drop in price so returns decline. However, if harvest is delayed long enough there is a significant yield increase that compensates for the price drop from Premium to Good or from Good to Fair. Which of these four outcomes occurs under real conditions depends on both the alfalfa market and growing conditions.

Analysis of intermountain returns

Gross returns were modeled for the first and second growth periods (figs. 5A and 5B, respectively), using actual field data (fig. 2) and the idealized curves for a high-price and low-price year (fig. 3). In the high-price year (1997), there was less price differential between the Premium and Fair hay compared with the low-priced year. For the first cutting (fig. 5A) this curve is similar to that in figure 4B, with a long harvest window. The situation was quite different in the low-price year (1999), which had a large price differential (fig. 5A). Returns were lowest when alfalfa was harvested at a very early growth stage — when yield is low and forage quality extremely high. Returns

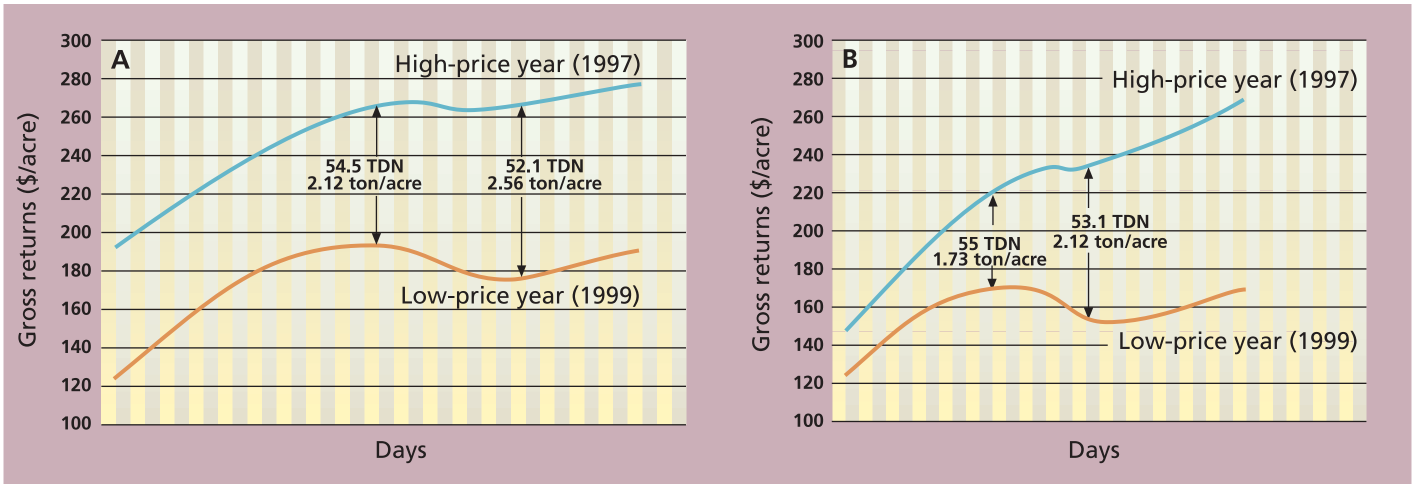


Fig. 5. Gross returns per acre as alfalfa matures for (A) first and (B) second growth period. Reflects yield and quality data from the field, with prices representing high-price (1997) and low-price (1999) year. Each vertical column represents 1 day.

peaked in the range where alfalfa is generally considered dairy quality. Returns then declined as harvest was delayed, until returns began to increase again when the increase in yield nearly compensated for the decrease in quality. So, in this case, returns were highest in the dairy-quality range or when harvest was delayed much later to obtain maximum yield.

The relationship between day of harvest and returns per acre was different for the second cutting, which is midsummer in the intermountain region (fig. 5B). As stated previously, yield increases and forage quality decreases at a faster rate for the second cutting than for the first (fig. 2). In the high-price year gross returns were highest at maximum yield (similar to fig. 4A). Only near the cutoff for dairy-quality hay did the increase in revenue even show signs of leveling off. However, after a few days delay in cutting, the gross returns continued to increase rapidly. In contrast, figure 4D most closely resembled the shape of the return curve in the poor-price example (1999). If harvest was delayed long enough, returns were greater at maximum yield than at dairy-quality hay.

No single harvest strategy is best for alfalfa. The decision on when to cut should be based on rates of change in alfalfa yield and quality, and the price differential between dairy and nondairy hay.

While this type of analysis can be revealing, growers must recognize the conditions and assumptions that were used. The market behavior was based on data provided by the USDA Hay Market News; local price data may vary. The analysis assumed current pricing behavior, with a tremendous drop in price from 56 to 54 TDN. This is a description of the market in California and may not be a true reflection of the hay's actual feeding value. There are a number of other quality factors in addition to ADF concentration, including digestibility of the fiber fraction, protein degradability and ash. This analysis also assumed that price is determined solely by forage quality (measured analytically by ADF or TDN). There are certainly other factors, especially for nondairy hay, including the overall physical appearance (color and the presence of weeds or mold) and suitability for export or the horse market.

This analysis also assumed that the increase in alfalfa yield over time is linear. In our data sets this was only true within normal cutting intervals. Eventually, as alfalfa becomes over-mature, the yield increase will level off. In addition, this analysis only examines the revenues from a single cutting. The timing of an individual cutting clearly influences the amount of growing time available for subsequent alfalfa cuttings. Therefore, to fully analyze different cutting management strategies it is necessary to consider the entire produc-

PROPER HARVEST TIMING — continued from previous page

tion season rather than just individual cuttings. This analysis also does not account for the long-term effect of cutting date on stand persistence and weed encroachment. Nonetheless, an economic analysis of the optimum timing for a single growth period is the first step toward a more complete analysis.

Cutting schedules, profitability

Alfalfa cutting schedules have a large influence on profitability in intermountain regions. There is a fundamental trade-off between yield and quality in alfalfa over a growth period, a biological relationship with large economic implications. During the first growth period, average changes in yield over 2 years of study were 80 pounds per day while ADF content increased 0.33 percentage points per day. Second-cut changes in yield were 112 pounds per day and 0.40% ADF per day. An analysis of gross returns using two distinct market years demonstrated that no single harvest strategy is best for all situations. Whether it is more profitable to aim for high forage quality or maximum yield depends on the rate of change in yield and quality and the price differential between dairy and nondairy hay. Since the price differences due to quality attributes vary significantly from year to year, a grower's cutting strategy should be flexible enough to respond to these market fluctuations.

S.B. Orloff is UC Farm Advisor, Siskiyou County; D.H. Putnam is Extension Agronomist, Agronomy and Range Science Department, UC Davis; and S.C. Blank is Extension Economist, Agricultural and Resource Economics Department, UC Davis.

References

Blank SC, Orloff SB, Putnam DH. 2001. Sequential stochastic production decisions for a perennial crop: The yield/quality tradeoff for alfalfa hay. J Agric Res Econ 26(1):195–211.

Konyar K, Knapp K. 1986. Demand for Alfalfa Hay in California. UC Giannini Foundation Research Rep No 333. 36 p.

Marble VL. 1980. Effect of harvest frequencies and varieties on yield, quality, and stand life. Proc 10th Calif Alfalfa Symp, Dec 10-11, Visalia, CA. p 22–38.

Orloff SB, Putnam DH. 2001. UC Intermountain Alfalfa Quality Prediction Stick: How to Predict the Quality of a Standing Alfalfa Crop. UC Cooperative Extension. http://alfalfa.ucdavis.edu/SUBPAGES/Stick/StickPage.htm

COMINGUP

Sudden oak death found in new hosts

Coming up in *California Agriculture*, UC scientists present the first comprehensive publication on the discovery of the sudden oak death pathogen, *Phytophthora ramorum*, in more than a dozen native plant species, including bay laurel, coast redwood and Douglas fir. While the pathogen does not kill all of its hosts, its broad host range may indicate the ability of sudden oak death to cause significant, long-term, landscape-level changes to California forests.

Also coming up:

- The olive fruitfly is here
- Binding arbitration for farmworkers
- Reuse of agricultural drainage water
- Diabetes awareness among Latino adults
- Special issue on soils

Visit *California Agriculture* on the Web:
http://danr.ucop.edu/calag/

calag@ucop.edu
Phone: (510) 987-0044
Fax: (510) 465-2659