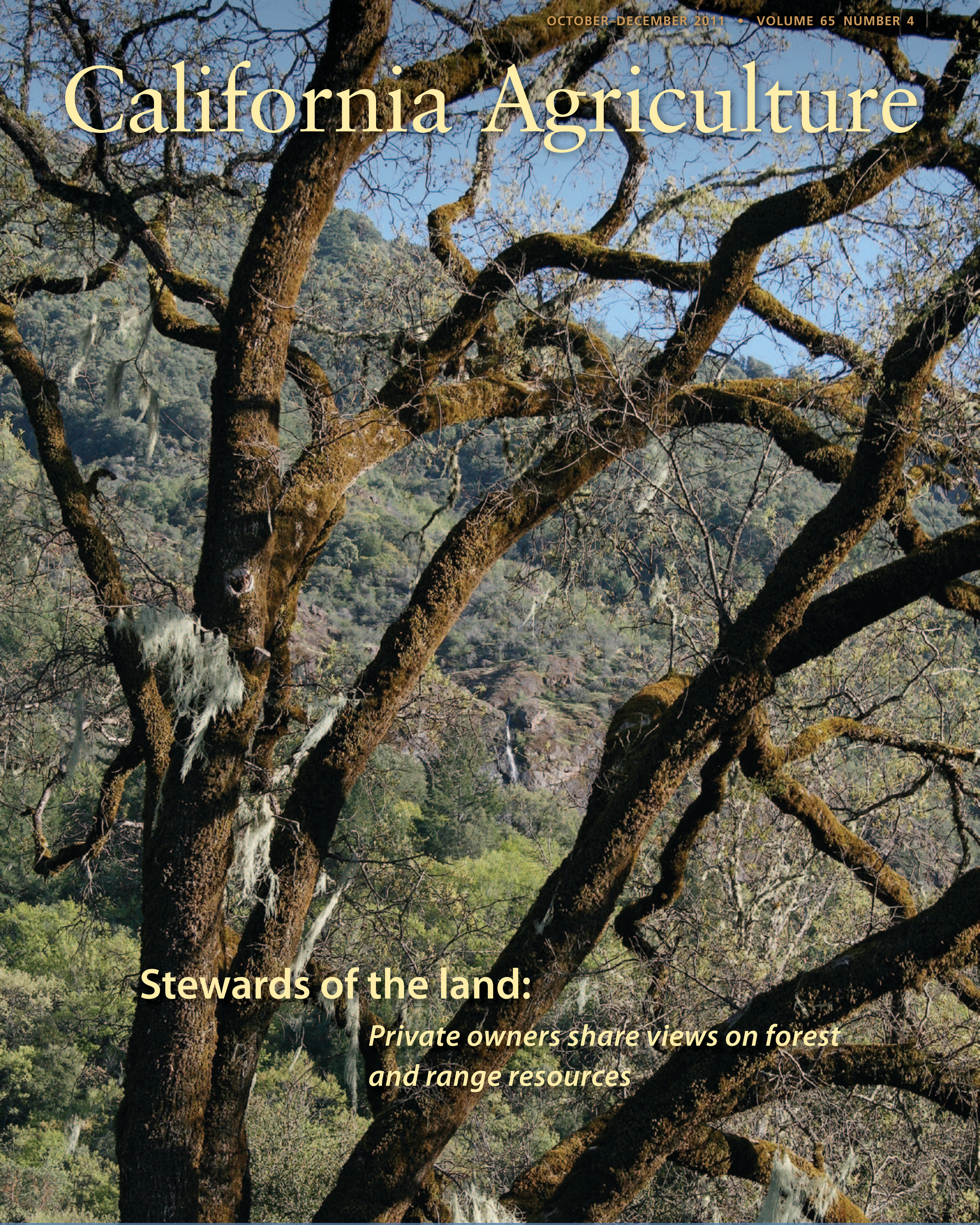
OCTOBER–DECEMBER 2011 • VOLUME 65 NUMBER 4

California Agriculture



Stewards of the land:

Private owners share views on forest and range resources

Research on fire and ecosystem services must incorporate climate realities

James W. Bartolome
Leader, Sustainable Natural Ecosystems Strategic Initiative, UC ANR

Max A. Moritz
UC Cooperative Extension Specialist, Wildland Fire, Berkeley

Mediterranean landscapes burn frequently and sometimes intensely. Likewise, environmental factors that favor fire — mild, moist winters and warm, dry summers — will continue to attract people to California in decades to come. Development pressure will simultaneously stress ecosystem services and increase vulnerabilities to fire.

For fire fighting alone, costs to taxpayers have exceeded a billion dollars in some years. Taking a “business as usual” approach to these problems, especially in light of climate change, will guarantee increasing losses on all fronts. These challenges require new science, difficult tradeoffs and creative solutions linking wildland fire and ecosystem services.

UC Agriculture and Natural Resources (ANR) scientists are in a unique position to advance such efforts. Our statewide network of ANR campus, regional and county scientists is advancing understanding of California landscapes and fire weather patterns. They have extensive connections to those who manage and rely on working landscapes. With on-the-ground expertise across the state, ANR’s research and extension faculty can help predict and control fire, working at the crossroads between basic research and its application, to quantify and maintain ecosystem services in a changing physical and political environment.

Ecosystem services describe the multiple ways in which the environment interacts positively with human needs, and they have increasingly been the focus of science and management. Understanding, predicting and controlling how a growing human population interacts with a changing environment is a central goal for ANR’s Sustainable Natural Ecosystems Strategic Initiative, and it was the focus of a conference last month (http://ucanr.org/sites/SNE).

There are four broad categories of ecosystem services: provisioning (food, water and forage), regulating (carbon sequestration and climate regulation), supporting (nutrient cycling, soil protection and pollination) and cultural (recreation and esthetics). Predicting ecosystem services requires understanding of how they function and the effects of management on ecosystem processes. Many ecosystem services are tightly linked to particular regions, landscapes, and plant and animal community types, and their spatial patterns.

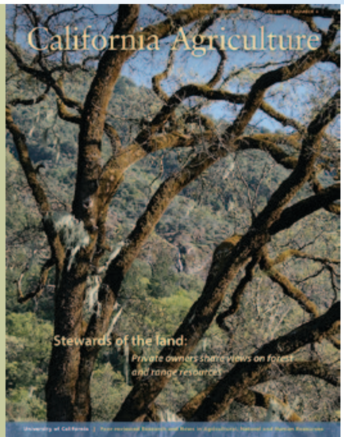
Wildland fires have different effects on ecosystem services in differing landscapes. For example, wildfire effects on carbon sequestration (removal of carbon from the atmosphere and its storage in carbon sinks such as forests) vary according to ecosystem type. Grasslands are spatially extensive, often grazed by livestock; they burn frequently, and most of their potential for long-term carbon storage is in soil. Forests can store larger quantities of carbon, much of it as wood, but are susceptible to re-emitting carbon if the wood burns. Shrublands can sequester significant quantities, but frequent and intense wildfires may limit long-term storage. Wetlands have potential for significant carbon sequestration as undecomposed organic material, but they are small and vulnerable to carbon loss if the moisture regime changes.

The relationship of management to carbon sequestration is also highly variable. In grassland systems, grazing management appears to have little effect on the carbon balance, whereas in forests specific activities such as fuel management can change carbon significantly. For example, in many mid-elevation forests that prehistorically burned in relatively frequent and low-intensity fires, a common management goal is to remove surface and “ladder” fuels that encourage stand-replacing crown fires. Such fuel treatments, even if done to avoid emissions, often serve multiple goals, including lowering fire hazards around communities and restoring habitat. In contrast, on shrubland landscapes where the majority of Californians live, the specific location and microclimate may be more important than management, as severe fire weather can overwhelm other factors.

By the same logic, fire affects the air we breathe and the water we drink, depending on the landscape. Although fire influences all ecosystem services, we tend to address them in isolation — and worse yet — reactively. New, regionally directed knowledge is needed to better understand how they are linked and altered by fire regimes, as well as what future shifts are likely under climate change scenarios.

Factoring in human development patterns and their associated impacts on both fire and ecosystem services is crucial, as is projecting the possible impacts of invasive species. We need new approaches to integrate the latest research into policy for adoption by political entities. Constraints posed by California’s economic and political realities make identifying and pursuing long-term solutions difficult, even when science indicates proactive and sustainable paths.

Fortunately, California tends to lead rather than follow when it comes to addressing environmental challenges. Linkages between fire and ecosystem services may be complex, but they affect too many lives and valuable natural resources to allow a passive approach and could serve as a model for landscape-level, multidisciplinary problem solving. Approaches may include new academic positions in emerging interdisciplinary areas such as land-change science, sustained funding for innovative research and demonstration projects, and outreach and coordination among the public and private sectors. Investment in this research will pay off many times over, strengthening ANR’s connections to California citizens, and to those who manage and rely on working landscapes.



COVER: About 34 million acres (42%) of California's forests and rangelands are privately owned. A new survey of these landowners found that most value the land for its natural amenities and as a financial investment, rather than primarily for income production (see page 184). *Photo of valley oak, Hopland: Laurence R. Costello*

OCTOBER–DECEMBER 2011 • VOLUME 65 NUMBER 4

Stewards of the land:

Private owners share views on forest and range resources

Research articles

E-Edition

Now in print

These articles were published online (July–September 2011) on the *California Agriculture* website, and appear after page 208.

News departments

About *California Agriculture*

University *of* California
Agriculture and Natural Resources

California Agriculture is a quarterly, peer-reviewed journal reporting research and reviews, published by the University of California Agriculture and Natural Resources (ANR). The first issue appeared in 1946, making *California Agriculture* one of the oldest, continuously published, land-grant university research journals in the country. There are about 17,000 print subscribers. The electronic journal logs about 6 million page views a year.

Mission and audience. *California Agriculture* publishes refereed original research in a form accessible to a well-educated audience. In the last readership survey, 33% worked in agriculture, 31% were university faculty or research scientists, and 19% worked in government agencies or were elected office holders.

Electronic version of record. In July 2011, the electronic journal became the version of record, and includes electronic-only articles. When citing or indexing articles, use the electronic publication date.

Indexing. The journal is indexed by AGRICOLA; Current Contents (Thomson ISI's Agriculture, Biology and Environmental Sciences database, and the SCIE database); Commonwealth Agricultural Bureau (CAB) databases; EBSCO (Academic Search Complete); Gale (Academic OneFile); Google Scholar; Proquest; and others, including open-access databases. It has high visibility on Google and Google Scholar searches. All peer-reviewed articles are posted to the ANR and California Digital Library's eScholarship repositories.

Authors and reviewers. Authors are primarily but not exclusively from ANR; in 2008 and 2009, 15% and 13% (respectively) were based at other UC campuses, or other universities and research institutions. In 2008 and 2009, 14% and 50% (respectively) of reviewers came from universities and research institutions or agencies outside ANR.

Rejection rate. The rejection rate has ranged between 20% and 25% in the last 3 years. In addition, associate editors and staff sent back 24% of manuscripts for revision prior to peer review.

Peer-review policies. All manuscripts submitted for publication in *California Agriculture* undergo double-blind, anonymous peer review. Each submission is forwarded to the appropriate associate editor for evaluation, who then nominates three qualified reviewers. If the first two reviews are affirmative, the article is accepted. If one is negative, the manuscript is sent to the third reviewer. The associate editor makes the final decision, in consultation with the managing and executive editors.

Editing. After peer review and acceptance, all manuscripts are extensively edited by the *California Agriculture* staff to ensure readability for an educated lay audience and multidisciplinary academics.

Submissions. *California Agriculture* manages the peer review of manuscripts online. Please read our Writing Guidelines before submitting an article; go to: http://californiaagriculture.ucanr.org/submit.cfm.

Letters. The editorial staff welcomes your letters, comments and suggestions. Please write to us at the address below. Include your full name and address. Letters may be edited for space and clarity.

Subscriptions. These are free within the United States, and $24 per year abroad. Single copies are $5 each. Go to: http://californiaagriculture.ucanr.org/subscribe.cfm or write us. International orders must include check or money order in U.S. funds, payable to UC Regents. MasterCard/Visa accepted; include address, signature and expiration date.

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Consulate features healthy Japanese foods

The recent articles on food ingredients — some of which play a big role in Japanese cuisine — are very timely ("Food as medicine," July–September 2011), and have been of interest to attendees at several consulate events with a "healthy foods" component. Some Japanese foods, such as soy, miso and green tea, have shown indications of positive health effects, with many of these points covered in your articles.

The Japanese consulate in Los Angeles featured *California Agriculture* at a recent event.

Our first event was a kick-off reception to a U.S.-Japan conference on inflammation, diabetes and cancers for more than a hundred researchers from Cedars-Sinai, UCLA, Japan and the City of Hope (which hosted the conference). At this reception, we displayed your articles and made available full copies. Many researchers at the event have long been engaged in studying the health effects of soy, etc., and appreciated the linkage between positive health indications and traditional Japanese dietary components. Your articles kicked off many interesting discussions, and we appreciate your allowing us to incorporate them into our displays.

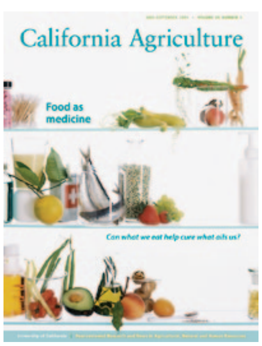
Your journal often uncovers interesting trends and research in California, and personally I've considered it a very rich resource for 20 plus years.

Brian Swords
Advisor, Economic Affairs
Consulate General of Japan
Los Angeles

Is grape juice healthy, too?

Re: "Food as Medicine" (July–September 2011). Red wine is considered good for us! What about Concord grape juice (nonfermented)? Has it similar benefits as a medicine or *any* benefits as a medicine? I am 93, and have been drinking it for years.

George Peabody
Placerville



July–September 2011 *California Agriculture*

UC Davis nutrition professors Carl A. Keen and Robert Rucker (emeritus) respond: Concord grape juice does contain substances with important health benefits, including flavonoids and related substances that may function in cell signaling or the modulation of reactive oxidants important to health and even blood flow. However, we must be careful when making direct comparisons to the health-related attributes of other berries, juices and fermented products, such as wine. We note that you have lived for more than nine decades; one can surmise that you have made some prudent dietary and environmental decisions. With respect to the consumption of nonfermented grape juice or wine, both have the capacity to contribute in a positive manner to the complex milieu we define as a healthful life.

For the authors' full response, with references, go to: http://ucanr.org/u.cfm?id=23

Fritz photos at UC Berkeley

Barbara Fritz, whose father Emanuel Fritz was featured in "Scientists discover redwoods resiliency in Fritz's Wonder Plot" (April–June 2011), visited the UC Berkeley library recently, with her niece and other relatives.

Emanuel Fritz, founder of the "Wonder Plot"

They came to see the Fritz-Metcalf Photo Collection, which was given to the Forestry Library, now part of the Marian Koshland Bioscience and Natural Resources Library. The photos will be displayed on a future website. I printed out a copy of the *California Agriculture* article and introduced them to Elliott Smith, who helped identify a key photograph for the "Wonder Plot" article.

Barbara Fritz spoke of her father's work in the redwoods and of her childhood trips with her father to Forestry Camp in the the 1920s (Camp Califorest Sugar Pine, in Meadow Valley).

Norma Kobzina
Marian Koshland Bioscience and Natural Resources Library
UC Berkeley, www.lib.berkeley.edu/BIOS

Expensive East Coast agritourism

Re: "California agritourism operations and their economic potential are growing," by Rilla et al. (April–June 2011). I am really shocked the farms in California don't charge for many events and programs. Out here they do, to the point that it costs way more to pick apples yourself than to buy them at the farmers market (which is in turn more expensive than the grocery store). It's a fun day out; but I think the prices here are offensive.

Michelle De Remer
New York, NY

April–June 2011 *California Agriculture*

RSVP

WHAT DO YOU THINK?

The editorial staff of *California Agriculture* welcomes your letters, comments and suggestions. Please write to us at: 1301 S. 46th St., Building 478 - MC 3580, Richmond, CA 94804, or calag@ucdavis.edu. Include your full name and address. Letters may be edited for space and clarity.

Biomass fuels California power plants

The July–September 2011 online article on switchgrass ("Switchgrass is a promising, high-yielding crop for California biofuel" by Pedroso et al.; see page E168) correctly notes that demand for ethanol in California is expected to increase in the future. A related blog post (http://ucanr.org/blogs/blogcore/postdetail.cfm?postnum=5487) discussed some of the policy drivers behind the desire to increase the production and use of cellulosic ethanol. The article implied that there are significant technical, economic and logistical challenges in converting ligno-cellulosic feedstocks such as switchgrass into ethanol at a commercial scale.

However, California already has a well-developed biomass-to-energy industry based on proven and deployed technology. California has approximately 30 operational biomass-to-electricity facilities, the most of any state, with 600 to 650 megawatts of capacity. Electricity from biomass comprises approximately 2% of the electricity used in California. The industry provides a disposal option for urban waste wood; woody biomass from fuels reduction and forest restoration; and agricultural residuals such as orchard removals, trimmings and nutshells.

Gareth J. Mayhead

In Fairhaven, a biomass plant converts wood chips into electricity.

The industry is currently in a state of flux due to differing power sales contracts and the fact that wider environmental benefits are not accounted for in the price of electricity. A 1999 National Renewable Energy Laboratory study put the value for the environmental services provided by biomass-to-electricity at 10 cents per kilowatt hour.

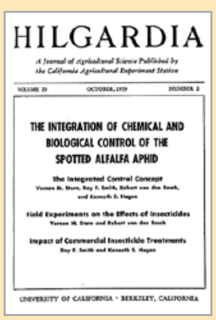
Developing new forms of bioenergy for the future is important, but society and decisionmakers should also understand and value the benefits delivered by the existing industry. To see current biomass power plants in California, go to: http://ucanr.org/BiomassPower.

Gareth J. Mayhead
Woody Biomass Technology and Marketing
Center for Forestry, UC Berkeley

Hilgardia scanning, Web posting to begin with $21,500 in donations

The *Hilgardia* Project, launched in April to bring the full text of the classic UC Agriculture and Natural Resources publication to the Internet, has received $21,500 in donations and pledges, allowing the first phase to begin.

Hilgardia was the primary technical publication of UC ANR for 70 years. Although production ceased in 1995, *Hilgardia* editions include classic research that is still widely cited in scientific literature, and many are considered cornerstones of current agricultural, environmental and nutritional research.



Hilgardia journal October 1959

Despite its scientific preeminence, *Hilgardia* journals have virtually no Web presence today, and one-half of published issues (including all articles in the first 24 volumes, and 58 others) are out of print. The remaining paperbound editions are subject to physical degradation.

UC faculty and staff are spearheading the effort to scan and digitize the series, all 967 articles and more than 31,000 pages. With donations and pledges, the *Hilgardia* Advisory Committee has reached two-thirds of their $30,000 goal.

The first phase will include scanning of the Grape and Wine Collection (67 *Hilgardias* published between 1925 and 1982) on subjects spanning winegrape physiology, anatomical structure, favorable soil characteristics, sensory and chemical evaluation, and management of pests and diseases.

"Targeted support for this initial collection came from the Lodi Winegrape Commission in acknowledgement of the tremendous importance of the monographs to the wine and grape industry today," said Deborah Golino, committee chair.

Each article will be posted as a high-resolution PDF with searchable text, and its essential headings (such as title, authors, abstracts and references with active links) will be posted in HTML.

As they are digitized, *Hilgardia* editions will be posted on a separate section of the website of *California Agriculture*, which for decades was the sister publication to *Hilgardia*. Through the search engines and databases that now index *California Agriculture*, *Hilgardia* will become fully discoverable and searchable on the Web. All articles will be freely available and accessible to scholarly and lay readers worldwide.

To make a donation or for more info, write to calag@ucdavis.edu, e-mail Deborah Golino at dagolino@ucdavis.edu, or go to http://californiaagriculture.ucanr.org/hilgardia.cfm. — *Janet White*

California Firewood Task Force's message: "Buy it where you burn it"

In 2006, the goldspotted oak borer (*Agrilus auroguttatus*, GSOB) was identified as the cause of increased oak die-off that had been occurring in San Diego County since at least 2002. Native to oak tree habitat in Mexico, Central America and Arizona, this invasive pest was likely brought to California on firewood imported from Arizona, traversing hundreds of miles of desert that normally would have provided a barrier to our forests.

GSOB's introduction into California is one of a growing list of insects and diseases found migrating into the United States and between states on firewood, often resulting in environmental and economic losses. Recognizing the clear risks associated with long-distance firewood movement as a potential vector for the spread of invasive species, a national movement is now under way, encouraging wood consumers to buy and burn wood locally.

"Working to coordinate messages among the various states involved in the firewood educational outreach campaign is the primary goal of the Firewood Outreach Coordinating Initiative (FOCI). Consistent key messages will help insure that the idea catches on and people embrace the 'Buy it where you burn it' motto," said Leigh Greenwood of The Nature Conservancy and the Continental Dialogue on Non-Native Forest Insects and Diseases.

Firewood task force. With the establishment of the California Firewood Task Force, California officially joined the firewood effort in November 2010. Prior to its establishment, UC had implemented a GSOB education outreach campaign, which also addressed firewood issues as they related to the spread of GSOB. Tom Scott of UC Riverside and Kevin Turner of the California Department of Forestry and Fire Protection (Cal Fire) led the effort to contact more than 100 local San Diego County firewood dealers, providing them with GSOB information and requesting their participation in voluntary best practices to limit the spread of pests through firewood.

Janice Alexander, UCCE Marin

Educational posters were placed throughout Yosemite National Park, including at the Tuolumne Meadows campground.

Janice Alexander of UC Cooperative Extension in Marin County and Katie Palmieri of UC Berkeley developed a youth firewood outreach activity and piloted it at Marin County's Farm Day, where more than 500 youth and adults learned about how moving their camping firewood could unintentionally spread pests to their favorite parks. This activity was then reproduced in San Diego with a specific GSOB focus and delivered to more than 3,000 youth and adults.

"The passport program was a super hit with the kids and parents," said Tracy Ellis of the San Diego County Department of Agriculture, Weights and Measures. "The kids really loved the participation, the passports, stamps and stickers. The parents could pick up a GSOB brochure along the way. Everyone gave the project a big thumbs up!"

Frances Healey, UCCE Marin

The concept of invasive forest pests moving on firewood was introduced at Marin County Farm Day in San Rafael, March 2011.

Outreach and education. UC continues to provide leadership in GSOB and firewood outreach coordination as well as research and extension expertise, guiding public education efforts. Primary goals of the effort are to educate the public to "buy it where you burn it" and "don't move firewood" in an effort to keep GSOB, sudden oak death, pitch canker and other forest pests from spreading.

Key outreach activities to engage the public have included a campaign targeted at campers. Implemented during the summer 2011 camping season, the pilot campaign provided posters, Frisbees and playing cards for distribution in Yosemite National Park, Sequoia/Kings Canyon National Park and San Diego County, and also trained campground hosts to deliver the firewood messages.

For more information:
www.firewood.ca.gov

Brian Mattos of Yosemite National Park said, "We've already saturated our campgrounds with posters and will be handing out the playing cards to campers to help spread the word more directly to the public."

The effectiveness of the pilot outreach program will be evaluated with surveys, assessing camper knowledge of firewood and invasive species. The responses will be compared against earlier data to gauge whether attitudes and behaviors were changed by this initial campaign.

"In the next few months, we will be forming a long-term strategic plan for firewood outreach in California," said Don Owen of Cal Fire and task force chair. "These surveys and data will help our task force focus on the most effective tools and strategies for getting this important message out to the public."

— *Janice Alexander and Katie Palmieri*

Water workgroup recommends new salinity guidelines for regulatory agencies

Leaching requirement guidelines published in the 1980s to help growers manage salt buildup in crop fields now need retooling, say workgroup members appointed by the UC Center for Water Resources. Workgroup chair John Letey, former director of the center, says the group found that current guidelines overestimate the leaching requirement and the negative effects of salinity.

Rather than issuing new recommendations for growers, however, the workgroup has proposed new guidelines for agencies that regulate the water quality of irrigation sources (table 1). They have shared them with *California Agriculture,* but plan no other formal report.

Excess salinity in irrigation water or soil can cause necrosis in citrus leaves.

Salinity is a sensitive issue for agriculture. If salts in irrigation water (such as chloride, sulfate, bicarbonate, sodium, calcium and magnesium) build up in the root zone, plant growth and yields can be affected. In the worst cases, soils become too saline for agricultural use. Leaching is application of extra water to carry salts below the root zone. The leaching requirement (LR) guidelines specify how much extra water (the leaching fraction, LF) should be applied to maintain maximum crop yields.

Significance of LR guidelines

Today, the LR guidelines are more significant than when they were published: If less water needs to be applied for leaching, as the workgroup suggests, groundwater might be more easily protected from pesticides and nitrates carried in drainage water. And if water with elevated salinity levels can be used for irrigation, more water might be available to growers and for competing urban and environmental uses.

Although now perhaps outdated, the LR guidelines were originally a formidable research undertaking.

"They have been published in textbooks and taught in class and are generally accepted as being valid and useful," Letey says. "I am not critical of them because they were the best that could be done at the time, and they have been useful. However, we can do better presently."

Members of the UC Center for Water Resources leaching fraction workgroup are: Christopher Amrhein, Dennis Corwin, Stephen Grattan, Glenn Hoffman, Jan Hopmans, John Letey, J.D. Oster, Donald Suarez and Laosheng Wu.

The original guidelines were calculated from steady-state analysis.

In an *Agricultural Water Management article* (February 2011), the workgroup explained the problem: "Mathematically, a steady-state flow analysis does not include a time variable . . . Steady-state specifies that applied irrigation water is continuously flowing downwards at a constant rate, irrespective of irrigation frequency . . . that evapotranspiration is constant over the growing season. Consequently, steady-state solutions assume that the salt concentration of the soil solution at any point in the soil profile is constant at all times. None of these is real."

There are several transient-state models available that can be used to assess salinity management. Using a transient-state model, a user enters real-time data, including the time and amount of each irrigation, the salinity of the irrigation water, the current evapotranspiration rate for the crop, and so on. The model then creates simulations of dynamic interactions in the root zone and continuously updates the conditions, such as soil-water and salinity, that can affect crop yield.

Recommendation to regulators

The workgroup has no plans to issue new LR guidelines for growers; however, it is recommending new guidelines for regulatory agencies, such as the California State Water Resources Control Board, that manage the quality standards for bodies of water that supply irrigation to growers, such as the San Joaquin River. The new guidelines are based on steady-state analysis but with two important modifications: They use a water-uptake-weighted average of salinity in the root zone instead of a linear average, and they take rainfall into account (table 1).

TABLE 1. Salinity of irrigation source waters that can be applied to obtain maximum yields in crops with a threshold salinity sensitivity of 1 dS/m*

Leaching fraction	Annual rainfall to total water applied						
	0%	10%	15%	20%	25%	30%	35%
	decisiemens per meter						
0.05	0.63	0.70	0.74	0.79	0.84	0.90	0.97
0.10	0.78	0.86	0.91†	0.98	1.04	1.11	1.20
0.15	0.90	1.00	1.05	1.12	1.20	1.28	1.38
0.20	1.00	1.11	1.17	1.25	1.33	1.43	1.54
0.25	1.06	1.17	1.25	1.32	1.41	1.51	1.63
0.30	1.18	1.31	1.39	1.48	1.57	1.68	1.81

* dS/m = deciseimens, a measure of electrical conductivity directly related to salinity.
† Corrected by workgroup after initial publication, November 9, 2011 : "0.91," not "1.01."

First, a leaching fraction is chosen, based on the extra water that must be applied to avoid yield loss in the most sensitive crop grown by area farmers; then rainfall is calculated for the area. Using these two figures, the maximum salinity level of the irrigation source can be read off the table. The new guidelines mean that regulators may accept higher salinity readings at any particular point in a river, allowing somewhat more saline discharge waters from growers or other users (such as cities) upstream.

If adopted, the workgroup's recommendations will potentially result in more saline water used in agriculture. Any changes in salinity recommendations are likely to be met with concerns about future water supplies, long-term damage to soils and other issues.

Jack Kelly Clark, UC Statewide IPM Program

New irrigation recommendations, based on more up-to-date models, use real-time data on rainfall, evapotranspiration rates and other factors to ensure that irrigation water does not damage crops such as, *above*, tomatoes.

Letey is expecting some resistance to the workgroup's recommendations.

"Oh, absolutely, I expect it," he says. "People will say 'You have to convince me', and that's as it should be. But if we can get by with less water, that's a good thing." — *Hazel White and Janet White*

Science briefs

Tree-killing pathogen traced back to California

Genetic detective work by an international group of researchers may have solved a decades-long mystery of the source of a devastating tree-killing fungus that has hit six of the world's seven continents.

In a Sept. 1 *Phytopathology* study, California emerged as the top suspect for the pathogen, *Seiridium cardinale*, that is the cause of cypress canker disease. *S. cardinale* was first identified as causing the disease in California's San Joaquin Valley in 1928. The fungus has made its way since to Europe, Asia, New Zealand, Australia, South America and Africa. In many regions, it has infected and killed up to 95% of iconic native trees in the cypress family, including junipers and some cedars.

Alberto Panconesi, Italian National Center for Research

An optical microscope image shows *Seiridium cardinale*, the fungal pathogen responsible for a global pandemic of cypress canker disease.

The researchers used DNA fingerprinting techniques to analyze 96 *S. cardinale* isolates of diseased tree samples from seven Mediterranean countries, eight California counties, Chile and New Zealand. The paper reports that strains of the pathogen with identical DNA profiles were found hundreds to thousands of miles apart, an indication that humans are moving the pathogen, most likely through the trade of infected plants.

"When Monterey cypress trees are planted in Monterey or along the coast, they are resistant to the disease," said Matteo Garbelotto, UC Cooperative Extension specialist, Berkeley, and an author of the study. "That suggests that in coastal areas, the environment is unfavorable for development of infections, despite the pathogen having been in California for a long time. The pathogen emerges when we place the tree in a foreign environment."

Robert Danti, Italian National Center for Research

Italian cypress trees near Siena, in Italy's Tuscany region, show symptoms of cypress canker disease. Researchers have traced the origin of the pathogen responsible for the disease back to California.

Garbelotto said that chemical treatments for cypress canker disease may become available in the near future, but they are costly and their effects on the environment are not clear so prevention is preferable.

The fungus kills a tree by entering through cracks in its bark, producing toxins that wreak havoc with its flow of sap and choke off its supply of water and nutrients. The disease has left an indelible mark throughout southern Europe.

For more info, go to: http://newscenter.berkeley.edu/2011/09/01/cypress-canker-pathogen-traced-to-california.

— *Sarah Yang*

RESEARCH ARTICLE

Forest and rangeland owners value land for natural amenities and as financial investment

by Shasta Ferranto, Lynn Huntsinger, Christy Getz, Gary Nakamura, William Stewart, Sabrina Drill, Yana Valachovic, Michael DeLasaux *and* Maggi Kelly

Forty-two percent of California's forests and rangelands are privately owned (34 million acres). These lands provide important ecosystem services such as carbon sequestration, pollination and wildlife habitat, but little is known about the people who own and manage them. We surveyed forest and rangeland owners in California and found that these long-time landowners value their properties for their natural amenities and as a financial investment. Owners of large properties (500 or more acres) were significantly more likely to use their land for income production than owners of smaller properties, and they were also more likely to carry out or be interested in environmental improvements. Many forest and rangeland owners reported they had been previously approached to sell their land for development. Only about one-third had participated in conservation programs; few had conservation easements. This survey can help guide outreach and education efforts, and the development of information, policies, programs and financial incentives for landowners.

A survey of forest and rangeland property owners in California found that the vast majority value their land for its natural beauty, and they voluntarily undertook environmental improvements and management practices. *Above,* an exurban development in coastal California.

Over the last 20 years, an "in-migration" of new landowners has occurred in California's forests and rangelands. Rural housing trends in California mirror similar trends in the nation: between 1940 and 2000, 10% of private forests and rangelands were fragmented into areas with more than one house per 20 acres (CDFFP 2003). The ecological and management impacts of exurban parcelization include decreased biodiversity (Hansen et al. 2005; Maestas et al. 2003; Parmenter et al. 2003), fragmentation of wildlife habitat (Hobbs et al. 2008) and more-difficult wildfire management (Moritz and Stephens 2008).

Changes in land ownership can also bring changes in social values and demographic characteristics. In-migrants seeking a better quality of life may more strongly support protection of amenity values, such as scenery and recreation, and more often participate in environmental activism (Jones et al. 2003). These values may conflict with more traditional views held by long-time residents (Walker and Fortmann 2003; Yung and Belsky 2007). New residents may also have less expertise in land management (Kendra and Hull 2005) or different views than long-term landowners on how undeveloped landscapes should be managed (Gosnell et al. 2006). These changes raise questions: As properties become fragmented into smaller management units, how do the goals and needs of landowners change? Do they use or manage their land differently? And what do these changes imply for future environmental sustainability?

Several studies have examined the physical patterns of fragmentation in the United States (Brown et al. 2005), and many predict future patterns of increased parcelization (Alig and Plantinga 2004; Nowak and Walton 2005; Theobald 2005; White et al. 2009). Few studies, however, have examined the social changes associated with fragmentation or the ecological implications of these changes. These issues are especially pertinent to California forests and rangelands, where fragmentation is predicted to continue (CDFFP 2003). Limited knowledge of the landowner population in California has made it difficult to assess this population and to establish a baseline for understanding how it might change over time, or with interventions of information, policy or financial resources. To improve outreach and education programs geared

Online: http://californiaagriculture.ucanr.org/landingpage.cfm?article=ca.v065n04p184&fulltext=yes
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to landowners, a team of UC Cooperative Extension and UC Berkeley researchers surveyed California forest and rangeland owners in 2008.

Survey design and analysis

There are approximately 34 million acres of privately owned forest and rangeland in California, concentrated in the Sierra Nevada and coastal regions (CDFFP 2003). Forest and rangeland owners with parcels greater than 3 acres from 10 California counties were mailed a questionnaire. Eight of the state's 10 bioregions contain forests or rangelands, as defined by the California Department of Forestry and Fire Protection (CDFFP, now known as Cal Fire) for natural resources assessment purposes. A minimum of one county was selected from each. Together, these eight bioregions contain 89% of the state's private forests and rangelands (CDFFP 2003). We sampled counties representative of each bioregion: Contra Costa, El Dorado, Humboldt, Mendocino, Plumas, San Diego, Santa Barbara, Shasta, Sierra and Sonoma (fig. 1). Because they have small populations, Sierra and Plumas counties, which are adjacent to one another, were treated as a single sampling unit.

Within each county, survey recipients were selected using a stratified random sampling design. The sample was drawn from a statewide land parcel database created in 2003 by CDFFP for the Forest and Range Assessment (CDFFP 2003). The database contains information on parcel size derived from county assessor tax records, and vegetation type at the parcel center derived from satellite imagery. Parcel vegetation type was categorized into either forest, including conifer and hardwood, or rangeland, including oak woodlands, grassland and shrubland.

Parcel size was then subcategorized into four groups: 3 to 9 acres, 10 to 49 acres, 50 to 499 acres, and 500 or more acres. A random sample of up to 30 parcels was drawn from each subcategory, for a total of approximately 240 parcels per county. All duplicate landowner addresses were dropped, so that landowners received only one survey regardless of how many parcels they owned.

We mailed the survey and follow-ups to 1,730 landowners in spring 2008, following a modified version of the Dillman Total Design Method (Clendenning et al. 2004; Dillman 2007). The questionnaire was a 17-page booklet with 38 questions, many of which contained multiple parts. Most questions were close-ended, with either categorical or Likert scale response choices. Respondents were also offered the option of taking an identical online survey. Questionnaires were returned by 670 people, with 8% answering online. After adjusting for undeliverable questionnaires and those sent to people who were not forest or rangeland owners, the final response rate was 42.5%.

A stratified sampling design ensured the inclusion of owners from all property sizes but created a sample disproportionate to true population ratios. Unless otherwise indicated, all data was weighted proportionally to sampling intensity to adjust for a disproportionate sampling intensity between different sampling strata. Proportional survey weights were calculated by multiplying the reciprocal sampling ratio (i.e., the total number of landowners in each sampling strata compared to the number of landowners sampled from each strata) by the overall sampling ratio (the overall sample size compared to the overall population) (Maletta 2007). Reported results are thus representative of true landowner population ratios.

All data analysis was done with SPSS 17.0 statistical software. Results are reported as percentages of the total number of respondents to each question. Several questions were based on a Likert scale from 1 to 5, ranging from "not at all important" (value = 1) to "highly important" (value = 5). Results for all Likert scale questions were grouped so that a response of "not important" included values 1 and 2, and a response of "important" included values 4 and 5. Comparisons between property sizes were based on the same size categories as used in the sampling (3 to 9 acres, 10 to 49 acres, 50 to 499 acres, and 500 or more acres), but respondents were reclassified based on the reported size of all the parcels owned and managed as a single property, rather than on assessor parcel records. (We use the term "property" when referring to the full property, and "parcel" when referring to a single parcel.) Differences in responses by property size were calculated using either Pearson's chi-square analysis for categorical data or analysis of variance (ANOVA) for continuous data.

Profile of landowners

Respondents were mostly male, over 60 and predominantly married or living with a partner. Few had children living at home, and they tended to be well educated and relatively affluent, with just over half earning more than $100,000 and just under one-third earning more than $200,000 per year (table 1). These results did not vary substantially based on property size, with the exception that property owners with 50 to 499 acres were significantly more likely to have a bachelor's degree, more likely to have children living at home and more likely to earn over $200,000 per year than landowners in other property size categories.

The most common careers, with about one-third of landowners in each category, were professional or management

Fig. 1. The study was conducted in 10 counties, within eight of California's 10 bioregions that contain forests or rangelands.

positions, retired and self-employed, with only slight variation between property sizes. Only 14% of respondents reported production-oriented enterprises (timber, agriculture or range) as their profession.

Ownership demographics. On average, respondents had owned their land or the land had been in their family for 31 years. The average length of ownership increased with property size; the most notable increase in land tenure was in the largest property size category (500 or more acres) (table 2). Most owned their land as private individuals (the landowner's name is on the deed). Owners of the largest properties (500 or more acres) were significantly more likely to be in corporate ownership — often a family corporation (table 2). The majority of respondents were primary residents. Owners were less likely to be primary residents as property size increased, with an almost equal ratio of primary to nonprimary residents in the largest property size category. Of the nonprimary residents, 46% used the land as a second, seasonal or vacation home, with no significant variation based on property size (table 2). Nonprimary residents tended to live fairly far from the property — 77% lived more than 20 miles away, and 44% lived more than 100 miles away.

Reasons for ownership. A variety of reasons were reported for owning land. To "live near natural beauty" was the objective ranked by most landowners as important (fig. 2). Other popular reasons included "land value appreciation," "escape from city crime and pollution," "financial investment" and "live in a small community." In general, amenity values and financial investment objectives were important to the most landowners.

When broken down by property size, several notable differences became evident. All property sizes ranked living near natural beauty and financial appreciation of the land as important. Only a small percentage of small property owners (less than 50 acres) considered family tradition or business as important; about half of landowners with 50 to 499 acres marked it as important; but this was the single most important objective for owners of large properties (500 or more acres) (fig. 3). Income source was not considered important to most owners of small properties but was important to over three-fourths of large property owners. In contrast, owners of large properties were less concerned than owners of small properties about escaping from the city, living in a small community or having a simpler lifestyle (fig. 3).

Resource use

Overall, landowners were more likely to utilize their land's resources such as timber, livestock forage or game for personal use than for income production (fig. 4). Only one-third reported earning income in one of the provided ways, while almost three-fourths used their land's natural resources for personal use.

As property size increased, landowners were more likely to use their land

TABLE 1. Demographic profile of California forest and rangeland owners based on property size, 2008

		All landowners	3 to 9 acres	10 to 49 acres	50 to 499 acres	500 or more acres	*P* value*	*n*
Age (years)	Mean age	62	63	61	60	64	0.02	516
Gender (%)	Male	65	67	65	62	65	0.62	578
	Female	35	32	33	38	35		
Education (%)	At least some college	90	92	86	92	90	0.19	568
	Bachelor's degree or higher	65	56	65	75	61	0.01	568
Marital status (%)	Married	81	77	81	84	83	0.48	576
Children (%)	< 18 years, living in household	22	14	19	35	15	0.00	515
Income (%)	> $100,000	56	55	48	64	56	0.06	523
	> $200,000	30	23	22	39	36	0.00	523

* Differences between property sizes, chi-square analysis.

TABLE 2. Ownership demographics among California forest and rangeland owners based on property size, 2008

		All landowners	3 to 9 acres	10 to 49 acres	50 to 499 acres	500 or more acres	*P* value*	*n*
Land tenure (years)	Mean length of ownership	31	19	21	29	60	0.00	629
	Std. deviation	29	12	15	23	41		
Ownership type (%)	Private individual(s)	70	80	79	67	45	0.00	596
	Trust	19	16	18	24	17		
	LLC	3	0	0	0	18		
	Partnership	2	1	2	1	7		
	Other	5	3	2	7	13		
Residency (%)	Primary	60	72	63	55	49	0.00	600
Nonresident property uses (% of nonprimary residents)	Vacation or second home	46	43	54	35	54	0.09	218
	Rental unit	7	2	7	15	0	0.01	218

* Differences between property sizes, chi-square analysis.

for income (fig. 4A). Over half of landowners with the largest properties (500 or more acres) harvested timber for income, and just under 40% raised livestock (fig. 4A). Hunting and fishing for personal use also increased with property size, but raising food crops or livestock, and harvesting timber for personal use all remained constant or decreased slightly as property size increased (fig. 4B). Harvesting fuelwood for personal use increased with property size until the 50-to-499-acre category, then dropped substantially in the 500-or-more-acres category (fig. 4B).

Land management practices

California forest and rangeland owners implemented a variety of land management practices for environmental

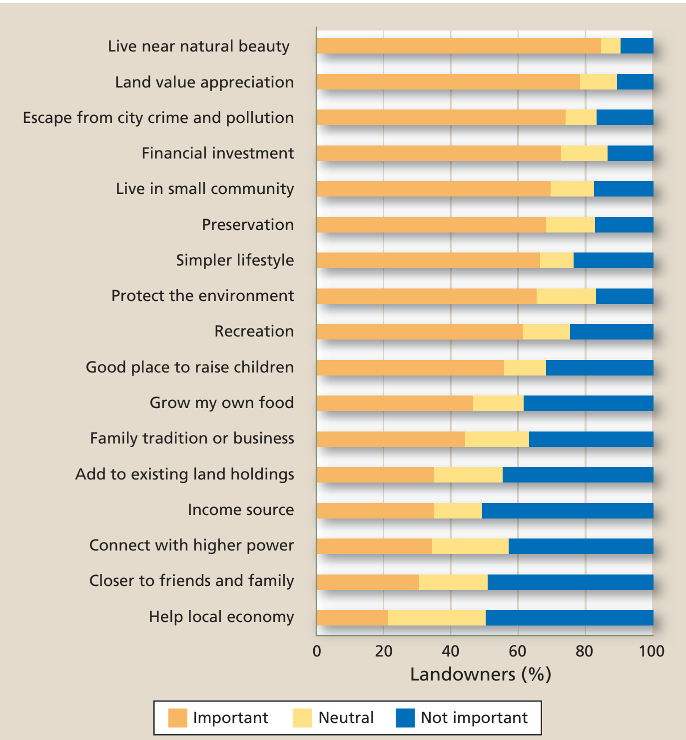

Fig. 2. California forest and rangeland owners' reasons for owning land ($n = 578$), 2008.

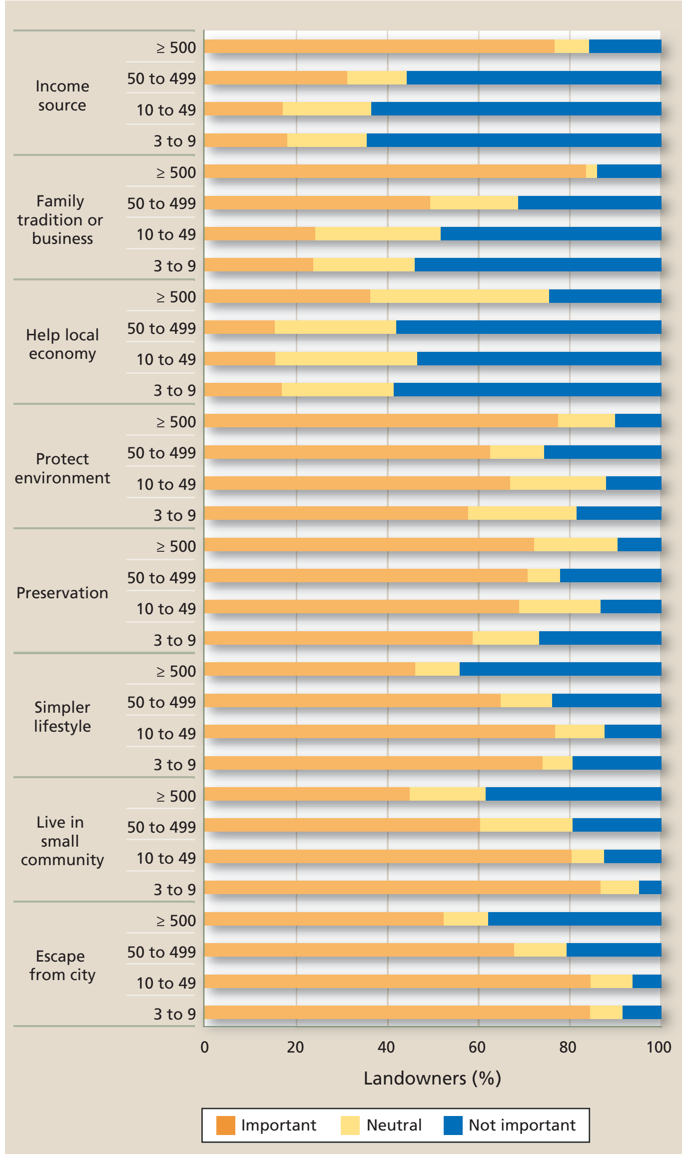

Fig. 3. California forest and rangeland owners' reasons for owning land based on property size, 2008. Ownership objectives with significant differences between property sizes are shown (chi-square analysis, $P < 0.01$, $n = 566$).

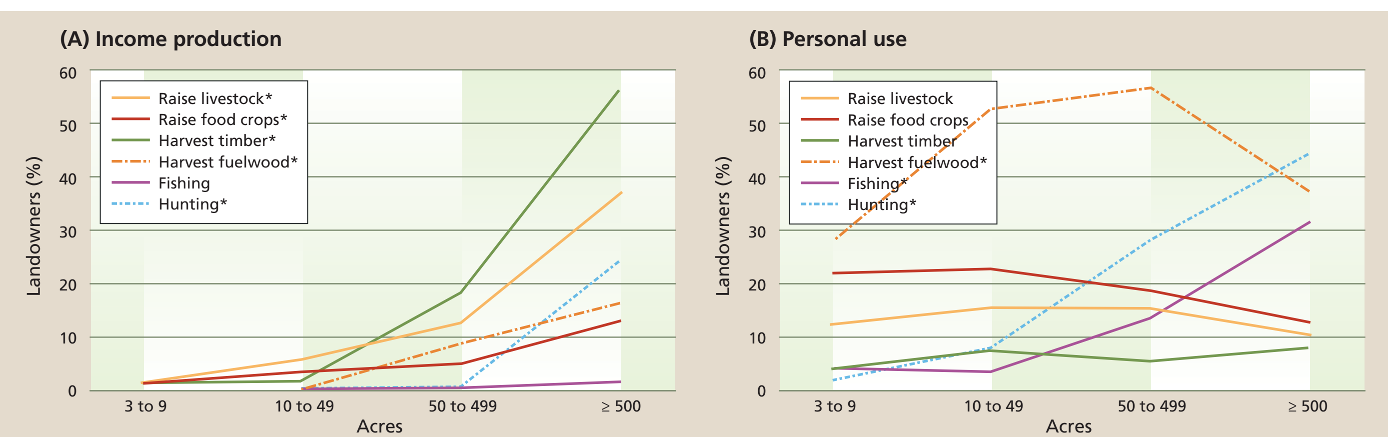

Fig. 4. (A) Income production from and (B) personal use of natural resources based on property size for California forest and rangeland owners, 2008; 80% of owners use resources in one of the ways shown (* = significant difference between property sizes, chi-square analysis, $P < 0.01$, $n = 627$).

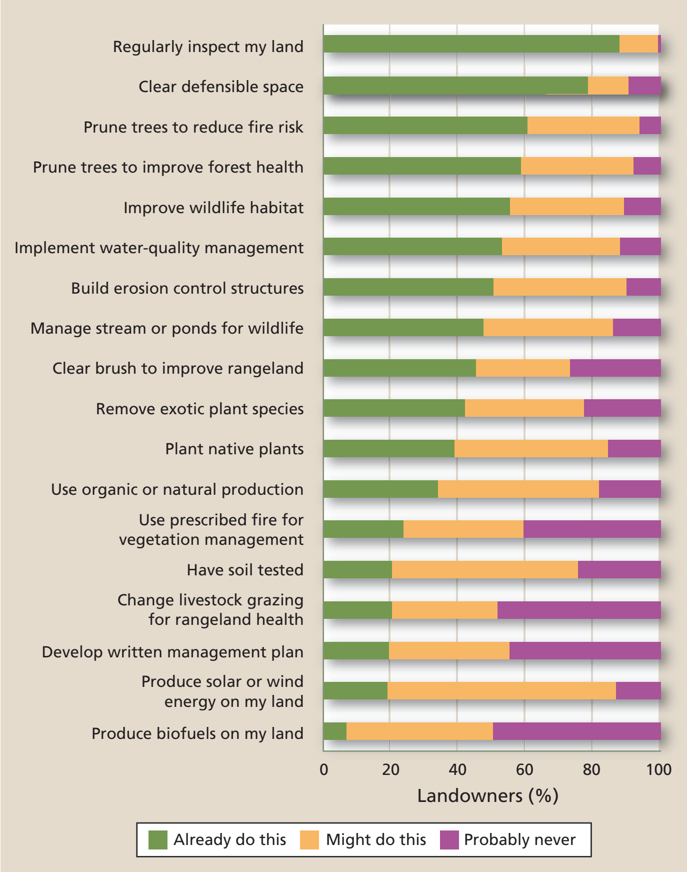

Fig. 5. Management practices used by California forest and rangeland owners (n = 615), 2008.

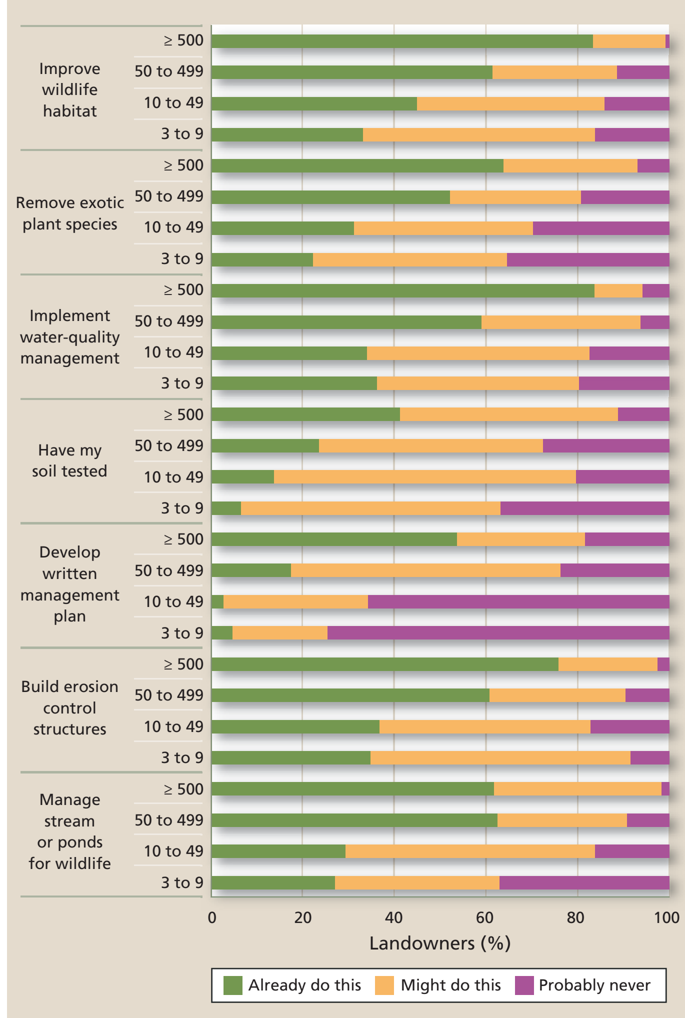

Fig. 6. Management practices commonly used by owners of larger properties (in acres) than owners of smaller properties (P < 0.01, n = 596), 2008.

improvement (fig. 5). Almost all respondents regularly inspected the condition of their land. Over half (for whom the question was applicable) cleared defensible space to reduce fire risk; pruned or cut trees to reduce fire risk or improve forest health; improved wildlife habitat; implemented water-quality management practices; or built erosion control structures (fig. 5). Of those who did not use these practices, many would consider using them in the future. For all of the management practices surveyed, over half of all respondents either currently implemented or would consider the practice in the future. Some practices, such as generating solar or wind energy, or testing the soil, although not currently implemented by many, were of interest to many landowners and may be areas where outreach could improve implementation.

Overall, owners of large properties were more likely to carry out or be interested in environmental improvements than owners of smaller properties. In particular, as the property size increased, landowners were notably more likely to improve wildlife habitat, remove exotic plants, implement water-quality management practices, have their soil tested, develop a written management plan, build erosion control structures or manage streams for wildlife (fig. 6). Practices such as clearing defensible space or pruning or cutting down trees to reduce fire risk were as common on small properties as they were on large ones.

Conservation programs

Only one-third of all respondents had participated in one of the land management or conservation programs identified in our survey (see box, page 189). The Williamson Act (California Land Conservation Act) program had the most participants, followed by the Timberland Production Zone (TPZ) program. These programs provide property tax reductions to eligible participants to encourage agricultural land (Williamson Act) or forest (TPZ) conservation. The Environmental Quality Incentives Program (EQIP) and the California Forest Improvement Program (CFIP) had the next highest participation (fig. 7).

These programs provide technical and financial assistance to landowners to address natural resource concerns on private land. Less than 5% of landowners reported that they had a written rangeland water-quality management plan; participated in the Wildlife Habitat Incentives Program (WHIP) under the U.S. Forest Service, which provides technical and financial assistance; had forest certification, a third-party certification of sustainable forest management operations; had a conservation easement limiting development on their property; had organic certification, ensuring that food is grown according to organic standards; or had received a grant from the California State Water Resources Control Board to

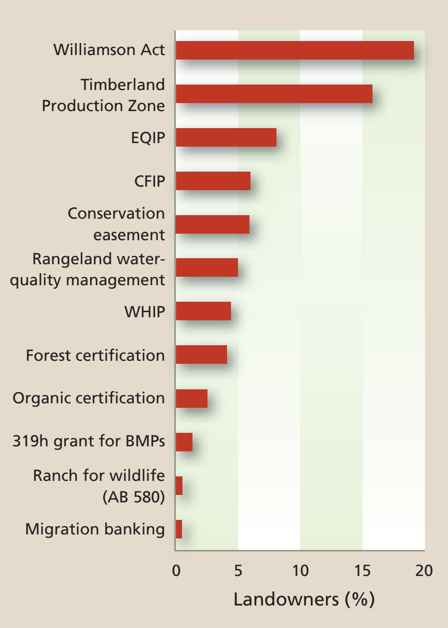

Fig. 7. California forest and rangeland owners participating in land management or conservation programs (n = 624), 2008.

implement water-quality improvements (319h grant for BMPs). Less than 1% of landowners reported participating in the Ranch for Wildlife Program (AB 580, now known as the Private Land Management Program of the California Department of Fish and Game), which offers increased fee-hunting opportunities in exchange for habitat improvements on private land; or participated in mitigation banking, a third-party system in which landowners protect or restore wetlands or streams on their property to compensate for impacts to wetlands and streams elsewhere.

Participation varied only slightly based on property size, and in most instances owners of the largest properties (500 or more acres) were no more likely to participate in land management or conservation programs than owners of smaller properties.

Future intentions for land use

When asked about their long-term plans, almost two-thirds of respondents reported that they planned to pass their land on to children or other family members, while one-sixth planned to sell their land. Few landowners were undecided or had never thought about it. Owners of large properties (500 or more acres) were more likely to plan to pass their land to children and less likely to sell than owners with other property sizes (table 3).

The role of land conservation programs

Land conservation programs can reward landowners for not fragmenting or developing their land, but only a small percentage of landowners participate in these programs (fig. 7), and most are tailored toward production-oriented ownership. We asked about three land conservation programs in the survey.

Williamson Act (California Land Conservation Act) enrollment. The program with the highest participation (19%) was the Williamson Act. This program reduces property taxes on agricultural properties through a rolling 10-year contract between landowners and counties, while the state provides funding to compensate counties for all or a part of the property tax losses. The 45-year-old Williamson Act is widely supported by agricultural groups, landowners, county governments and environmentalists as a method to restrict the conversion of farms and ranches to urban uses, but its fate is tenuous due to recent state budget cuts (Sokolow 2010). The program is also not accessible to all landowners. The specifications for enrolling include having a property large enough for commercial use and located within a county-designated "agricultural preserve," as well as other requirements set by each county. To change the land use without penalty, a landowner must stop renewing the contract and wait 9 years while property taxes gradually increase to normal levels. About 15 million acres were enrolled in 2010, with 9 million on "nonprime" sites typical of rangelands.

Timberland Production Zone (TPZ) designation. The TPZ program had the second highest participation (16%). County governments initially classified lands as TPZs in the 1970s, but landowners can petition to change the county zoning. Lands zoned as TPZs have larger minimum parcel sizes and limitations on residential uses. Similar to the Williamson Act, TPZs have specific acreage and site requirements that vary by county. The landowner receives a lower tax assessment based on timber production rather than development potential. A successful petition for rezoning and a 10-year period of gradually increasing property taxes are needed to remove land from a TPZ without penalties. About 4.3 million of the 5.6 million acres in TPZ designation in 2010 are owned by forestry businesses, and the rest are owned by families.

Conservation easement establishment. Conservation easements, in contrast, can be implemented on any type of landscape with conservation value. A landowner voluntarily gives up the development rights for a property in return for a monetary payment and/or tax reductions (Gustanski and Squires 2000). The development rights are then held by a land trust or agency and recorded in the property title. The easement may also have other provisions such as limitations on particular practices, but these are individually negotiated for each property. Over the last decade, conservation easements have become an increasingly important conservation tool, but like other conservation programs, they are limited by the level of private donations to land trusts and the availability of public funds. Only 6% of the landowners surveyed had conservation easements on all or part of their property.

Mitigation easements. Mitigation easements are another form of environmentally oriented easement; although they were not asked about in the survey, some respondents may have treated them as conservation easements. Mitigation easements are similar to conservation easements in that they change the property title to restrict certain activities. However, they are funded when a developer has to mitigate, for example, habitat loss for a particular species. The landowner agrees to provide that habitat, and anything that might harm it is permanently restricted from the area.

Limitations of land conservation programs. Limitations in available funding and the high transaction costs per project make these programs inaccessible to the vast majority of landowners (fig. 7). Programs for large properties can preserve the greatest number of acres with the least logistical overhead. Still, with continuing fragmentation in California's forests and rangelands, it will become increasingly important to consider the ecosystem services provided by moderate- to small-sized properties and adopt more comprehensive strategies to preserve these services.

TABLE 3. California forest and rangeland owners' future intentions for their land (n = 595), 2008*

Future intentions	All landowners	3 to 9 acres	10 to 49 acres	50 to 499 acres	500 or more acres
	....	....	%	....	....
Pass to children or family member	62	48	63	61	79
Sell	16	26	13	18	6
Undecided	11	12	14	11	5
Other	6	7	5	5	9
Never thought about	3	7	3	2	0
Donate	2	1	2	2	1

*$P < 0.01$, differences between property sizes, chi-square analysis.

Landowners were also asked what reasons would influence a hypothetical future decision to sell their land. Almost 20% reported that none of the reasons applied to them because they would never sell. Of the remaining 80%, just over half chose "it is too much work to maintain," followed by "can't afford to keep it," "property taxes too expensive," "to finance retirement" and "inheritance taxes too expensive" (fig. 8).

Development pressure. A high percentage (43%) of landowners reported that they had been previously approached to sell their property for development. As property size increased, landowners were significantly more likely to have been approached ($\chi^2 = 86.4$, $P < 0.0005$). Of the owners of large properties (500 or more acres), 73% had been approached, compared with 49% for 50 to 499 acres, 32% for 10 to 49 acres and 21% for the smallest properties.

Conservation easements. Conservation easements are voluntary contracts between a landowner and land trust or agency that restrict real estate development, certain land-use practices, and other relevant activities on private property in exchange for payment or tax relief for the owner. Of the landowners surveyed, 41 had a conservation easement on their property (unweighted data), or 6% of all landowners from the weighted sample. Because of this small number, all subsequent statistics on easement holders are unweighted. There were no significant differences in easements based on property size. Together, the 41 easements covered approximately 41,000 acres and represented 3% of the total acres reported. Of the 41 landowners, 30% indicated that they sold the easement, 30% donated the easement, 13% reported a combination of selling and donating, and 28% purchased the property with an existing easement.

Easements were sold or donated to more than 23 different land trusts. Pacific Forest Trust, a regional land trust focused on protecting private working forests, held seven easements from our sample. Two-thirds of the easements were obtained since 2000. The most popular reasons for selling or donating the easement were "to conserve the land," "for tax benefit" and "to preserve land for heirs." When asked whether they would sell or donate the easement again, 92% of landowners said they would.

Although most respondents did not have a conservation easement, there was general interest: 33% of owners without easements indicated that they would consider selling one in the future, and 9% would consider donating an easement. Another 34% indicated that they did not know enough about easements to make a decision.

Ownership trends, fragmentation

Although a small percentage of the surveyed forest and rangeland owners earned income from their land, the majority earned little to no income; they predominantly benefited from its amenity and investment value. Only landowners with the largest properties ranked ownership objectives such as "family tradition or business" and "income source" as important reasons for owning their land and reported income-generating land uses (figs. 3 and 4A).

These results are consistent with other studies of California landowners. In a study of California oak woodland owners with more than 20 acres, Campos et al. (2009) found that landowners were willing to forgo significantly greater income from using their land equity for alternate investments in order to keep their land and enjoy its amenities. Drawing on the same population of oak woodland owners, Huntsinger et al. (2010) found that while the acreage grazed by livestock has remained relatively consistent since 1992, the number of owners selling livestock declined, reliance on other income sources increased and the number of owners with small parcels increased.

These findings imply an overall shift from production-oriented owners to amenity and investor ownership in California forests and rangelands. The shift is more pronounced among smaller properties. How this shift might influence the ecological integrity of California's forests and

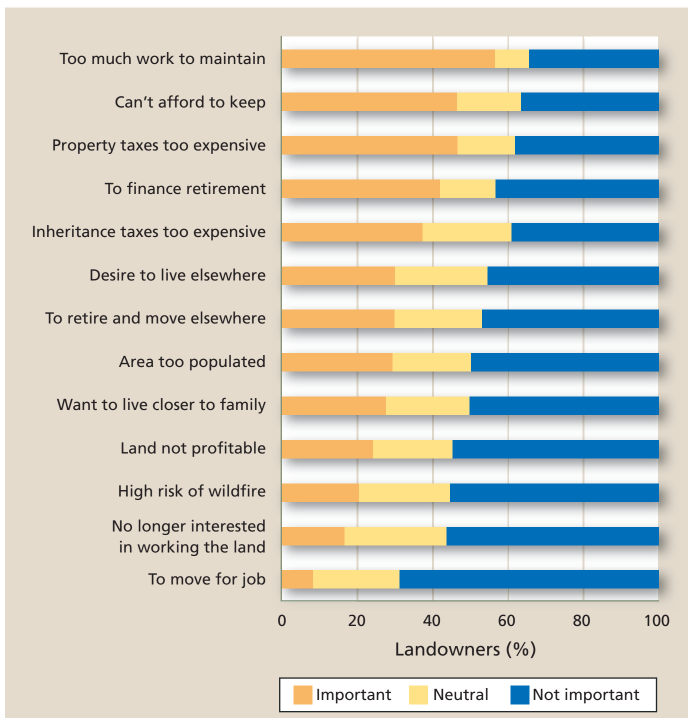

Fig. 8. Reasons California forest and rangeland owners stated they might sell their land someday (n = 552), 2008.

rangelands is not clear. Rural landowners clearly value the scenic qualities of their land — the most common reason chosen for owning land was to "live near natural beauty." "Preservation" and "protecting the environment" were also important to a strong majority of landowners of all property sizes (figs. 2 and 3), indicating that many feel a sense of stewardship and want to preserve their land's scenic and environmental qualities. Many of these qualities provide ecosystem services that are shared by society and benefit the public (Huntsinger et al. 2010).

However, owners of large properties, the category with the longest land tenures, were more likely than smaller landowners to implement environmental management or improvement practices (fig. 6). These results raise the question of whether fragmentation may affect environmental health by facilitating an in-migration of landowners less likely to implement environmental practices. Addressing this question will be an important challenge for conservation in California. The fact that landowners from all property sizes expressed widespread interest in implementing environmental management practices in the future gives cause for optimism, and it highlights the importance of outreach and assistance designed to help landowners better manage their properties.

Landowners face land management costs as well as liquidity challenges when a major portion of their assets is tied up in forest and rangeland. Four of the five most popular reasons why respondents might someday sell their land were related to financial concerns (fig. 8). California has some of the highest land values in the country (Kroll 2009), and landowners can tap into this monetary value only if they choose to sell land or some of the associated development, timber harvesting, mineral or other rights. Since landowners obtain significant amenity benefits from moderate to small properties (Campos et al. 2009), owners of large properties can capture considerable monetary value by selling off parcels, while still maintaining the quality of life they value on their remaining, slightly smaller, property. In fact, this is a tradition among cash-poor livestock producers.

Future of privately owned lands

What will happen when privately owned forests and rangelands change ownership — either through generational transfer of land or sale — is unknown. Family land transfers across the United States are expected to be substantial in the next 10 to 20 years (Butler and Leatherberry 2004). California forest and rangeland owners are 62 years old on average, with a high proportion retired, and many more nearing retirement. The majority of these landowners, especially owners of large properties, plan to pass ownership on to their children or family members. Without proper estate planning, inheritance taxes and disagreements among heirs could make it difficult for many families to keep their properties. Without technical knowledge on environmental management and improvement practices, it may be difficult to maintain the desired amenities.

New owners, through inheritance or in-migration, may bring a new set of ownership goals and objectives, or the current trend toward valuing amenities more than revenue generation may continue. It will be important to update knowledge of these landowners so that forestry and range professionals can effectively provide advice, assistance and outreach, and encourage protection of the ecosystem services that support quality of life for all Californians.

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References

Alig RJ, Plantinga AJ. 2004. Future forestland area: Impacts from population growth and other factors that affect land values. J Forest 102:19–24.

Brown DG, Johnson KM, Loveland TR, Theobald DM. 2005. Rural land-use trends in the conterminous United States, 1950–2000. Ecol Appl 15:1851–63.

Butler BJ, Leatherberry EC. 2004. America's family forest owners. J Forest 102:4–9.

Campos P, Oviedo JL, Caparros A, et al. 2009. Contingent valuation of woodland-owner private amenities in Spain, Portugal and California. Rangeland Ecol Manag 62:240–52.

[CDFFP] California Department of Forestry and Fire Protection. 2003. The Changing California: Forest and Range 2003 Assessment. Sacramento, CA. http://frap.cdf.ca.gov/assessment2003.

Clendenning G, Field DR, Jensen D. 2004. A survey of seasonal and permanent landowners in Wisconsin's Northwoods: Following Dillman and then some. Soc Natur Resour 17:431–42.

Dillman DA. 2007. *Mail and Internet Surveys: The Tailored Design Method* (2nd ed.). New York: Wiley. 464 p.

Gosnell H, Haggerty JH, Travis WR. 2006. Ranchland ownership change in the greater Yellowstone ecosystem, 1990–2001: Implications for conservation. Soc Natur Resour 19:743–58.

Gustanski JA, Squires RH (eds.). 2000. *Protecting the Land: Conservation Easements Past, Present and Future*. Washington, DC: Island Pr. 566 p.

Hansen AJ, Knight R, Marzluff JM, et al. 2005. Effects of exurban development on biodiversity: Patterns, mechanisms and research needs. Ecol Appl 15:1893–905.

Hobbs NT, Galvin KA, Stokes CJ, et al. 2008. Fragmentation of rangelands: Implications for humans, animals and landscapes. Global Env Chang 18:776–85.

Huntsinger L, Johnson M, Stafford M, Fried J. 2010. California hardwood rangeland landowners 1985 to 2004: Ecoystem services, production and permanence. Rangeland Ecol Manag 63:325–34.

Jones RE, Fly JM, Talley J, Cordell HK. 2003. Green migration into rural America: The new frontier of environmentalism. Soc Natur Resour 16:221–38.

Kendra A, Hull B. 2005. Motivations and behaviors of new forest owners in Virginia. Forest Sci 51:142–54.

Kroll CA. 2009. California Housing in the Subprime/Credit Crisis — Overview and a Forward Look at Recovery. UC Berkeley Fisher Center for Real Estate and Urban Economics. http://escholarship.org/uc/item/9h1898m1.

Maestas JD, Knight RL, Gilgert WC. 2003. Biodiversity across a rural land-use gradient. Conserv Biol 17:1425–34.

Maletta H. 2007. Weighting. www.spsstools.net/Tutorials/WEIGHTING.pdf.

Moritz MA, Stephens SL. 2008. Fire and sustainability: Considerations for California's altered future climate. Clim Change 87:265–71.

Nowak DJ, Walton JT. 2005. Projected urban growth (2000–2050) and its estimated impact on the U.S. forest resource. J Forest 103:383–9.

Parmenter AW, Hansen A, Kennedy RE, et al. 2003. Land use and land cover change in the greater Yellowstone ecosystem: 1975–1995. Ecol Appl 13:687–703.

Sokolow A. 2010. Outlook: Budget cuts threaten the Williamson Act, California's longstanding farmland protection program. Cal Ag 64:118–20.

Theobald DM. 2005. Landscape patterns of exurban growth in the USA from 1980 to 2020. Ecol Soc 10:32.

Walker P, Fortmann L. 2003. Whose landscape? A political ecology of the "exurban" Sierra. Cult Geogr 10:469–91.

White EM, Morzillo AT, Alig RJ. 2009. Past and projected rural land conversion in the U.S. at state, regional and national levels. Landscape Urban Plan 89:37–48.

Yung L, Belsky JM. 2007. Private property rights and community goods: Negotiating landowner cooperation amid changing ownership on the Rocky Mountain Front. Soc Natur Resour 20:689–703.

Tree shelters and weed control enhance growth and survival of natural blue oak seedlings

by Douglas D. McCreary, William Tietje, Josh Davy, Royce Larsen, Morgan Doran, Dustin Flavell *and* Sergio Garcia

Blue oak is regenerating poorly in portions of its range. Techniques to artificially regenerate trees by collecting acorns, growing seedlings in a nursery and then planting them are effective but costly. Improving the growth and survival rate of existing volunteer seedlings in woodlands could be more cost efficient and therefore more widely used. We tested tree shelters and weed control treatments over 3 years at six woodland sites to evaluate whether they helped blue oak seedlings grow into saplings. The tree shelters enhanced height growth, and weed control improved survival. Together, these two techniques can improve the chances for managing blue oak sustainably and conserving this native California oak for future generations.

Blue oak seedlings can be transplanted into rangeland and successfully regenerate, but the process is costly. The researchers investigated strategies for protecting naturally occurring seedlings with tree shelters and weed control.

For over a century, there has been concern that several native California oak species are not naturally regenerating adequately to sustain populations (Jepson 1910). Blue oak (*Quercus douglasii* Hook & Arn.) is one of these species (Bolsinger 1988; Muick and Bartolome 1987). Endemic to California, blue oak distribution extends from the Siskiyou Mountains in the north to the Tehachapi Mountains in the south; however, it grows primarily in the Sierra Nevada foothills and coastal mountain ranges. The majority of the woodlands where blue oak grows are used for grazing and beef cattle production.

Although blue oak is long lived and relatively few seedlings and saplings are needed in any one year to replace mature trees that die, research indicates that in portions of its range this natural regeneration is not occurring. Swiecki et al. (1997) assessed 15 sites representing the broad range of blue oak and reported that the number of saplings at 13 sites was inadequate to offset recent losses in density and canopy cover caused by natural mortality and tree cutting. Even though blue oaks will sprout after their tops are killed by fire or felling (McClaran and Bartolome 1989; Mensing 1992; Standiford et al. 2011), the ability of seedlings to grow into mature trees is essential for the species to sustain itself and prosper.

One theory suggests that the apparent shortage of oak saplings may not signal a regeneration problem but only a lull in natural recruitment, which occurs in spurts, or pulses. These pulses happen when a rare combination of events, such as a wet, late spring following a good acorn crop, combined with, for example, low populations of seedling-eating animals, occurs. The optimal conditions for regeneration may therefore occur only once or twice in a century. For a very long-lived species such as blue oak, these infrequent pulses may be adequate to sustain populations. At present, however, there is little evidence to support this theory, since aging studies of blue oak stands indicate that seedling recruitment occurs over long intervals rather than during short pulses (Kertis et al. 1993; McClaran 1986; Mensing 1992; White 1966).

The reasons for poor regeneration of blue oak vary by site. They include competition from dense annual grasses, browsing by domestic livestock, and herbivory by grasshoppers, squirrels, gophers, voles, rabbits, deer and other animals. Aggravating the situation is the fact that the regions where blue oak grows best have a Mediterranean climate, with a dry period that normally extends from midspring until early fall. Soil conditions can become exceedingly dry, making it difficult for oaks to become established. The bottleneck, or problematic interval in the regeneration process, is from the seedling to the sapling stage (Swiecki et al. 1997). During most years, a sufficient number of acorns germinate, and small seedlings begin to grow in the understory, but few survive to become established saplings. Swiecki et al. (1997) defined saplings as having a diameter at breast height (DBH) between 0.4 and 1.2 inches (1 and

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3 centimeters). The low seedling survival rate has resulted in a bimodal size distribution in many blue oak stands, with considerable numbers of seedlings and trees but few saplings.

For over two decades, UC researchers and others have been developing techniques to artificially regenerate California oaks, including blue oak. Research has included collecting, storing and planting acorns; producing oak seedlings in container and bare-root nurseries; and planting and maintaining seedlings in the field (McCreary 2001). Overall, the research demonstrates that sapling-sized oaks can be established artificially — in less than 5 years — but the substantial management required is costly. As a result, these techniques are not being used for large areas.

An alternative oak regeneration strategy is to promote the advancement of naturally occurring seedlings on-site, helping them to reach the sapling stage. This strategy could produce considerable savings because no effort or cost would be expended to collect acorns or to grow and plant seedlings. An additional advantage is that only genetically adapted plant material would be used, alleviating concerns about using off-site planting stock that is not adapted to local conditions. Given these economic, ecologic and genetic advantages, landowners may be more likely to adopt natural regeneration practices than artificial regeneration.

An alternative oak regeneration strategy is to promote the advancement of naturally occurring seedlings on-site, helping them to reach the sapling stage.

Tests at six seedling sites

To test the strategy of enhancing natural blue oak regeneration, we initiated a study in spring 2007 at six sites broadly representing the range of blue oak in California (fig. 1). The northernmost site was near Red Bluff in Tehama County, and the southernmost site was in Santa Barbara County about 18.6 miles (30 kilometers) west of Cuyama. At each site, 144 naturally occurring blue oak seedlings between about 1 and 23 inches (2 and 58 centimeters) tall were identified and tagged. We selected seedlings on each site such that half were under the canopy of existing trees and half were outside the drip line of the trees and in the open.

Treatments. The 72 seedlings per canopy treatment at each site were arranged in 18 groups of four seedlings each. Except for a few cases where closely spaced seedlings were difficult to locate, seedlings within each group of four were no closer than 4 feet (1.2 meters) apart and no farther apart than 20 feet (6.2 meters). In spring 2007, one member of each group of four was randomly selected to be covered with a 4-foot (1.2-meter) tree shelter. Tree shelters are solid, double-walled plastic cylinders that are placed over individual seedlings. They were developed in England in the early 1980s and are reported to protect seedlings from browsing and to stimulate aboveground growth (Tuley 1983).

We eliminated the surface vegetation within approximately 2 feet (60 centimeters) of a second seedling in each group by spraying with contact herbicide (glyphosate [Roundup]) and reapplied the herbicide each subsequent spring. We covered the third seedling of each group with a tree shelter and sprayed for weed control. The fourth seedling was a control without protection or weed control.

Data collection. Before we installed the treatments, we recorded each seedling and its height (distance from the ground to the tip of the highest bud with the seedling held straight). In the falls of 2008, 2009 and 2010, we assessed each seedling for survival and total height. In cases where the top of the seedling had died, we recorded the height from the base to the highest living point as indicated by green foliage or green tissue under the bark. When we found seedlings that had died, we tried to identify the cause (e.g., gopher damage, aboveground herbivory, drought), but this proved difficult so no results are reported here. We collected management history for each site from the landowners and average annual precipitation in the 2007–2008, 2008–2009 and 2009–2010 growing seasons (measured from Oct. 1 to Sept. 30), from local weather databases (table 1).

Statistical analysis. The seedling data was analyzed as a doubly nested randomized block experiment with sites as the main plots, shade as the subplots and factorial combinations of tree shelters and weed control as the sub-sub plots. Before analysis, the data was averaged over shade, shelter and weed control treatments for each site. Differences were considered significant at the $P \leq 0.05$ level.

Each response variable (height growth and survival) for each year was tested for significance, as were all two-way interactions. When we found significant differences for the sites, we performed least significance difference (LSD) tests to determine which sites were significantly different from the others ($P \leq 0.05$). We also

Fig. 1. Oak distribution (green) in California and the six field sites. Green areas show forest and woodland formations of at least 25% tree cover, with at least 20% oak or tanoak. Species include black oak, blue oak, valley oak, coast live oak, interior live oak, Oregon oak, canyon live oak, Engelmann oak and tanoak (genus *Lithocarpus*). Source: Griffin and Critchfield 1972.

examined all significant two-way interactions to determine their cause. Finally, we computed partial correlations to find out if initial seedling height (measured in 2007) was related to subsequent growth and survival.

Growth and survival differences

Height growth. Height growth can be critical to the survival of blue oak seedlings, because they are only relatively resistant to browsing damage from cattle, or clipping of the aboveground portion of the seedling, when they reach 6.5 feet (2 meters) (McCreary and George 2005). Without protection, seedlings may languish in a stunted state, due to repeated browsing, for decades (White 1966).

In our study, tree shelters significantly increased seedling height growth at all sites (table 2). However, responses were not consistent over sites, and there were highly significant site/shelter interactions for height growth each year. For instance, at the San Luis Obispo County site, two seedlings in the shelter treatment grew 4 feet (1.2 meters) — to the tops of the shelters — during 2008. This represented an annual height growth of over 2 feet (60 centimeters) for each of these two seedlings. At the Yolo County site, on the other hand, no seedlings grew more than 1.6 inches (4 centimeters) during 2008, and the average change in height for each of the treatments, including the shelter treatment, was negative.

There were also significant shade/shelter interactions for height growth each year, because the positive effects of the tree shelters were much less for seedlings under the canopies than they were for seedlings in the open. Height growth each year was also positively correlated with initial seedling height. Partial correlations, adjusted for site, of initial height and height growth were highly significant each year — the taller the seedlings were initially, the more they grew.

There was much greater height growth in the last year of the study (2010), which corresponded to an above-average rainfall year. Height growth in 2010, averaged over all sites and treatments, was approximately double that in 2009 and more than triple that in 2008. The difference in height growth for sheltered compared with unsheltered seedlings was also greatest in 2010.

Survival. The differences in survival were less pronounced than they were for height growth, although there were significant site differences in survival every year (table 3). In 2008 and 2010, there were also significant differences in survival for weed control treatments, with seedlings receiving weed control having greater survival than those not receiving it. In 2009, those receiving a weed control treatment had higher average survival, but the differences ($P = 0.10$) were not significant. The initial size of seedlings was also significantly and positively correlated with subsequent survival.

Tree shelters improved growth

In previous research, tree shelters consistently promoted the height growth of artificially planted blue oak seedlings (Costello et al. 1991; McCreary 1997; McCreary and Tecklin 1997). This accelerated growth results from environmental changes within the tubes — including elevated CO_2 levels, increased humidity and higher temperatures — as well as protection that the tubes provide to seedlings from damage by animals. Shelters therefore offer the possibility of allowing seedlings to grow more rapidly to a height where they are relatively resistant to animal impacts. A study at the UC Sierra

TABLE 1. Site characteristics for study of natural regeneration of blue oaks

Site county	Average precipitation				Management
	Annual	2007–2008	2008–2009	2009–2010	
	inches (centimeters)				
Tehama	24.0 (61)	15.0 (38)	17.7 (45)	24.0 (61)	Seasonal grazing
Yuba	27.2 (69)	18.5 (47)	23.2 (59)	26.0 (66)	Seasonal grazing
Yolo	22.0 (56)	23.2 (59)	18.1 (46)	27.2 (69)	Seasonal grazing
San Benito	13.4 (34)	14.2 (36)	10.6 (27)	18.5 (47)	No grazing
San Luis Obispo	19.7 (50)	20.1 (51)	12.6 (32)	27.6 (70)	Seasonal grazing
Santa Barbara	8.3 (21)	5.9 (15)	5.9 (15)	10.6 (27)	Seasonal grazing

TABLE 2. Average annual height growth in study of natural regeneration of blue oaks

Treatment	Initial height 2007	Height growth 2008	2009	2010
Site	inches (centimeters)			
Tehama	3.7 (9.3)*	0.1 (0.3)	0.2 (0.4)a†	0.5 (1.2)
Yuba	5.1 (13.0)	0.9 (2.4)	2.0 (5.0)c	2.3 (5.8)
Yolo	3.7 (9.3)	−0.6 (−1.4)	0.5 (1.2)ab	0.5 (1.2)
San Benito	6.5 (16.4)	0.3 (0.8)	0.5 (1.3)ab	2.5 (6.4)
San Luis Obispo	7.7 (19.5)	2.0 (5.1)	1.1 (2.9)bc	3.0 (7.7)
Santa Barbara	4.2 (10.6)	0.5 (1.3)	1.2 (3.0)bc	1.0 (2.6)
Tree shelter				
No	5.0 (12.8)	−0.7 (−1.9)a	0 (0.0) a	0.2 (0.6)a
Yes	5.2 (13.2)	1.8 (4.6)b	1.8 (4.6)b	3.0 (7.7)b
Shade				
No	5.7 (14.5)	0.8 (2.1)	1.3 (3.3)a	2.5 (6.4)a
Yes	4.5 (11.5)	0.2 (0.5)	0.5 (1.3)b	0.7 (1.9)b
Weed control				
No	5.1 (12.9)	0.5 (1.3)	0.9 (2.4)	1.8 (4.6)
Yes	5.2 (13.2)	0.5 (1.3)	0.9 (2.2)	1.5 (3.7)
Average	5.1 (13.0)	0.5 (1.3)	0.9 (2.3)	1.6 (4.1)

* Data is averaged, and for surviving seedlings only.
† Within the same treatment, different letters mark values significantly different at $P \leq 0.05$ (LSD test).

Foothill Research and Extension Center in Yuba County, near one of the field sites, found that shelters caused dramatic (and significant) increases in seedling height growth (Tecklin et al. 1997). Shelters had been placed over seedlings that were planted 2 years earlier but languished with little growth. Almost immediately, the seedlings began to grow rapidly, and 2 years later average seedling height was nearly 4 feet (1.2 meters). By comparison, the controls grew very little and remained less than 1 foot (30 centimeters) tall.

In our current study, tree shelters also significantly increased height growth, although the increase was not as great as that measured for artificially planted seedlings (McCreary 1997; McCreary and Tecklin 1997). Each year, livestock rubbing caused some shelters to be displaced so that they no longer covered the seedlings when we came to measure them in the fall. This may have contributed to reduced growth, though it was impossible to determine when during the year (or at least when after the spring weed control treatments) this had occurred. But we did observe browsing damage to some of these seedlings before we repositioned the tree shelters over them.

The effects of the tree shelter treatments were not uniform over all sites. Consequently, there were significant interactions in all 3 years for height growth between the shelter treatment and sites. For instance, while 2008 height growth was larger for seedlings in tree shelters at all sites, the magnitude of this difference varied considerably. At the San Luis Obispo site, the shelter treatment resulted in an average height increase of over 2 inches (5 centimeters) in 2008, while at the other sites the enhancement from the shelters was far less dramatic. Furthermore, the effects of tree shelters seemed somewhat dependent on initial seedling size, with larger seedlings benefiting more from the shelters. For example, the regressions of initial seedling height with subsequent height growth each year indicated that these variables were positively, and significantly, correlated.

TABLE 3. Average annual survival of seedlings in study of natural regeneration of blue oaks

Treatment	Seedling survival 2008	2009	2010
Site		%	
Tehama	86.7a*	67.4b	57.9cd
Yuba	93.8a	79.9a	72.2abc
Yolo	70.8b	67.4b	63.9bc
San Benito	90.3a	84.7a	77.8ab
San Luis Obispo	88.2a	84.7a	84.0a
Santa Barbara	56.9c	50.7c	47.2d
Tree shelter			
No	80.7	72.0	66.2
Yes	81.5	72.9	68.1
Shade			
No	83.0	74.0	70.7
Yes	79.3	70.9	63.6
Weed control			
No	78.2a	70.3	63.2a
Yes	84.1b	74.6	71.1b
Average	81.1	72.4	67.2

* Within the same treatment, different letters mark values significantly different at $P \leq 0.05$ (LSD test).

Impact of other factors

Weed control. California's hardwood rangelands commonly have dense understories of introduced Mediterranean annual grasses (Heady 1977), which compete with oak seedlings for moisture, nutrients and light and can make it difficult for the oak seedlings to grow into saplings (Welker and Menke 1987). Removing this vegetation around the seedlings increases the resources, especially moisture, available for them. It may also reduce damage from voles (Tecklin and McCreary 1993) and grasshoppers. Weed control around artificially planted blue oak seedlings has been shown to enhance their growth and survival (Adams et al. 1997; McCreary and Tecklin 1997). In our study results, the weed control treatment apparently had little effect on height growth (no significant differences were detected), but, importantly, it significantly increased survival in 2 of the 3 years (table 3).

Seedling mortality. Altogether, 28.2% of the original seedlings died (244 of 864 seedlings). The causes of seedling mortality were difficult to determine. At the Yolo and San Benito county sites, feral hog rooting (foraging in the soil with snouts and tusks) disturbed the soil and eliminated over a dozen seedlings. At the Yuba and Santa Barbara county sites, livestock and deer browsing appeared to reduce seedling height and likely killed some seedlings not in shelters. At all of the sites, there was evidence of browsing of nonsheltered seedlings, and in many cases these seedlings were either killed or lost height during one or more years.

Jack Kelly Clark

About 80% of California oak woodlands are privately owned, mostly managed for livestock. Tree shelters can protect seedlings from grazing.

At the San Luis Obispo and Yuba county sites, there was extensive gopher activity close to some seedlings, although only a couple of them appeared to be affected. The extremely high mortality at the Santa Barbara County site was most likely due to below-normal rainfall during 2008 and 2009, only 5.9 inches (15 centimeters) each year, compared with the long-term average of 8.3 inches (21 centimeters). Even though blue oak is relatively drought resistant, it is not surprising that mortality was so high under these extremely dry conditions.

Shade. Whether seedlings were growing in shade (under tree canopies) influenced how they performed. Shaded seedlings grew less, and differences in total height and height growth between shaded and nonshaded treatments were significantly different in 2009 and 2010.

There were significant interactions for shade and shelter for height growth in all years — seedlings in tree shelters did not grow as much in shade as did those in the open. This is not surprising since tree shelters reduce light levels reaching the seedlings inside, often by 50% or more (Devine and Harrington 2008). In our study, light levels for seedlings in tree shelters in the shade were apparently too low to allow substantial growth.

Seedling size. The height of the seedlings initially, at the start of the study, was strongly and positively correlated with how much the seedlings subsequently grew. It was also significantly positively correlated with survival. Taller seedlings have more biomass and photosynthetic tissue and would be expected to grow

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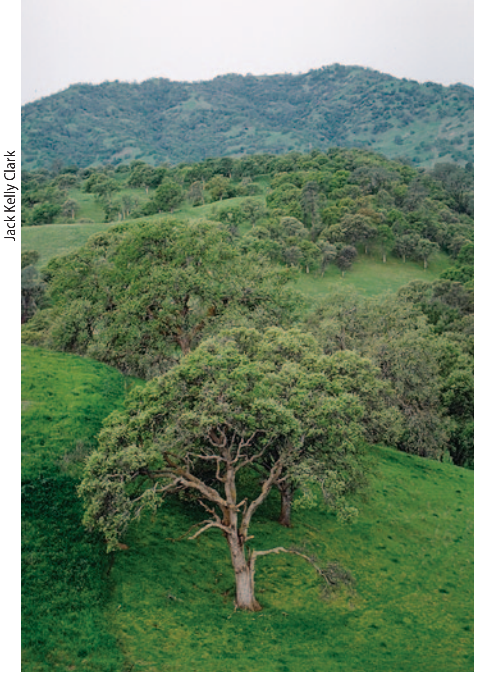

Helping blue oak seedlings to reach the sapling stage can help ensure the survival of this iconic California tree.

more; for regeneration, they are the best candidates for protection or weed control.

Rainfall. This study took place during 3 consecutive relatively dry years (including 2007, the year the plots were established), followed by one average or above-average rainfall year. We cannot say for certain that the large increase in 2010 seedling height growth compared to the previous 2 years' growth was primarily due to increased rain, but it appeared that more soil moisture contributed to greater growth. For instance, we noticed more seedlings exhibiting second flushing — a second period of active shoot elongation — in 2010 than in previous years. The positive effects of the shelter treatments were also greatest in 2010, suggesting that tree shelters are most beneficial when there is abundant moisture.

Improved regeneration

Our study has been under way for less than 4 years — a relatively short time in the life of blue oaks — but the data strongly suggests that tree shelters can enhance growth and that weed control can increase survival. Both techniques improved the chances for blue oak seedlings to grow into saplings. These trends were especially evident in the last year of the study, when annual precipitation was above average at most sites, and seedlings growing away from tree canopies and in full or near-full sunlight had the maximum benefit.

In our experience, blue oak seedlings in the open covered with tree shelters generally grow into saplings in less than a decade. Compared with artificial regeneration techniques, this natural regeneration strategy is more cost efficient and therefore more likely to be widely adopted by California landowners. We estimate that this approach would cost less than half of what it costs to plant seedlings. We feel that using tree shelters and weed control to enhance early growth and survival of naturally occurring blue oak seedlings could significantly improve the regeneration of this important woodland species and promote its long-term conservation.

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References

Adams T Jr, Sands PB, McHenry WB. 1997. Weed control improves survival of transplanted blue oak. Cal Ag 51(5):26–30.

Bolsinger CL. 1988. The Hardwoods of California's Timberlands, Woodlands and Savannas. USDA Forest Serv Pac NW Res Stat Res Bull PNW-148. 148 p.

Costello LR, Schmidt RH, Giusti GA. 1991. Evaluating tree protection devices: Effects on growth and survival — first-year results. In: Standiford R (tech. coord.). Proc Symp Oak Woodlands and Hardwood Rangeland Management, Oct. 31–Nov. 2, 1990, Davis, CA. USDA Forest Serv Pac SW Res Stat Gen Tech Rep PSW-126. Berkeley, CA. p 31–5.

Devine WD, Harrington CA. 2008. Influence of four tree shelter types on microclimate and seedling performance of Oregon white oak and western red cedar. USDA Forest Serv Pac NW Res Stat Res Pap PNW-576. Portland, OR. 35 p.

Griffin JR, Critchfield WB. 1972. The distribution of forest trees in California. US Forest Serv Res Paper PSW Vol 82:1–114.

Heady HF. 1977. Valley grassland. In: Barbour MG, Major J (eds.). *Terrestrial Vegetation of California*. New York: J Wiley. p 383–415.

Jepson WL. 1910. *The Silva of California*. Berkeley, CA: UC Pr. 480 p.

Kertis JA, Gross R, Peterson DL, et al. 1993. Growth trends of blue oak (*Quercus douglasii*) in California. Can J Forest Res 23:1720–4.

McClaran MP. 1986. Age structure of *Quercus douglasii* in relation to livestock grazing and fire. PhD dissertation, UC Berkeley.

McClaran MP, Bartolome JW. 1989. Fire-related recruitment in stagnant *Quercus douglasii* populations. Can J Forest Res 19:580–5.

McCreary DD. 1997. Tree shelters: An alternative for oak regeneration. Fremontia 25(1):26–30.

McCreary DD. 2001. Regenerating Rangeland Oaks in California. UC ANR Pub 21601. Oakland, CA. 62 p.

McCreary DD, George M. 2005. Managed grazing and seedling shelters enhance oak regeneration on rangelands. Cal Ag 59(4):217–22.

McCreary DD, Tecklin J. 1997. Effects of seedling protectors and weed control on blue oak growth and survival. In: Pillsbury NW, Verner J, Tietje WD (tech. coords.). Proc Symp Oak Woodlands: Ecology, Management and Urban Interface Issues, Mar.19–22, 1996, San Luis Obispo, CA. USDA Forest Serv Pac SW Res Stat Gen Tech Rep PSW-160. Berkeley, CA. p 243–50.

Mensing S. 1992. The impact of European settlement on blue oak (*Quercus douglasii*) regeneration and recruitment in the Tehachapi Mountains, California. Madroño 39(1):36–46.

Muick PC, Bartolome JW. 1987. Factors associated with oak regeneration in California. In: Plumb PR, Pillsbury NH (tech. coords.). Proc Symp Multiple-Use Management of California's Hardwood Resource, Nov. 12–14, 1986, San Luis Obispo, CA. USDA Forest Serv Pac SW Res Stat Gen Tech Rep PSW-100. Berkeley, CA. p 86–91.

Standiford RB, McCreary DD, Barry SJ, Forero LC. 2011. Blue oak stump sprouting evaluated after firewood harvest in northern Sacramento Valley. Cal Ag 65(3):148–54.

Swiecki TJ, Bernhardt EA, Drake C. 1997. Stand-level status of blue oak sapling recruitment and regeneration. In: Pillsbury NW, Verner J, Tietje WD (tech. coords.). Proc Symp Oak Woodlands: Ecology, Management and Urban Interface Issues, Mar. 19–22, 1996, San Luis Obispo, CA. USDA Forest Serv Pac SW Res Stat Gen Tech Rep PSW-160. Berkeley, CA. p 147–56.

Tecklin J, Connor JM, McCreary DD. 1997. Rehabilitation of a blue oak restoration project. In: Pillsbury NW, Verner J, Tietje WD (tech. coords.). Proc Symp Oak Woodlands: Ecology, Management and Urban Interface Issues, Mar. 19–22, 1996, San Luis Obispo, CA. USDA Forest Serv Pac SW Res Stat Gen Tech Rep PSW-160. Berkeley, CA. p 267–73.

Tecklin J, McCreary DD. 1993. Dense vegetation may encourage vole damage in young oak plantings. Restor Manag Notes 11:2(153).

Tuley G. 1983. Shelters improve the growth of young trees in the forest. Q J Forest 77:77–87.

Welker JM, Menke JW. 1987. *Quercus douglasii* seedling water relations in mesic and grazing-induced xeric environments. In: Proc Int Conf Measurements of Soil and Plant Water Status, Vol. 2 — Plants, July 6–10, 1987, Logan, UT. p 229–34.

White KL. 1966. Structure and composition of foothill woodland in central-coastal California. Ecol 47(2):229–37.

Hedgerows enhance beneficial insects on farms in California's Central Valley

by Lora Morandin, Rachael F. Long, Corin Pease *and* Claire Kremen

Hedgerows of native California shrubs and perennial grasses bordering field crops were examined for the abundance of beneficial and pest insects compared with adjacent weedy areas. During 2 years of sampling in the Sacramento Valley, hedgerows attracted more beneficial than pest insects, while weedy areas showed the opposite trend, attracting significantly more pest than beneficial insects. We conclude that replacing weedy areas at field crop edges with managed hedgerow plantings will sustain or increase beneficial rather than pest insects on farms.

Hedgerows of California native shrubs and perennial grasses, including at Fong Farms in Yolo County, were compared to weedy field margins for the abundance of beneficial and pest insects.

Hedgerows are rows of trees, shrubs, forbs and grasses that surround farm fields. They may be remnants of existing vegetation from cleared lands, a result of natural plant dispersal, or established via direct plantings (CAFF 2004; Long and Anderson 2010). Their many benefits include enhanced weed control, soil fauna, erosion control, sediment retention, game hunting, biodiversity, and air- and water-quality protection (Hannon and Sisk 2009; Kleijn et al. 2006; Kort et al. 1998; Smith et al. 2008). There also is evidence that hedgerows may increase the abundance of beneficial insects such as pollinators and natural enemies, possibly improving crop pollination and biological pest control in adjacent crops (Griffiths et al. 2007; Hopwood 2008; Thomas and Marshall 1999).

The enhanced biodiversity and potential ecosystem service benefits of hedgerows have prompted the USDA Natural Resource Conservation Service (NRCS) and Resource Conservation Districts to support growers in planting native shrubs and perennial grasses on their farms. Thirteen miles of hedgerows were established on California farms in 2009, compared to 3 miles in 2005. However, the adoption of hedgerows on farms is constrained by a lack of information about how they will alter pest and natural enemy communities in field edges as well as the benefits they may provide, including biocontrol of pests in adjacent crops (Brodt et al. 2009).

The type of field edge habitat around farmlands influences the abundance and diversity of insects they attract, including pests that may be of concern to growers in adjacent crops (Pease and Zalom 2010). Our study evaluated how hedgerows of California native shrubs and perennial grasses affect beneficial and pest insect abundance in comparison to weedy field edges.

Hedgerows of shrubs and grasses

Beneficial and pest insects were examined in four hedgerows in Yolo County for 2 years.

Species planted. Hedgerows at each site consisted of a row of perennial shrubs bordered by native perennial grasses. They ranged from 1,000 to 1,800 feet (305 to 550 meters) long and were established in 1996. Plant species composition for each site varied slightly, but all contained California lilac (*Ceanothus griseus*), coffeeberry (*Rhamnus californica*), California buckwheat (*Eriogonum fasciculatum*), toyon (*Heteromeles arbutifolia*), elderberry (*Sambucus mexicana*) and coyote brush (*Baccharis pilularis*). These are drought-tolerant native California shrubs that provide pollen and nectar for beneficial insects (Bugg et al. 1998; Long et al. 1998) and have successive and overlapping bloom periods (table 1).

The perennial grass stands were planted 10 feet (3 meters) wide along one or both sides of the shrubs to help suppress weeds and create overwintering habitat for natural enemies. The grasses included purple needlegrass (*Nassella pulchra*), nodding needlegrass (*N. cernua*), California melic (*Melica californica*), one-sided bluegrass (*Poa secunda*), blue wildrye (*Elymus glaucus*) and creeping wildrye (*Leymus triticoides*).

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All four hedgerows were adjacent to approximately 80 acres (32 hectares) of rotational field crops typical of crop production in this region, including wheat, processing tomatoes and alfalfa. At each hedgerow site, insect populations were monitored in an adjacent weedy, relatively unmanaged area (mowed or sprayed once or twice a year) of about 1,000 square feet. The primary herbaceous weeds in these adjoining weedy areas were wild mustard (*Sinapis arvensis*), black mustard (*Brassica nigra*), wild radish (*Raphanus raphanistrum*) and knotweed (*Polygonum* spp.).

Monitoring and identification. Insects on hedgerow shrubs were monitored every 2 weeks from April to November 1999 and March to November 2000. At each sampling, two plants from each of the shrub species were randomly chosen within each hedgerow and visually inspected for insects. To assess the more mobile insect groups, such as syrphids, tachinids, lacewings and wasps, the number of visitors to each plant was observed and recorded for 2 minutes. Small insects that were not readily visible inside the flower heads were sampled by shaking all the flower heads on each shrub over a white sheet of paper and counting the number of insects dislodged. Weather conditions were monitored, and insects were sampled when temperatures were generally between 75ºF to 85ºF (25ºC to 30ºC) with sunny or bright overcast skies, and the fields were dry. In the early spring and fall samplings, temperatures were cooler and samples were taken as long as the temperature did not fall below 60ºF (16ºC).

Insects were identified to the taxonomic levels feasible from visual observation, by experienced observers who had carried out preliminary sampling in the hedgerows during 1997 and 1998. The UC Davis Bohart Entomology Museum also helped with species identification. The types and numbers of insects observed were recorded (table 2; fig. 1). The pest insects sampled were those of concern in adjacent field crops; the beneficial insects sampled were those that feed on major field crop pests. Few caterpillars (Lepidoptera), aphids, spider mites or leafminers were found in the hedgerows, so they were not included in our insect counts or data analyses. Thrips were not included because at the time of this study they were not considered a major field crop pest in this region. However, due to the introduction of new thrips-transmitted viruses since this study, our current research is focusing on monitoring thrips in hedgerows.

Plant size and sampling frequency. To standardize the counts from visual observations and flower shake samples among plants, the size of each shrub sampled was estimated by measuring the average length and width of each plant (most plants were relatively circular) multiplied by height, giving an approximate square area in meters. Insect numbers were divided by plant size (which varied considerably, particularly in height), providing a measurement of insect abundance per square meter.

The perennial grasses in the hedgerows and adjacent weedy areas were also sampled every 2 weeks from April to November 1999 and March to November

TABLE 1. Flowering periods of California native shrubs monitored in hedgerow study, Yolo County

Shrubs	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
California lilac (*Ceanothus griseus*)	●	●	●							
Coffeeberry (*Rhamnus californica*)		●	●		●	●	●			
California buckwheat (*Eriogonum fasciculatum*)			●	●	●	●	●	●	●	
Toyon (*Heteromeles arbutifolia*)			●	●						
Elderberry (*Sambucus mexicana*)			●	●	●	●	●	●		
Coyote brush (*Baccharis pilularis*)							●	●	●	●

TABLE 2. Beneficial and pest insects sampled in hedgerows of native shrubs and perennial grasses and in weedy areas, Yolo County

Insect group	Species or higher order	Prey/crop preference
Beneficial insects		
Minute pirate bugs	*Orius tristicolor*	Generalist predators; prey includes caterpillars, thrips, aphids, Lygus bugs, leafhoppers
Assassin bugs	*Zelus renardii, Sinea diadema*	
Big-eyed bugs	*Geocoris punctipes, G. tricolor*	
Collops beetles	*Collops vittatus*	
Damsel bugs	*Nabis* spp.	
Lacewings	*Chrysoperla* spp., *Chrysopa* spp.	Aphids
Soldier beetles	Cantharidae	
Syrphid flies	Syrphidae	
Lady beetles	*Hippodamia convergens*	
Wasps	Ichneumonidae	Generalist and specific predators and parasitoids; prey includes caterpillars and aphids
	Braconidae	
	Polistes spp.	
	Vespula spp.	
	Sphecidae	
Tachinid flies	*Archytas* spp.	Caterpillars, stinkbugs, squash bugs
	Gymnosoma spp.	
	Trichopoda pennipes	
	Cylindromyia spp.	
Pest insects		
Lygus bugs	*Lygus* spp.	Strawberries, dry beans, cotton, seed crops
Flea beetles	*Phyllotreta* spp., *Epitrix* spp.	Seedling field crops
Stinkbugs	*Euschistus conspersus, Thyanta pallidovirens, Nezara viridula, Chlorochroa uhleri*	Tomatoes
Spotted cucumber beetles	*Diabrotica undecimpunctata*	Cucurbits

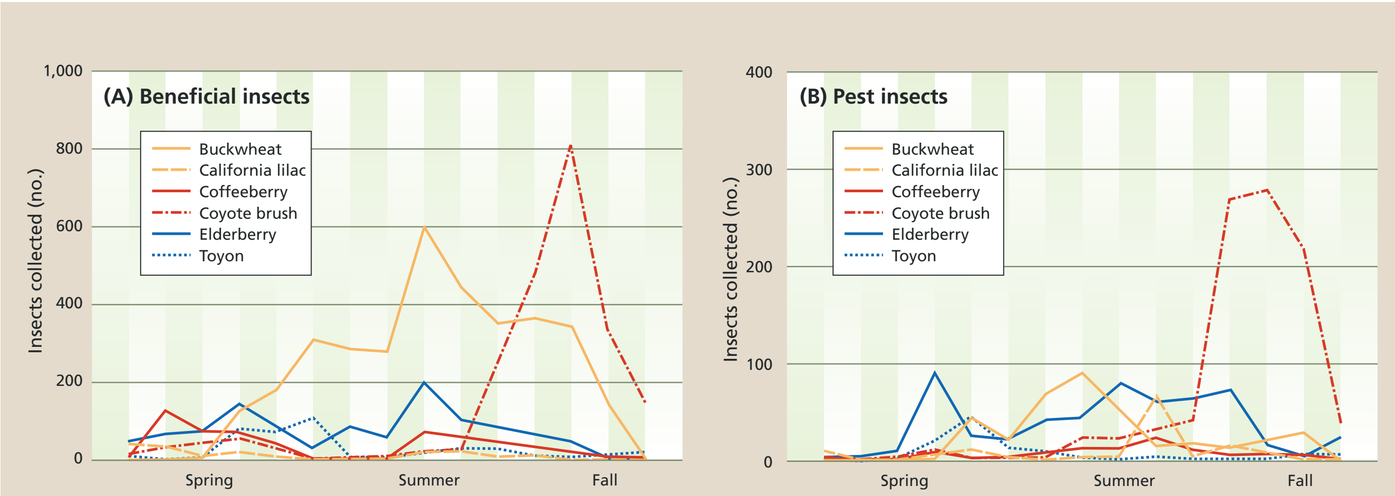

Fig. 1. Total number of (A) beneficial and (B) pest insects on shrub species, collected over 2 years during the growing season in four hedgerows, Yolo County.

The abundance of beneficial insects was consistently greater than pests in the hedgerow shrubs compared with weedy areas during each season.

2000 using a standard sweep net (UC IPM 2006). At each site, 10 sweeps were taken in each of four different areas of both the hedgerow grasses and weedy areas.

Statistical analysis. Beneficial and pest insect abundances within each vegetation type (shrub, grass and weed) were compared from spring to fall using a full factorial mixed model ANOVA (SAS 1999). Sample period was a repeated factor; insect type (pest or beneficial), year (1 and 2) and plant species (1 to 6) were fixed effects; site (1 to 4) was a random factor; and abundance of insects was the response variable.

For post hoc comparisons, we coded sample period by season (spring, summer and fall) and included season and its interactions as fixed effects. Abundance data were Poisson-distributed and square-root (plus constant of one) transformed before analyses. To compare shrub data (collected by surveys of plants) to grass and weed data (collected by standardized sweep samples), we compared the proportion of beneficial insects among vegetation types using a general linear model with a binary distribution and a logit link function (SAS 1999).

Insect population counts

Beneficial insects. Of 8,045 beneficial insects collected in the four hedgerows over 2 years, 31% were minute pirate bugs, 17% syrphid flies, 13% assassin bugs, 13% tachinid flies, 10% big-eyed bugs, 6% lacewings, 6% wasps, 3% lady beetles and 0.4% damsel bugs. The greatest abundance of beneficial insects was collected on California buckwheat, followed, in decreasing amounts, by coyote brush, elderberry, coffeeberry, toyon and California lilac. The greatest beneficial insect abundance on each shrub species coincided with the bloom period of that species, when nectar and/or pollen were available (fig. 1A).

Pest species. Of 2,278 pests collected in the four hedgerows over 2 years, 42% were spotted cucumber beetles, 25% Lygus bugs, 18% flea beetles and 14% stink bugs, with the greatest abundance also occurring during plant bloom (fig. 1B). The increased number of pests on California buckwheat during summer was caused primarily by Lygus bugs. Similarly, spotted cucumber beetles were the primary cause of the pest population increase in coyote brush during the fall bloom. Flea beetles were most numerous on the hedgerow plants during summer, and stink bugs were most abundant during summer and fall, when the shrub berries were ripening.

Insect abundance. Of 10,323 total insects collected in the hedgerows during the growing seasons over 2 years, 78% were beneficial insects and 22% were pests. The abundance of beneficial insects was consistently greater than pests in the hedgerow shrubs compared to weedy areas during each season ($P < 0.0001$ Bonferroni; fig. 2). Overall, a greater abundance of insects was collected in year one than year two ($F_{1,11.3} = 7.92$, $P = 0.0164$). But there was no difference in relative abundances of pest and beneficial insects between the two years (year by insect type interaction; $F_{2,1252} = 0.01$, $P = 0.940$) or interaction among year, insect type and season ($F_{2,1252} = 2.18$, $P = 0.114$).

Examination of sweep sample collections showed that pests were more abundant in the weeds than in the native perennial grass stands in spring ($t_{317} = -6.17$, $P < 0.0001$ Bonferroni), summer ($t_{317} = -13.20$, $P < 0.0001$ Bonferroni) and fall

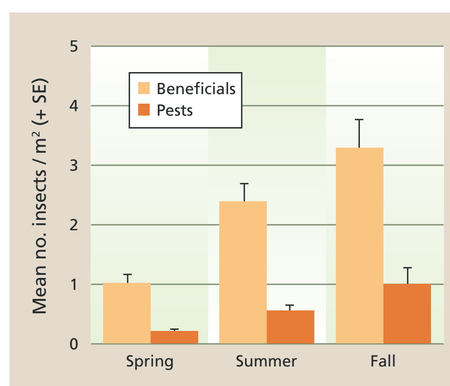

Fig. 2. Mean number of beneficial and pest insects per square meter collected over two growing seasons on six shrub species in four hedgerows, Yolo County. *P* values for differences between beneficial and pest insect abundance were < 0.0001 in all three seasons.

In this study, hedgerows enhanced the ratio of beneficial to pest insects compared with weedy areas. Plantings at Sierra Orchards in Solano County include deer grass, California lilac and elderberry. *Inset left to right,* the beneficial insects identified included lady beetles, syrphid flies and their larvae (feeding on aphids).

($t_{317} = -5.32$, $P < 0.0001$ Bonferroni; fig. 3). Beneficial insect abundance increased on weeds during summer but not to the same extent as the pest insects. In summer, the grasses dried and few insects were found.

Across seasons ($\chi^2_1 = 384.11$, $P < 0.0001$) and within each season, there was a greater proportion of beneficial to total (beneficial plus pest) insects in shrubs than in weeds, with grasses having a proportion of beneficial to pest insects intermediate to shrubs and weeds (fig. 4).

Growing interest in hedgerows

Our results show that field edge plantings of native California shrubs and perennial grasses can enhance beneficial insect abundance. The enhancement of beneficial insects may occur in several ways. First, most beneficial insects require or benefit from nectar or pollen sources from flowering plants that hedgerows provide, helping them survive and reproduce, especially during times of prey scarcity (Bugg et al. 1998). This was apparent in our study; beneficial insect abundance was greatest on shrubs during bloom, suggesting that insects were using floral resources. Second, hedgerows provide some beneficial insects with alternative prey or hosts, which may also be most important during wintertime (Corbett and Rosenheim 1996). Third, hedgerows provide beneficial insects with overwintering habitat, which is important when neighboring fields are cultivated and fallow for the winter, and there are few other refuges (Dennis et al. 1994).

Our study provides evidence that hedgerow plantings can enhance ratios of beneficial to pest insects compared with weedy areas, where pests were found in significantly greater abundance than beneficial insects. The extent to which this enhanced abundance of beneficial insects in hedgerows will improve biological pest control in adjacent crops is largely unknown. Previous research showed that beneficial insects used floral resources provided by hedgerows and moved into adjacent crops (Long et al. 1998). In a review of natural pest control, 74% of cases studied showed that landscapes with high proportions of noncrop habitat had enhanced natural enemy populations in crop fields (Bianchi et al. 2006). Further, eliminating edge weeds (by mowing or spraying) or replacing them with managed vegetation such as native perennial grasses has led to reduced pest pressure in adjacent crops (Ehler 2000; Mueller et al. 2005; Pease and Zalom 2010).

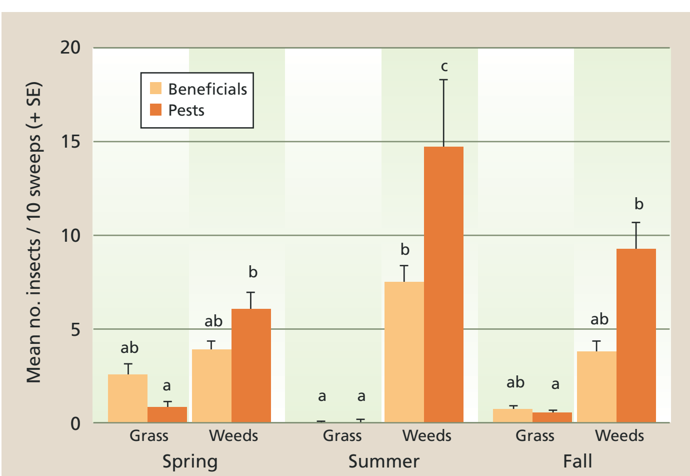

Fig. 3. Mean number of beneficial and pest insects per 10 sweeps in four native perennial grass stands and adjacent weedy areas, collected over two growing seasons, Yolo County. Different letters above bars indicate differences in beneficial and pest abundance within each season ($P < 0.05$).

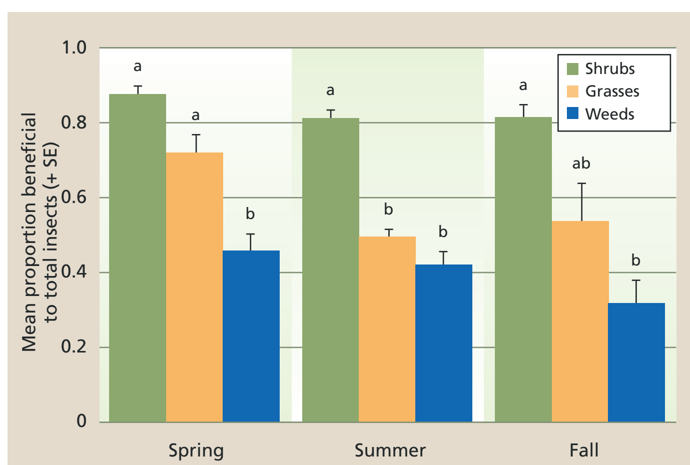

Fig. 4. Mean proportion of beneficial to total (beneficial plus pest) insects in native shrubs and grasses in four hedgerows and adjacent weedy areas, collected over two growing seasons, Yolo County. Different letters above bars indicate significantly different values within seasons ($P < 0.05$).

Compared with weedy areas, hedgerows did not increase populations of insects such as redshouldered, consperse and southern green stink bugs, pests of tomatoes and other crops.

Current studies are examining insect populations in crops adjacent to hedgerows and weedy field edges, such as, *above*, black mustard near an agricultural field.

For improved biocontrol through hedgerow plantings on farms, it is important that plants enhance beneficial insects without increasing pest populations (Fiedler and Landis 2007). In our study, the native shrubs and perennial grasses, though used by pests, were not as preferred as the weeds were, as noted by the significantly greater proportion of beneficial insects compared with pests in the hedgerow plantings. Although California buckwheat attracted Lygus bugs during summer and coyote brush attracted spotted cucumber beetles during fall, beneficial insect abundance was far greater than pests on those plants.

As noted earlier, one of the impediments to growers adopting hedgerows is the concern that they will harbor and enhance pest insect populations in adjacent crops. Our data show that hedgerow plantings can sustain or enhance beneficial insects and serve as replacement vegetation for weedy field edges, which harbor pests.

Recently, more hedgerows have been adopted in the Sacramento Valley. In our current studies, we are standardizing the crop adjacent to hedgerows and examining insect populations and pest control in the crop. These studies will address the question of whether hedgerows are concentrating existing populations of beneficial insects or whether they are increasing beneficial populations for enhanced pest control in adjacent crops. The study reported here and our current evaluations of the economic benefits of hedgerows on pest control may lead to the wider adoption of hedgerow plantings on farms, helping to enhance the many ecosystem service benefits they provide in agricultural landscapes.

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References

Bianchi F, Booij CJH, Tscharntke T. 2006. Sustainable pest regulation in agricultural landscapes: A review on landscape composition, biodiversity and natural pest control. In: Proc Royal Soc B-Biologic Sci 273:1715–27.

Brodt S, Klonsky K, Jackson L, et al. 2009. Factors affecting adoption of hedgerows and other biodiversity-enhancing features on farms in California, USA. Agroforest Syst 76(1):195–206.

Bugg RL, Anderson JH, Thomsen CD, Chandler J. 1998. Farmscaping in California: Hedgerows, roadside plantings and wild plants for biointensive pest management. In: Pickett CH, Bugg RL (eds.). *Enhancing Biological Control: Habitat Management to Promote Natural Enemies of Agricultural Pests*. Berkeley, CA: UC Pr. p 339–74.

[CAFF] Community Alliance with Family Farmers. 2004. Hedgerows for California Agriculture: A Resource Guide. caff.org/programs/bio-ag/hedgerows/. 70 p.

Corbett A, Rosenheim JA. 1996. Impact of a natural enemy overwintering refuge and its interaction with the surrounding landscape. Ecol Entomol 21:155–64.

Dennis P, Thomas MB, Sotherton NW. 1994. Structural features of field boundaries which influence the overwintering densities of beneficial arthropod predators. J Appl Ecol 31:361–70.

Ehler LE. 2000. *Farmscape Ecology of Stink Bugs in Northern California*. Lanham, MD: Entomol Soc Am. 59 p.

Fiedler AK, Landis DA. 2007. Plant characteristics associated with natural enemy abundance at Michigan native plants. Environ Entomol 36:878–86.

Griffiths GJK, Winder L, Holland JM, Thomas CFG. 2007. The representation and functional composition of carabid and staphylinid beetles in different field boundary types at a farm-scale. Biol Conserv 135:145–52.

Hannon LE, Sisk TD. 2009. Hedgerows in an agri-natural landscape: Potential habitat value for native bees. Biol Conserv 142:2140–54.

Hopwood JL. 2008. The contribution of roadside grassland restorations to native bee conservation. Biol Conserv 141:2632–40.

Kleijn D, Baquero RA, Clough Y, et al. 2006. Mixed biodiversity benefits of agri-environment schemes in five European countries. Ecol Lett 9:243–54.

Kort J, Collins M, Ditsch D. 1998. A review of soil erosion potential associated with biomass crops. Biomass Bioenerg 14:351–9.

Long RF, Anderson J. 2010. Establishing Hedgerows on Field Crop Farms in California's Central Valley. UC ANR Pub 8390. Oakland, CA. 7 p.

Long RF, Corbett A, Lamb C, et al. 1998. Beneficial insects move from flowering plants to nearby crops. Cal Ag 52(5):23–6.

Mueller SC, Summers CG, Goodell PB. 2005. Composition of Lygus species found in selected agronomic crops and weeds in the San Joaquin Valley, California. Southwest Entomol 30:121–7.

Pease CG, Zalom FG. 2010. Influence of non-crop plants on stink bug (Hemiptera: Pentatomidae) and natural enemy abundance in tomatoes. J Appl Entomol 134:626–36.

SAS. 1999. *SAS System for Windows*. SAS Institute, Cary, NC.

Smith J, Potts SG, Woodcock BA, Eggleton P. 2008. Can arable field margins be managed to enhance their biodiversity, conservation and functional value for soil macrofauna? J Appl Ecol 45:269–78.

Thomas CFG, Marshall EJP. 1999. Arthropod abundance and diversity in differently vegetated margins of arable fields. Agr Ecosyst Environ 72:131–44.

[UC IPM] University of California Integrated Pest Management. 2006. www.ipm.ucdavis.edu/PMG/r1900311.html.

Water sensors with cellular system eliminate tail water drainage in alfalfa irrigation

by Rajat Saha, Narendra S. Raghuwanshi, Shrinivasa K. Upadhyaya, Wesley W. Wallender *and* David C. Slaughter

Alfalfa is the largest consumer of water among all crops in California. It is generally flood-irrigated, so any system that decreases runoff can improve irrigation efficiency and conserve water. To more accurately manage the water flow at the tail (bottom) end of the field in surface-irrigated alfalfa crops, we developed a system that consists of wetting-front sensors, a cellular communication system and a water advance model. This system detects the wetting front, determines its advance rate and generates a cell-phone alert to the irrigator when the water supply needs to be cut off, so that tail water drainage is minimized. To test its feasibility, we conducted field tests during the 2008 and 2009 alfalfa growing seasons. The field experiments successfully validated the methodology, producing zero tail water drainage.

To irrigate alfalfa, water is pumped in at the top of rows and flows down to the end. If the flow is not turned off before it reaches the bottom, substantial runoff can result. A system utilizing water sensors and cellular communications can help irrigators to minimize such runoff.

Alfalfa is a major crop in the western United States, cultivated on 1.1 million acres in California, and it is the largest water user of all the state's crops. It accounts for nearly 20% to 27% of California's irrigation water use (Hanson and Putnam 2000). Alfalfa (*Medicago sativa* L.) is predominantly flood irrigated (Schwankl and Prichard 2003), with or without cutting off or "checking" the flow before water reaches the bottom of a row. In these systems, the alfalfa field is divided into bays, which are separated by parallel ridges or borders. Water flows down the field's slope as a sheet guided by the ridges. On steeply sloping lands, the ridges are more closely spaced and may be curved to follow the land's contours.

The check technique is often inefficient in terms of water use and management, because water often runs off at the end of the row. Efficiency can be improved if the water is cut off at the right time, before it reaches the bottom end of the field. The wetting front (the front trajectory of the moving water) then advances to the end of the field, but runoff is minimized, conserving water and improving application efficiency.

Under current practice, the alfalfa irrigator makes several trips to the field to determine when the wetting front has reached a certain distance from the tail (bottom) end of the check before turning off the irrigation. Even making several trips, the irrigator may miss the wetting-front advance, which results in excessive tail water drainage.

Our research sought to develop an efficient alternative irrigation method. We investigated a wetting-front advance sensor with a cellular communication system, to detect the arrival of the water at a predetermined location and eliminate the need for several trips to the field. However, reducing tail water drainage and improving efficiency would still depend on the irrigator's judgment of the cutoff distance (how far the water was from the bottom of the field). Cutoff distance and time can be precisely determined using a volume balance model. (This model equates the sum of the volumes of surface water [SW] and infiltrated water [IW] to total applied water [TAW]. Assuming a constant volume of infiltration per unit length of the border and a constant inflow rate, the volume balance is TAW = SW + IW). With this model, irrigation system characteristics (inflow, length, slope and surface roughness) and soil infiltration must be known. In general, irrigation system characteristics are known or can be obtained easily, but infiltration characteristics are not known without taking field measurements. As a result, available surface irrigation models, which do not consider local soil infiltration characteristics, cannot be used to determine accurate cutoff times for managing check irrigation. The alternative we considered was to evaluate infiltration parameters using real-time information on the wetting front's advance provided by sensors in the field.

Upadhyaya and Raghuwanshi (1999) characterized furrow infiltration by the Horton infiltration function and

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represented the trajectory of the wetting front's advance by an empirical exponential function. A decade later, Saha et al. (2009) published details of a modified Horton infiltration equation that could accurately model the field-observed wetting-front advance in a check-irrigated system. It seemed possible then to accurately determine irrigation cutoff times by combining a wetting-front sensing system with the water advance model. Our research tested the feasibility of this approach in alfalfa field trials during the 2008 and 2009 growing seasons. Our objectives were (1) to develop and evaluate wetting-front sensors that incorporate a cellular communication system and (2) to develop a water advance model for managing cutoff irrigation in check-irrigated alfalfa.

Designing a sensing system

Water sensor. The task was to develop a sensor that recognized the presence of water within a check. Our idea was to use two separated metal electrode terminals, between which an electrical circuit would close when water arrived; sudden changes in resistance or voltage at the terminals would then be transmitted to a data logger. When we talked to local growers, we were advised to develop a sensor that would not interfere with cultural operations such as harvesting, so we designed one that would be buried less than 2 inches below the soil surface.

We investigated several designs. The most reliable sensor consisted of two conductive terminals with a fine wire mesh surrounding them, enclosed by plastic plates (fig. 1). The diameter of the plates is about 3 inches, and the gap between the two terminals is about 1 inch. To facilitate drainage, the unit was surrounded by gravel and sand and placed in a plastic container with a hole at the bottom. The jacket of gravel and sand also helped to avoid clogging the sensor with fine-textured soil. The wire leads were about 6 inches long and extended beyond the sensor jacket, making it easy to connect the sensor to a data acquisition system.

To be sure of the sensor's responsiveness, we performed laboratory tests and recorded the change in resistance under dry and wet conditions. These tests revealed that the sensor resistance was high (about 3,000 micro-ohm [mohm]) when there was no water inside the sensor units (dry) and low (around 700 mohm) when the units were filled with water (wet).

Suitable circuitry was designed to interface the sensors to the data logger (Model CR 3000; Campbell Scientific, Logan, UT). The data logger was programmed to record sensor responses and the time in Julian day, hour, minute and seconds.

Cellular communication system. Several components supported the cellular communication system (fig. 2). The data logger monitored the wetting-front sensors at regular time intervals (every 5 seconds). When the resistance between terminals of a particular sensor dropped from high to low, the data logger generated an alert message consisting of the check number, sensor number and water arrival time.

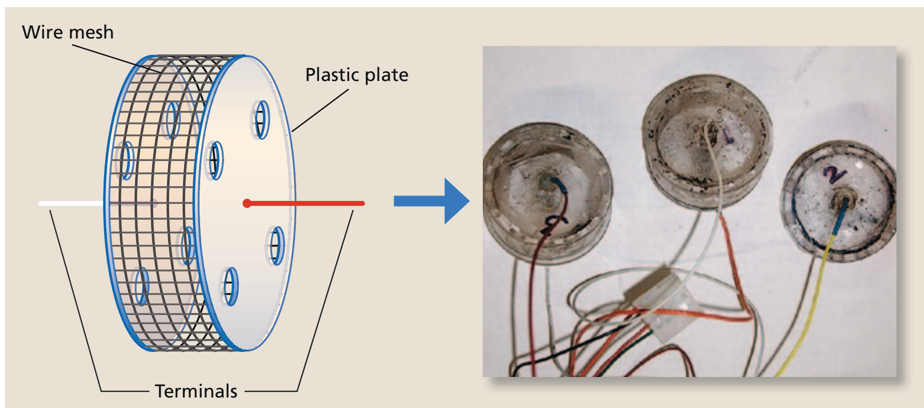
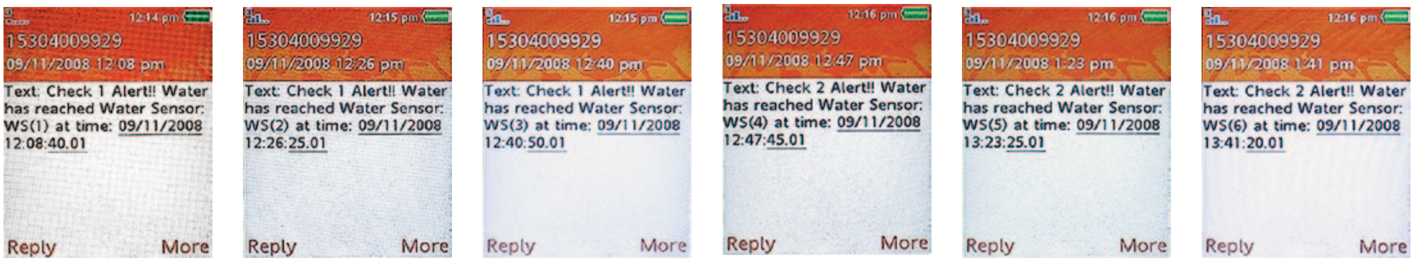


Fig. 1. The water-arrival, or wetting-front, sensor.

Fig. 2. The cellular communication system contains: (A) wetting-front sensors, (B) central module/ data logger, (C) digital cellular modem, (D) cellular antenna and (E) cell phone.

The wetting-front sensor consists of a plastic container surrounded by a gravel and sand jacket.



Cellular text alert messages were received as a wetting front reached different sensors during an irrigation on Sept. 11, 2008.

To transmit this message to the irrigator, the data logger was interfaced with a GPRS (General Packet Radio Service) or EDGE (Enhanced Data rates for GSM Evolution) digital cellular modem (Raven 110; Campbell Scientific). The modem, a full-duplex Airlink product compatible with AT&T digital cellular networks, transmitted the alert to the local cellular tower with an 800 MHz 1 dBd Omni cellular antenna, using either the GPRS or EDGE network. The data string was then sent from the tower to the designated cellular phones of the irrigators in the form of text alerts.

Water advance model

Saha (2010) showed that the wetting-front advance can be modeled by the following relationship, based on the modified Horton infiltration function:

$$A = A_{max}\,(1-e^{-ct}) \quad (1)$$

where A is the wetted area (square feet) of the alfalfa check; $A_{max} = \frac{q}{i_f}$ is the maximum area (square feet) that can be irrigated with a steady inflow rate, q (cubic feet per minute); i_f is the final infiltration rate (feet per minute); t is the elapsed time (minutes) since the beginning of irrigation; c is given by $\left(\frac{i_f}{I_i + h_0}\right)$; I_i is the magnitude of initial infiltration (feet); and h_0 is the average depth of water (feet) above the soil surface during an irrigation event. Note that h_0 could be found by multiplying the depth of water at the inlet (for example, h_i) by a surface shape factor (for example, σ_0), such that $h_0 = h_i \sigma_0$. While the values of σ_0 range from 0.77 to 0.80 for surface irrigation hydraulics, a value of 0.80 is commonly used for level surfaces (Guardo 1988).

In surface irrigation, particularly of Yolo silt loam or clayey soils, infiltration is often characterized using the Kostiakov equation, which does not include the steady state infiltration term i_f (Colla et al. 2000; Holzapfel et al. 2004). Therefore, in the present study, if we neglect i_f (i.e., c is negligible), the velocity (v) becomes constant and can be shown to be (Saha 2010):

$$v = \frac{q}{2w\,(I_i + h_0)} \quad (2)$$

Field tests conducted during our investigations have indicated that this assumption of $i_f = 0$ is reasonable. The error introduced due to this assumption in water-arrival time at the field end was always less than 15 minutes. Equation 2 can be solved for the magnitude of initial infiltration I_i once the wetting-front velocity is known from sensor recordings, since inflow rate (q), check width (w) and average depth of water (h_0) are known or measured values. This value of I_i can be substituted in equation 3 to obtain irrigation water cutoff time (t_0):

$$t_0 = \frac{2wY_L\,(I_i + h_L)}{q} \quad (3)$$

where t_0 is the time (minutes) at which water is to be turned off following its arrival at the sensor, Y_L is the distance (feet) to the tail end of the check from the sensor location and h_L is the height of water (feet) when the wetting front arrives at the tail end. Note that the irrigator selects a value of h_L based on an acceptable amount of drainage.

Alfalfa field studies

To test the wetting-front sensing system and related water advance model that we developed (see box), we conducted experiments in a conventional flood-irrigated alfalfa field of Yolo silt loam soil on the UC Davis campus. The field contained 48 alfalfa checks, out of which four checks (A, B, C and D) were selected (fig. 3). Each check was approximately 720 feet (220 meters) long and 50 feet (15 meters) wide, with a slope of 0.01%. Checks on the field edges were excluded to avoid edge effects. The two checks adjacent to our test checks were separated by slightly raised (around 4-inch [10-centimeter]) ridges. To monitor the advance rate of the wetting front, three sensors were placed in each check along the direction of flow. The distance between two adjacent sensors was 25 feet (about 8 meters). Apart from the sensors, six flags were also placed in each check (fig. 3), to allow manual monitoring of the water advance rate during irrigation and comparison with the sensor results. These monitoring locations help in capturing the shape (front trajectory) of the wetting front as well as determine its velocity.

In the control checks, which received conventional flood irrigation, water was allowed to reach the end of the check before the source valve was turned off; in these four cutoff trial checks, water was cut off at a distance predicted by the water advance model, assuming a tail water height of 2 inches (5 centimeters). Seven sets of irrigation were performed during the 2008 growing season between May and October (May 23–24, June 5–6, June 26, Aug. 4–5, Aug. 19–20, Sept. 11–12 and Sept. 25–26). Since one inflow valve irrigated two side-by-side checks (either A and B, or C and D) during an irrigation (fig. 3), only one of the two was monitored for ease of operation. For example, on May 28, 2008, checks A and B were both irrigated, but only check A was monitored. During each irrigation set, the check to be monitored was selected randomly. Similarly, two sets of irrigations were performed during the 2009 season (Sept. 12–13 and Sept. 28–29); in the Sept. 12, 2009, irrigation, both the side-by-side checks were monitored.

During all of them, inflow was monitored with a portable Doppler flow meter (PDFM 4.0; Greyline, Massena, NY), and drainage was recorded with an area velocity flow meter (AVFM II; Greyline). The time of water arrival at each designated location was recorded either manually (from flag positions) or with a CR 3000 data logger (from sensor positions). In this setup, a CR 3000 data logger can monitor up to six buried sensors — two checks — simultaneously.

System assessment

The cellular communication system, designed to generate text alerts when the wetting front reaches individual sensors, worked well. The communication lag time was less than 5 seconds for all irrigations.

The wetting-front arrival time was monitored manually for all nine locations (six flags plus three sensors) in each check. The velocity of the wetting front between two consecutive monitoring locations along the flow was determined by dividing the distance between them by the time difference in water arrival at these locations. We plotted the observed versus sensor-predicted wetting-front velocity for all the tests (fig. 4A). The very high R^2 value (coefficient of determination) of about 0.94 between the observed (based on nine monitoring points in each check) and sensor-predicted (based on three sensor points in each check) velocities suggests accurate prediction by the wetting-front sensors when they were placed 25 feet (about 8 meters) apart.

The experimental data was analyzed using the water advance model to obtain initial infiltration (I_i) based on the measured values of wetting-front advance

The wireless system can easily be moved from one location to another, reducing the initial investment necessary to implement the system.

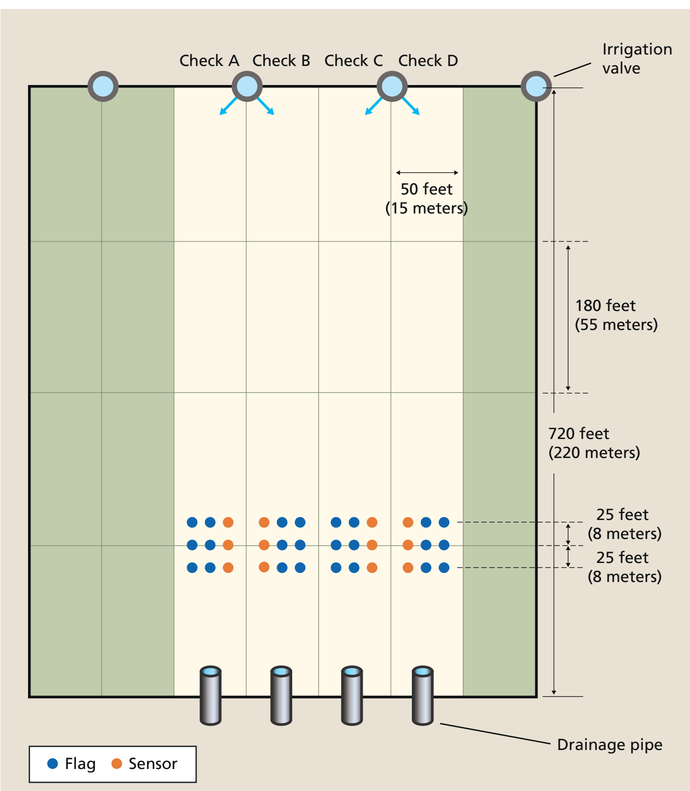


Fig. 3. Layout of experimental plots, including placement of wetting-front sensors (orange) and flags used to verify sensor-measured velocities (blue). The horizontal lines divide the fields (720 feet) into quarters (180 feet). The sensors were placed at the three-quarter point, where the water front's velocity is steady.

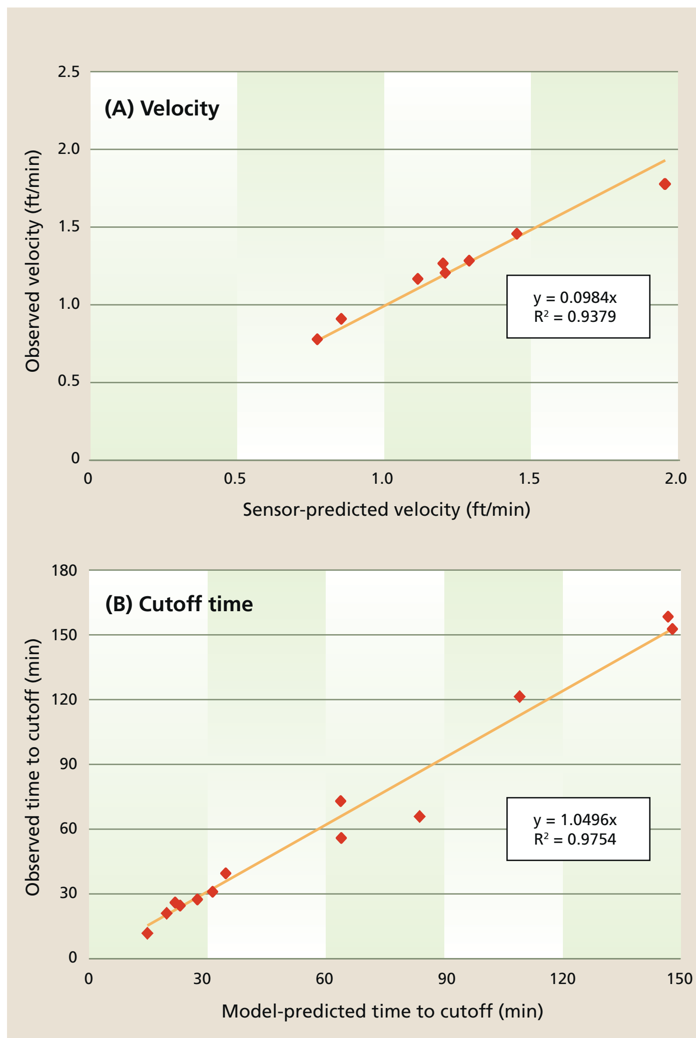


Fig. 4. Comparison between (A) observed and sensor-predicted wetting-front advance velocities and (B) observed and model-predicted times for the wetting front to reach the cutoff.

velocity obtained from the sensors, inflow rate and average water depth (surface storage). This information was used to estimate the cutoff time and the location of the wetting front at the cutoff time. We compared the observed and model-predicted times for the wetting front to reach the cutoff point for all 2008 and 2009 irrigations (fig. 4B).

The very high R^2 (> 0.97) and a slope that is close to 1.0 (i.e., slope of 1.05 indicates an error of about 5%) between the observed and predicted times reconfirms that the cutoff irrigation system developed in this study is reliable.

Furthermore, the conventional flood irrigation resulted in a substantial volume of drainage water loss, between about 5,800 and 10,000 liters per irrigation, whereas our cutoff irrigation system resulted in zero tail water drainage for all irrigations (table 1). (The drainage pipe was placed at a height equal to the allowable height of water at the tail.)

After successful testing of the system (with three sensors per check), local growers were asked for their impressions. They indicated a strong preference for a wireless system, since rodents often chew wires in the field and installing the sensors requires additional field operations (although the sensors can be left in the field for several years). In response, we developed a completely wireless system. The single sensor communicates with a central module wirelessly when it senses the wetting front (fig. 5). The central module can monitor up to 99 wireless wetting-front sensing devices within a 2-mile radius and generate a cell-phone message to the irrigator when water arrives in a specific check at the desired location. The text message is generated in the same way as in the earlier system, and the wireless system works reliably.

TABLE 1. Observed and sensor-predicted velocities, predicted wetting-front arrival times and drainage from checks in irrigated alfalfa fields, 2008 and 2009

2008

Date	May 23	May 24	June 5	June 6	June 26	Aug 4	Aug 5	Aug 19	Aug 20	Sept 11	Sept 12	Sept 25	Sept 26
Check monitored	A	C	D	B	B	A	C	D	B	B	D	C	A
Irrigation type	Conventional	Conventional	Conventional	Conventional	Cutoff	Cutoff	Cutoff	Cutoff	Cutoff	Cutoff	Cutoff	Cutoff	Cutoff
Irrigation start time	7:11	7:04	7:17	7:00	7:20	7:55	7:03	7:07	7:03	7:20	7:14	7:15	7:12
Average inflow (liters per minute)	927	846	952	980	851	866	860	903	898	937	923	840	815
Sensor-predicted velocity (feet per minute)	1.43	1.43	1.19	0.88	0.83	1.45	1.29	1.21	1.11	0.85	1.20	1.96	0.78
Observed velocity (feet per minute)	1.08	1.10	1.07	0.98	0.94	1.45	1.28	1.20	1.17	0.91	1.26	1.77	0.77
Time water reaches last set of sensors	13:14	12:28	11:58	12:06	13:43	12:30	12:59	12:40	11:56	13:36	12:36	11:06	14:04
Distance still to travel before reaching cutoff (feet)	NA	NA	NA	NA	101	50	25	26	17	132	80	41	113
Predicted time for water to reach cutoff	NA	NA	NA	NA	15:31	13:04	13:20	13:02	12:11	16:01	13:39	11:29	16:30
Observed time for water to reach cutoff	NA	NA	NA	NA	15:45	13:10	13:22	13:06	12:08	16:15	13:32	11:31	16:37
Irrigation end time	16:05	14:57	14:37	14:13	15:45	13:10	13:22	13:06	12:08	16:15	13:32	11:31	16:37
Observed time of reaching check end	16:05	14:57	14:37	14:13	16:46	14:37	15:28	15:08	14:05	16:37	14:37	12:35	17:42
Total drainage (liters)	7,252.0	9,975.5	6,709.1	5,842.1	0	0	0	0	0	0	0	0	0

2009

Date	Sept 12	Sept 12	Sept 13	Sept 28	Sept 29
Check monitored	C	D	A	A	C
Irrigation type	Cutoff	Conventional	Cutoff	Cutoff	Cutoff
Irrigation start time	7:15	7:15	7:35	7:30	7:27
Average inflow (liters per minute)	1,392	1,389	975	1,032	1,300
Sensor-predicted velocity (feet per minute)	0.82	0.84	0.84	1.56	1.74
Time water reaches last set of sensors	13:15	13:16	13:56	12:33	11:46
Distance still to travel before reaching cutoff (feet)	85	NA	100	112	54
Predicted time for water to reach cutoff	14:38	NA	14:59	13:00	12:17
Observed time for water to reach cutoff	14:21	NA	15:09	13:01	12:17
Irrigation end time	14:39	14:38	15:09	13:01	12:17
Observed time of reaching check end	16:23	14:38	16:23	15:11	12:50
Total drainage (liters)	0	6,520	0	0	0

Ready for installation

The model-based cutoff irrigation system developed in this study can minimize drainage water loss from surface-irrigated alfalfa fields and substantially improve water management. It was successfully demonstrated to dozens of farmers at the Alfalfa Field Day sponsored by UC Cooperative Extension on May 19, 2010, at the UC Davis Agronomy Field Headquarters. Our sensor and cellular communication–based cutoff irrigation system is still under development and is not currently being used in California alfalfa fields; it may be commercially available by early 2012.

The wetting-front sensors are inexpensive, about $25 per unit. The central module costs about $500 and the modem about $200, for a total of between $800 and $1,000. Moreover, the wireless system can easily be moved from one location to another, reducing the initial investment necessary to implement the system. With the typical five irrigations per alfalfa season, water savings could be about 35,000 to 60,000 liters per acre.

Although the experimental system described eliminates guesswork and minimizes tail water drainage, a simpler system, with one sensor per check, may be attractive to some growers as a starting point. This system would alert the irrigator when the wetting front arrives at the single sensor. However, the efficacy of the system in minimizing tail water runoff would entirely depend on the irrigator's judgment on placement of the sensor within the check.

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References

Colla G, Mitchell JP, Joyce BA, et al. 2000. Soil physical properties and tomato yield and quality in alternative cropping systems. Agron J 92:924–32.

Guardo M. 1988. Kinematic Model for Designing Level Basins. Doctoral dissertation, Colorado State University, Fort Collins, CO.

Hanson B, Putnam D. 2000. Can alfalfa be produced with less water? In: Proc California Alfalfa Symposium. Dec. 11–12, 2000, Las Vegas, NV. p 43–54.

Holzapfel EA, Jara J, Zuniga C, et al. 2004. Infiltration parameters for furrow irrigation. Ag Water Manage 68:19–32.

Saha R. 2010. An Investigation of Surface and Subsurface Flow Characteristics During an Alfalfa Irrigation Event. Doctoral dissertation, Department of Biological and Agricultural Engineering, UC Davis, CA.

Saha R, Upadhyaya SK, Wallender WW. 2009. Modified Horton's equation to model advance trajectory in furrow irrigation systems. J Irrig Drain Eng ASCE 136(4):248–53.

Schwankl L, Prichard T. 2003. Improving irrigation water management of alfalfa. In: Proc California Alfalfa and Forage Symposium, Dec. 17–19, 2003. Monterey, CA.

Upadhyaya SK, Raghuwanshi NS. 1999. Semiempirical infiltration equation for furrow irrigation systems. J Irrig Drain Eng ASCE 125(4):173–8.

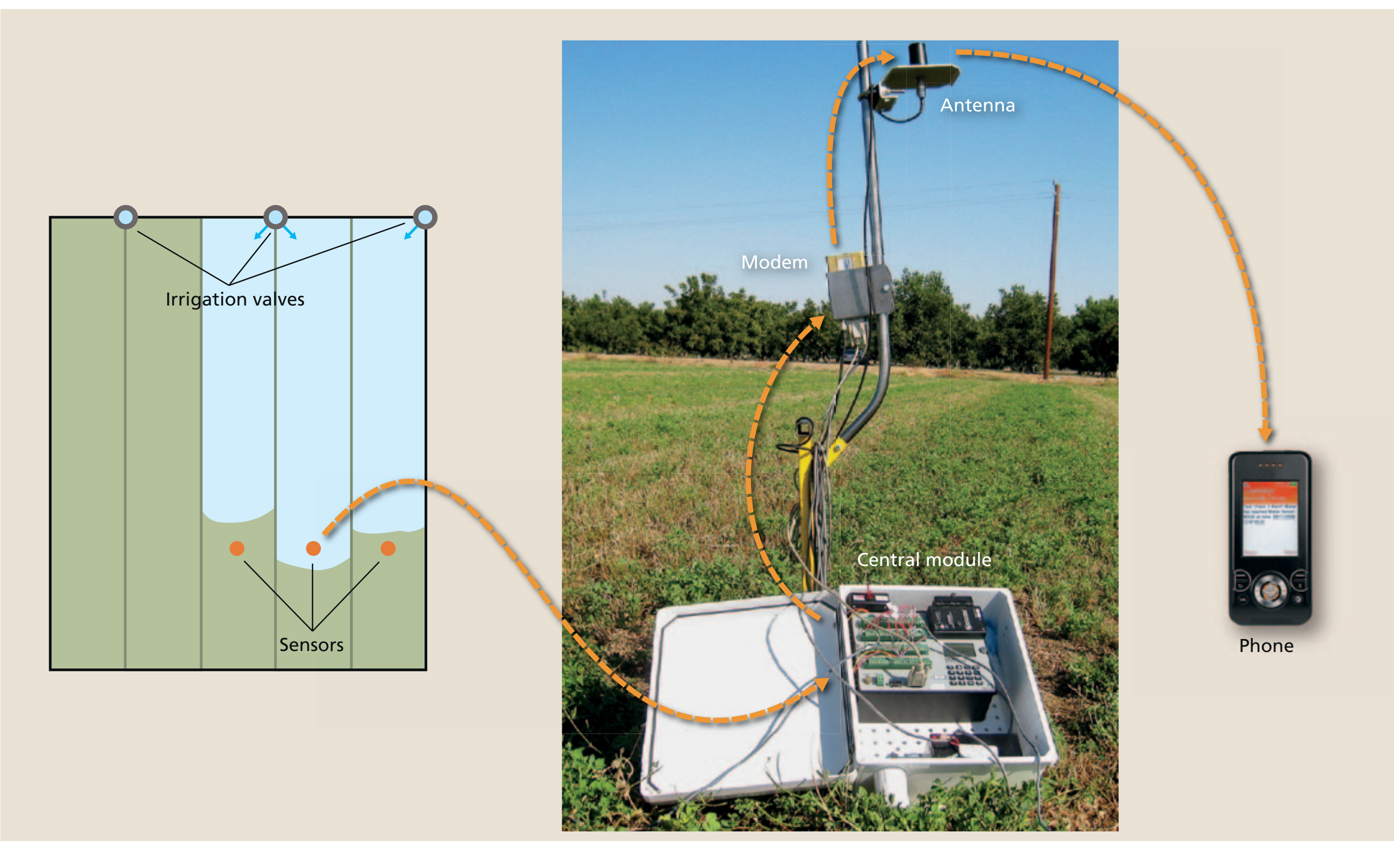

Fig. 5. The cellular communication system, with single wireless sensors. The portable sensor pole can easily be removed during alfalfa field operations.

RESEARCH ARTICLE ABSTRACT

Totally impermeable film retains fumigants, allowing lower application rates in strawberry

by Steven A. Fennimore *and* Husein A. Ajwa

The California strawberry industry is highly dependent on soil fumigation to control soil pests and maintain high productivity. Plastic films are used to hold fumigants in the soil at the doses needed to control pests and to prevent the loss of fumigant. Totally impermeable film (TIF) was compared to standard film (STD) for the retention of soil fumigants. 1,3-dichloropropene plus chloropicrin concentrations under TIF were 46% to 54% higher than under standard film, and higher fumigant concentrations under TIF were correlated with higher strawberry fruit yields and better weed control. The results suggest that to achieve fruit yield and weed control similar to methyl bromide and chloropicrin, 33% less 1,3-dichloropropene plus chloropicrin is needed under TIF than standard films.

About 80% of California strawberry fields, such as these in Santa Maria, are treated with soil fumigants prior to planting. Plastic tarps are applied to prevent leakage of the fumigants.

The California strawberry industry produces about 85% of the strawberries grown in the United States, on 37,000 acres, with a value of $1.5 billion in 2008 (ERS 2009). To control soilborne diseases and weeds, California strawberry fields have long been fumigated with methyl bromide (MB) plus chloropicrin (Pic). However, methyl bromide is being phased out as an ozone-depleting substance under the Montreal Protocol (USDS 2009), an international treaty. Currently, some California strawberries can still be treated with methyl bromide under a critical-use exemption, subject to annual review by parties to the Montreal Protocol.

Alternative fumigants permitted for use in California strawberries are 1,3-dichloropropene (1,3-D), chloropicrin and, as of December 2010, methyl iodide. About 81% of California strawberries are grown in soils that were previously treated with chloropicrin (Pic), while 30% are also fumigated with 1,3-D and 43% with methyl bromide (CDPR 2008).

Since soil treatments began in the 1960s, entire fields have been covered with polyethylene film to hold in the fumigant at concentrations needed to kill soil pests (called "flat fumigation") (Wilhelm and Paulus 1980). More recently, a sizable portion (45% to 55%) of strawberry acreage has been treated with fumigants applied to beds via the drip irrigation system (Ajwa et al. 2002; USDS 2009).

The major alternatives to methyl bromide, 1,3-D and chloropicrin, are heavily regulated. The transition away from methyl bromide to alternatives has been complicated by regulations aimed at protecting workers and others from exposure to fumigants. In California, 1,3-D use per 36-square-mile township is limited to 90,250 pounds, called a "township cap," which severely limits its availability in key strawberry production areas (Carpenter et al. 2001). The recent critical-use nomination for strawberry (allowing methyl bromide use) indicates that "township caps currently limit the use of 1,3-D on 40% to 62% of total strawberry land" (USDS 2009). In other words, methyl bromide use continues in California because restrictions on alternative fumigants leave few options.

Among the reasons that fumigants are so heavily regulated in California is that they are classified as volatile organic compounds (VOCs). Alternative fumigants such as 1,3-D are released into the air and, after reacting with nitrogen oxides, can convert to form ground-level ozone — a harmful air pollutant (Gao 2009; Segawa 2008). Regulations have been developed to reduce the contribution of fumigants to ozone formation, which, for example, has seriously affected the use of fumigants in Ventura County, a key strawberry production area.

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Transgenic rice evaluated for risks to marketability

by Dustin R. Mulvaney, Timothy J. Krupnik *and* Kaden B. Koffler

The California Rice Certification Act mandates specific planting and handling protocols for rice varieties, including transgenic rice, that may pose economic risks to California rice growers. Based on a literature review and extensive interviews, we describe this policy's evolution as a system for identity preservation and explain how it shapes the potential commercialization of transgenic rice. Several studies suggest that transgenic rice would be profitable for California growers, but the challenges in assuring 100% identity preservation — especially when access to export markets is at risk — means that the commercial approval of transgenic rice in California is unlikely until there is widespread market acceptance and growers are assured of no sales interruptions.

Herbicide-tolerant rice has been developed to help farmers with costly weed problems. *Above,* Colusa County rice with at least three severe weed species.

Ten years after the first regulatory approval of genetically engineered, or transgenic, rice in the United States, none is grown commercially. This contrasts with high adoption rates for transgenic soy (93%), corn (70%) and cotton (78%) (ERS 2010). The trend is similar globally: the transgenic rice closest to market is 'Xianyou 63', an insect-resistant (Bt, *Bacillus thuringiensis*) variety that was approved by China in 2009 and is expected to be available by 2012 (James 2009). Some experts contend that commercialization in China will usher in a wave of transgenic rice approvals and adoption (Serapio 2010), which could have implications for the California rice industry.

We review the economic benefits and risks from transgenic rice and explain how market concerns shape California growers' perceptions of transgenic rice. Several studies suggest that transgenic rice would benefit California rice growers — particularly herbicide-tolerant varieties to help manage weeds (Annou et al. 2000; Bond et al. 2005). However, transgenic rice also presents economic risks to California rice growers, who rely on exports for half of their sales. Buyers could refuse to purchase stocks contaminated by transgenic rice, impose costly testing requirements or shut down markets permanently.

In 2001, UC Cooperative Extension surveyed 213 California rice growers, and 37% stated that if herbicide-tolerant rice were available they would not plant it. A subgroup of 78% suggested that this was due to "market concerns" (UCCE 2001). California growers produce over 1,980 tons (1,800 metric tons) annually valued at over $200 million, and close to $500 million when government payments are factored in. Many rice growers rely on export markets; as much as 40% of California rice is sold to Japan annually (Fukuda et al. 2003). These export markets, however, are not entirely secure, and the U.S. Department of Agriculture's Economic Research Service (2001) has described U.S. involvement as "thin, volatile and risky" (see sidebar, page 163).

To manage risks to marketability, the California Rice Certification Act (CRCA) regulates rice with "characteristics of commercial impact," including transgenic rice. The CRCA relies on a risk management scheme called identity preservation (IP), which refers to "production, handling and marketing practices that maintain the integrity and purity of agricultural commodities" (Sundstrom et al. 2002). Many crops — such as cotton, where keeping varieties of different fiber consistently separate is critical to marketability — require identity preservation for quality control. Identity preservation is also used to manage "genetic pollution" risks from transgenic crops (Ellstrand 2006), particularly those not approved for human consumption or used to make pharmaceuticals (Marvier 2007). In these latter cases, identity preservation must be 100% effective.

To explore the CRCA's evolution and effectiveness, all published accounts were surveyed, including journals, reports, media coverage, industry newsletters and regulatory agency publications. Forty-eight semistructured interviews

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were conducted with key policymakers, scientists, activists and growers working on issues related to transgenic crops and the rice industry. Using snowball sampling methodology, interviewees provided new contacts until additional interviews yielded no new informants, and informants yielded no new pertinent information (Salganik and Heckathorn 2004). Interviews and follow-up conversations were conducted from 2004 to 2010 and included 14 UC and industry scientists, eight rice growers, six rice marketers, six activists and 18 policymakers. This approach captured the range of views expressed by key individuals, firms and public institutions.

Glossary

Adventitious presence: A low-level, inconsequential presence of unintended genetic materials (e.g., transgenic seed).

Breeder, foundation and certified seed: Crops grown to produce seeds for planting.

Coexistence: The dual production, distribution and marketing of transgenic and nontransgenic varieties, with an emphasis on keeping them separate.

Commingling: The inadvertent mixture of seed or grain products.

Containment: Using spatial, temporal or biological isolation to prevent gene flow by keeping biological materials inside a set boundary.

Gene flow: The movement and exchange of genetic traits or biological organisms from one population to another.

Genetically engineered, genetically modified or transgenic organism: An organism produced by combining DNA from different sources, either from within the organism's genome or from another organism.

Identity preservation (IP): Handling practices to ensure that a product can be traced to its genetic/biological source (seed) and production location (e.g., a specific agricultural field).

Precautionary principle: When the consequences of a proposed action are severe or irreversible, policy should err on the side of caution.

Potential transgenic rice benefits

Weeds strongly affect yields and profitability in California rice production. Weed management requires multiple herbicide applications, which can be costly. Growers can spend up to $200 per acre on herbicides (Bond et al. 2003). One proposed weed control strategy is herbicide-tolerant rice modified to contain genes resistant to broad-spectrum herbicides. Herbicide-tolerant rice allows herbicides to be sprayed shortly after seedlings emerge, when rice-weed competition is highest and the potential for weed-inflicted yield losses is greatest. Reducing weed density and biomass early gives herbicide-tolerant rice seedlings a competitive advantage for solar radiation, nutrients and water.

Herbicide-tolerant rice could simplify weed management because it requires just one herbicide, rather than multiple selective herbicides for specific weed biotypes. One study suggests that herbicide-tolerant rice could decrease herbicide requirements by up to 84% (Bond et al. 2005). This would reduce costs and provide environmental benefits by promoting alternatives to more toxic herbicides (Ueji and Inao 2001). After accounting for additional costs — including seed technology fees, identity preservation costs, short-term yield reductions and CRCA fees — such research suggests that herbicide-tolerant rice would be profitable for California growers (Bond et al. 2003).

However, important impacts are obscured when costs and benefits are analyzed without considering how the adoption of transgenic rice would affect the marketability of exported rice. These studies assume no change in marketability or prices, and that transgenic herbicide-tolerant rice would be broadly accepted. However, market rejection of exports could have severe economic repercussions, so profitability analyses will ultimately hinge on successfully containing risks.

LibertyLink contamination

In August 2006, the U.S. Food and Drug Administration announced that Bayer's long-grain LibertyLink transgenic rice (LL601) — not yet approved for human consumption — extensively commingled with long-grain 'Cheniere' rice and foundation seed grown in five southern U.S. states (FDA 2006). Over the ensuing months, major importers of U.S. rice — Japan, South Korea, Taiwan, Mexico, Russia and the European Union (EU) — banned or halted all imports of long-grain rice from the United States (Vermif 2006). The FDA retroactively approved LL601 for human consumption to reassure consumers that it was safe. But by that time, rice futures prices had fallen on the Chicago Board of Trade, and growers had entered into futures contracts at lower prices than anticipated (GAO 2008). University of Arkansas economists later confirmed a large and adverse (but short-lived) price drop (Li et al. 2010).

Another of Bayer's LibertyLink varieties (LL604) was later found in 'Clearfield 131' rice seed marketed by a competing seed company, BASF. It was recalled after USDA asked that it not be sold or distributed, costing BASF millions of dollars in seed sales (GAO 2008). These events prompted additional testing requirements in export markets, and significant resources were mobilized to remove LibertyLink rice from the seed supply. An industry executive estimated domestic impacts to growers between $80 million to $100 million (Cole 2006), while an attorney representing affected growers in a class-action lawsuit against Bayer estimated damages at $1 billion (GAO 2008).

The LibertyLink incidents did little to instill confidence that experimental field trials of transgenic crops could always be adequately contained.

Drawing on USDA data, the U.S. Rice Federation suggested that rice exports to the European Union fell 68% from 2005 to 2007 (Cummings 2009). EU importers who deliver U.S. rice to market were also affected, losing an estimated €52 million to €111 million in 2006 and 2007 (Brookes 2008). While USDA did not definitively identify the contamination source, a jury awarded a dozen growers a $48 million judgment against Bayer, which owned the LibertyLink varieties grown in experimental field trials from 1999 to 2001 at a research station in Louisiana. Bayer has lost six similar cases so far, and hundreds more are pending (Cronin Fisk and Whittington 2010).

Rice futures prices eventually recovered, as energy costs and commodity speculation drove bidding to record highs in 2008. But LibertyLink was detected in subsequent shipments, preventing marketers from taking advantage of high prices and effectively restricting U.S. ride trade with the European Union (GAO 2008). California rice growers were largely unaffected by the LibertyLink incident, because they primarily grow short- and medium-grain rice (table 1). Only one

TABLE 1. Regulatory status and field-test locations for Bayer's LibertyLink (LL) rice

Variety	Grain type	Federal regulatory status*	Calif. certification status†	Field-trial locations
LL62	Medium	Approved 1999	Approved for greenhouse trial in 2008	La. (2); Puerto Rico (2); Calif.
LL06	Medium	Approved 1999	Not approved	Calif. (10); Puerto Rico (2)
LL601	Long	Approved 2006‡	Not approved	Ark., Miss., Mo., Texas, La., Puerto Rico
LL604	Long	Not approved	Not approved	Ark., Miss., Mo., Texas, La., Puerto Rico

* Includes Food and Drug Adminstration, Environmental Protection Agency and U.S. Department of Agriculture Animal and Plant Health Inspection Service. Federal approval does not automatically entail approval at the state level.

† State regulatory agencies include California Department of Food and Agriculture and California Rice Commission task force.

‡ Approval came after discovered mixed with nontransgenic rice varieties in southern United States.

Biosafety or trade barrier? Japan's tenuous trade with California

Japan is the California rice industry's largest international customer, purchasing more than $421 million in 2009 — over 40% of the industry's exports (FAS 2010). If tests on imports find transgenic traits, Japan has suggested that it would deny rice shipments. Some observers question whether such policies are about biosafety or if they constitute a barrier to trade.

Rice is culturally, religiously and politically significant in Japan. Japan has invoked national food-security policies that promote self-sufficiency and smallholder paddy production (Ohnuki-Tierney 1993); nonetheless, it is a leading food importer, deriving about 40% of its total calories from imports (Sato 2007). Like California, Japan produces temperate, medium-grain japonica varieties. In Japan, however, per-acre production costs are 10 or more times higher, and consumer prices are two to three times higher than in California (Fukuda et al. 2003). Post–World War II land reforms divided rice-growing areas into holdings of less than 7 acres. In contrast with other food commodities, Japan is self-sufficient in rice production and tends to guard its domestic rice markets against imports.

During the 1994 Uruguay Round of international trade negotiations, Japan yielded to U.S. pressure and agreed to phase out rice import restrictions, reduce government subsidies and annually increase the amount of rice it imported. Japan is required to import more than 680,000 tons of rice per year (Fukuda et al. 2003). About 100,000 tons of this rice is used in food and beverage manufacturing; the rest is directed to government warehouses for eventual re-exportation as foreign food aid (Fukuda et al. 2003). In 2006, Japan announced that the rice surpluses stored in government warehouses would also be used for biofuels (Annon 2006), and production commenced in 2009 (Takada 2009).

Churl Han

Japan's strict policies on transgenic rice are rooted in both concerns about biosafety and economic protectionism. The Cartagena Protocol on Biosafety — part of the United Nations Convention on Biodiversity — allows countries to base decisions about transgenic organisms on the precautionary principle. When risks from biotechnologies are severe and potentially irreversible, nations can implement labeling and other regulatory requirements. Codex Alimentarius, the international standards-setting organization for food safety, has developed guidelines for food derived from biotechnology (i.e., transgenic foods) and suggests labeling as an appropriate approach to risk management (Codex 2003). Both institutions seek to ensure that restrictions on trade are not rooted in protectionism and are informed by the best available information about food safety and environmental consequences.

Unfortunately for California rice growers, other foreign customers that also import japonica rice, such as Taiwan, Turkey and South Korea, maintain rice import protocols similar to those of Japan. Both Taiwan and South Korea also have Uruguay Round commitments that are contradictory to the interests of domestic rice farmers in those countries, and both have asserted strict import restrictions on transgenic rice. Turkey banned transgenic rice altogether. While it is difficult to determine whether protectionism, culture or biosafety are the main forces driving such policies, all play a role in influencing the deployment of transgenic rice.

— D.R. Mulvaney, T.J. Krupnik, K.B. Koffler

References

Annon A. 2006. Stockpiled import rice to be used in biofuel. Asahi Shimbun. www.asahi.com/english/Herald-asahi/TKY200611140179.html (accessed Feb. 27, 2008).

[Codex] Codex Alimentarius. Foods Derived From Biotechnology. ftp://ftp.fao.org/codex/Publications/Booklets/Biotech/Biotech_2003e.pdf (accessed Dec. 5, 2010).

[FAS] Foreign Agricultural Service. 2010. Global Agricultural Trade System Online. US Department of Agriculture. Wash., DC. www.fas.usda.gov/gats (accessed Dec. 7, 2010).

Fukuda H, Dyck J, Stout J. 2003. Rice Sector Policies in Japan. Electronic Outlook Report. US Department of Agriculture, Economic Research Service. Washington, DC. RCS-0303-01.

Ohnuki-Tierney E. 1993. *Rice as Self: Japanese Identities Through Time*. Princeton, NJ: Princeton Univ Pr. 184 p.

Sato S. 2007. Japan Biotechnology Annual Report. Global Agriculture Information Network Rep JA7040. US Department of Agriculture, Foreign Agricultural Service. Washington, DC.

Takada A. 2009. Japan sake brewer to begin biofuel output from imported rice. Bloomberg News. http://checkbiotech.org/node/25683 (accessed Nov. 1, 2009).

importer who resells rice from the affected region lost sales (B. Lundberg, Lundberg Family Farms, personal communication, 2006).

The LibertyLink incidents did little to instill confidence that experimental field trials of transgenic crops could always be adequately contained. Contamination from transgenic rice field trials was involved in 20 of 39 international commingling incidents in 2009 and 2010 (GMO Contamination Register 2010). Since 1996, more than 100 field trials of transgenic rice have been conducted in California (table 2), although to date seasonal testing of California rice seed for transgenic traits has found no contamination (CRC 2010).

Regulating risks

In 1999, the seed company AgrEvo, which is now owned by Bayer, petitioned to deregulate another LibertyLink variety (LL62). At that time, controversies over transgenic crops were making headlines. Exports of U.S. transgenic soy and corn were refused at European ports (Goldberg 2000), and from 1997 to 2005, U.S. exports of corn to the European Union fell $211 million annually to $200,000, while U.S. soy fell from $2.3 billion to $511 million (Zerbe 2007). A number of other high-profile, unauthorized releases of regulated transgenic crops into the food supply followed (table 3).

California rice growers and industry representatives were aware that the improperly managed introduction of transgenic rice could have economic repercussions, including poor consumer confidence, and lost sales and market access. With the support of a number of nonprofit organizations, the California Rice Commission (CRC), which represents about 1,000 rice growers, pursued a regulatory mechanism to control such risks. By 2000, the California Rice Certification Act (CRCA) was law (see box).

Under the CRCA, the CRC can propose regulations to the California Secretary of Agriculture for rice with characteristics that affect its marketability, including those difficult to identify without specialized testing and those considered expensive or impossible to remove. Though not named explicitly, transgenic rice is clearly regulated by the CRCA. When rice with problematic characteristics is identified, the CRC convenes a task force — representing growers, marketers, UC, the California Warehouse Association and the Cooperative Rice Research Foundation — to develop identity preservation protocols and keep it out of commodity streams for conventional rice.

Identity preservation requires special planting, handling and auditing procedures along the path from the rice field to customer. Gene flow — the movement and exchange of genetic traits or biological organisms from one population to another — must be contained in rice fields. This requires physical or biological barriers to prevent rice pollen and seed from moving via wind, wildlife or flooding (Lu and Snow 2005). For rice, pollen-mediated gene flow is restricted by short dispersal (Song et al. 2003) and brief viability (Lu and Snow 2005). Seed-mediated gene flow can occur over longer distances, because rice seed remains viable for much longer, and dispersal can be assisted by high winds during aerial seeding, floods, wildlife or human error. California's rice fields are habitat to hundreds of millions of waterfowl migrating along the Pacific Flyway, making them potentially important gene-flow vectors. Seed dispersal can be minimized through spatial isolation, prohibitions on aerial seeding, closed-loop water recirculation requirements and wildlife exclusion nets (see box, page 165), although such precautions are likely to significantly

Key provisions of the California Rice Certification Act (AB2622)

Rice industry partners will work cooperatively to maintain consumer confidence and the acceptance of rice produced and milled in the state.

The task force shall recommend regulations relating to rice identified as having characteristics of commercial impact.

The CRC has the authority to establish terms and conditions for the production and handling of rice to minimize the potential for commingling of various types of rice, and to prevent commingling where reconditioning is infeasible or impossible.

TABLE 2. Applications to USDA for transgenic rice trials in California, 1996–2009*

Trait	Institution	Applications
Herbicide tolerance	UC Davis, Louisiana State University, Aventis, Bayer Crop Science, Syngentia, AgrEvo and Monsanto	61
Pharmaceutical	Ventria Biosciences	7
Salinity tolerance	Arcadia Biosciences	7
Nitrogen-use efficiency	Arcadia Biosciences	6
Sterility	Bayer	4
Yield enhancements	Research for Hire, Monsanto	8
Bacterial/disease resistance	UC Davis	10
Altered metabolism/proteins	Aventis	6
Visual markers	UC Davis	6

Source: ISB 2009.
* Organisms with multiple transformations were counted multiple times. Not all applications were approved.

TABLE 3. Unauthorized releases of regulated transgenic crops into the food supply

Year	Product	Crop	Trait	Cause	Detection
2000	StarLink	Corn	Insect resistance, herbicide tolerance	Cross-pollination, commingling after harvest	3rd-party testing
2002	Prodigene	Corn	Pharmaceutical protein	Cross-pollination, uncontrolled volunteers	USDA inspection
2004	Syngenta Bt10	Corn	Insect resistance	Misidentified seed	3rd-party testing
2006	LibertyLink 601	Rice	Herbicide tolerance	Not determined	3rd-party testing
2006	LibertyLink 604	Rice	Herbicide tolerance	Not determined	3rd-party testing
2008	Event 32	Corn	Insect resistance	Under investigation	Developer testing

Source: GAO 2008.

raise production costs. Monitoring for rice crop volunteers in subsequent seasons and leaving land fallow between transgenic and conventional cultivation can also reduce gene flow. Pollen and seed management are most critical where commercial seed is produced, since the distribution of contaminated seed would have far-reaching impacts. Breeders provide foundation seed to contract growers of certified seed, who in turn produce seed for growers. While breeders already employ practices that limit gene flow, the prospect of incidental transgenic contamination raises the stakes for maintaining purity. This point was underscored in the LibertyLink incidents, where 'Cheniere' and 'Clearfield 131' foundation seed (representing 39% of the certified seed acreage in Arkansas) were contaminated (Schultz 2006). Growers seeking nontransgenic seed can not use these varieties until the transgenic traits are no longer detected, which can be several years.

Ultimately, the extent to which identity preservation can mitigate risk depends on the enforcement of standards set by buyers. Most identity preservation systems allow for a low-level presence of unintended characteristics, referred to as adventitious presence. Postharvest buyers typically only permit the adventitious presence of traits posing no human health risks. For example, Japan allows up to 5% of soy imports to contain transgenic soy that has been approved by its food safety regulators. But there is zero tolerance for unapproved crops, which often include experimental crops; with no margin for error, identity preservation is considerably more challenging.

Japan, the largest foreign importer of California rice, maintains some of the world's strictest food safety standards. Incoming shipments of rice are routinely tested for transgenic traits, which if found can result in refusal of the shipment. The LibertyLink incidents suggest that Japan will continue to maintain zero-tolerance policies for transgenic rice and would reject contaminated rice imports.

Many forecasts that determine potential impacts from the adoption of herbicide-tolerant rice base their claims on farm budget analyses that assume market acceptance (Bond et al. 2005). These studies assume modest cost increases for identity preservation but do not incorporate the economic risks associated with contamination incidents. These assumptions are important, because rice contaminated by transgenic traits can cause severe, long-lasting and potentially irreversible impacts on marketability.

The CRCA has drawn attention as a model policy for managing economic risks from transgenic crops (Taylor et al. 2004). While such management is unique, there are precedents for employing identity preservation systems: the cotton industry ensures consistent fiber quality, organic certification tracks crops for labeling, and seed purity is maintained in seed certification and quality control programs (Sundstrom et al. 2002).

Pharmaceutical rice protocols

The CRCA first applied identity preservation to transgenic rice in late 2003, when Ventria Biosciences sought approval to commercially plant out two rice varieties engineered to produce pharmaceutical compounds that have antimicrobial qualities. The proposed varieties were engineered with recombinant (r-) human proteins, r-lacto-ferrin and r-lysozyme, which were intended for use in the production of iron supplements and anti-diarrheal medicines. "Pharm" rice was grown in experimental plots in California from 1999 to 2003 (ISB 2009). When Ventria notified the CRC of its intent to commercialize production, a task force

Lundberg Family Farms clearly labels its products as "non-GMO," meaning that they contain no genetically modified organisms. ***(Lundberg Family Farms rice are Non-GMO Project verified. Lundberg Family Farms does not support the deregulation of "transgenetic" rice.)***

Containment and identity preservation practices

Containment

- Spatial/temporal isolation or buffer zones between transgenic and nontransgenic crop fields.
- Clearly labeled and dedicated equipment for seeding, harvesting, transporting and handling.
- Netting to keep birds and other wildlife from entering fields.
- Screens to keep seed and seedlings from moving into drainage ditches and other waterways.
- Prohibitions against aerial seeding.
- Monitoring for crop volunteers on fields and margins.
- Postharvest tillage to reduce the regrowth of rice from stubble.
- Seed sterility.

Identity preservation

- Transgenic/nontransgenic labeling on rice bags, silos and trailers.
- Dedicated equipment for drying, hulling, processing and shipping.
- Inspections and documentation demonstrating that shared equipment has been properly cleaned out between processing transgenic and nontransgenic products.
- Clear product custody reports along the distribution path.
- Preventing seed spillage when transferring seed or grain in and out of equipment.

Raymond Panaligan, IRRI

Above, **leaf samples of transgenic rice lines that were subjected to DNA extraction in the laboratory.**

was convened to develop planting and handling protocols. These protocols were not yet complete when Ventria asked the CRC to permit planting on an emergency basis so they could cultivate during the 2004 growing season (Moschini 2006).

In March 2004, the CRC task force voted six to five to approve Ventria's request, but with several restrictions. Pharm rice was permitted only in counties that were geographically isolated from California's primary rice-growing regions. Aerial seeding was prohibited, and practices to discourage wildlife movement and dedicated equipment were required.

Since these protocols modify the California agriculture code, the Secretary of the California Department of Food and Agriculture (CDFA) can veto decisions by the CRC task force within 10 days. CDFA received a letter from the Japanese Rice Retailers Association that stated, "It is certain that the commercialization of [pharm] rice in the United States will evoke a distrust of U.S. rice as a whole among Japanese consumers, since we think it is practically impossible to guarantee no rice contamination . . . If the crop is actually commercialized in the United States, we shall strongly request the Japanese government to take measures not to import any California rice" (Taylor et al. 2004). Such threats were not without precedent: in January 2002, Japan briefly blocked imports of rice bags with lead-based pigments because of food safety concerns (Fukuda 2002).

According to our interviews, concerns about market losses strongly influenced the CDFA decision to veto the planting protocol. The official decision was justified on the grounds that insufficient time was provided for public comment, and that Ventria had not obtained the relevant federal-level permits (Marvier 2007). Ventria subsequently moved operations to Missouri, and Anheuser-Busch said they would refuse to purchase Missouri rice if pharm crops were planted. Ventria next moved to North Carolina, a state without commercial rice production; however, the pharm rice field trials are reportedly taking place near the Tidewater Research Station, where many rice varieties are bred and tested (UCS 2006).

Gaps in CRCA oversight

Even before the LibertyLink incidents, many of our interviewees expressed concern about experimental field trials for transgenic crops (see box). These trials are the responsibility of the USDA Animal and Plant Health Inspection Service (APHIS), which requires strict containment protocols. Early in CRCA implementation, additional regulation was considered redundant. But in the wake of the LibertyLink incidents, which originated from experimental trials, there were calls for the CRCA to regulate field trials (RPC 2006). The CRC responded, and now experimental field trials require CRCA approval.

Another area of concern was the proximity of experimental field trials to the foundation rice seed supply. The California Rice Experimental Station in Biggs (Butte County) hosts many breeding programs and is where much of the industry's seed originates. Although no transgenic rice field tests have occurred there since 2003, there is no formal policy on future research. Tests of Biggs foundation seed found no transgenic-rice traits from 2007 to 2010 (CRC 2010). Nonetheless, several interviewees proposed a prohibition against transgenic tests near California rice seed production sites.

An additional gap in oversight is due to an exemption for UC researchers. The CRCA states that it "shall not apply to research conducted by the University of California except for rice produced directly from the research that enters the channels of trade" (AB2622 2000). While the industry works closely with researchers to follow proper protocols (T. Johnson, California Rice Commission, personal communication, 2006) not all growers are convinced that this adequately mitigates risk (RPC 2006).

Managing risks to rice marketing

Food safety concerns such as BSE (bovine spongiform encephalopathy, or mad cow disease), *E. coli* and *Salmonella* have led buyers to implement testing requirements and even reject food shipments (O'Neill 2005). Unapproved transgenic crops receive similar scrutiny. To manage the economic risks from transgenic rice, the CRCA requires strict identity preservation for any crop that might affect the marketability of rice. While deemed a model policy, the extent to which other commodities might adopt similar policies is limited because of three unique circumstances surrounding California rice.

On the LibertyLink incident

"Any rational person would probably say, yeah, those protocols probably didn't work. I think there is an even-keeled, good case to be made that we have a good example that didn't work, and we need to look at that."

— *Rice grower*

On containment

"No one is going to control the birds . . . there is nothing we can do unless we eliminate the plot."

— *Rice grower*

On export market risks

"We have a policy in place that speaks very clearly to the fact that GE [genetically engineered] rice should not be planted until such time as there is commercial acceptance."

— *Rice industry representative*

First, the California rice industry recognized the economic risks of transgenic rice contamination, prompting preemptive legislation to ensure that the problem could be managed. Second, the rice supply chain is amenable to identity preservation because the industry already separates rice based on grain type and color. Third, the reproductive biology of rice makes identity preservation more feasible. For crops that pose greater gene-flow risks, or that have more homogenous supply chains and distribution channels, similar policies are less feasible. For example, corn plants shed significant amounts of pollen to produce kernels, and much of the corn supply is delivered to elevators with homogenous supplies of corn from various sources. Identity preservation requirements are also unlikely in commodities facing little opposition to transgenic crops, such as cotton.

Herbicide-tolerant rice may be beneficial for California rice growers. But predictions of the economic benefits from transgenic rice must be considered alongside market risks. Rice shipments testing positive for transgenic traits could be rejected, likely with long-lasting repercussions. California growers could consequently face severe oversupply, lower prices and possibly decreased production (Childs and Burden 2000), underscoring the importance of a precautionary approach to market risks.

In the meantime, alternative weed-management options include breeding for weed-suppressive crop traits (Gibson et al. 2003); alternative tillage and stand establishment methods to pregerminate and then control weeds (Linquist et al. 2007); and long-term strategies aimed at shifting weed communities to make broad-spectrum herbicides more effective (Fischer 2004). Until transgenic rice gains market acceptance, these management strategies are likely to be less risky options for California growers.

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References

AB2622. 2000. The California Rice Certification Act. www.leginfo.ca.gov/pub/99-00/bill/asm/ab_2601-2650/ab_2622_bill_20000923_chaptered.pdf (accessed Aug. 16, 2004).

Annou MM, Wailes E, Cramer G. 2000. Economic Analysis of Adopting Liberty Link Rice. Rice Situation and Outlook. RCS–2000. USDA Economic Research Service. Washington, DC.

Bond CA, Carter CA, Farzin YH. 2003. Medium grains, high stakes: Economics of genetically modified rice in California. AgBioForum 6(4):146–54.

Bond CA, Carter CA, Farzin YH. 2005. Economic and Environmental Impacts of Adoption of Genetically Modified Rice in California. UC Giannini Foundation of Agricultural Economics. Gianinni Found Res Rep 350. Berkeley, CA.

Brookes G. 2008. Economic Impacts of Low Level Presence of Not Yet Approved GMOs on the EU Food Sector. Briefing Document, GBC Ltd. www.agrodigital.com/images/estudio.pdf.

Childs N, Burden A. 2000. The US Rice Export Market. USDA Economic Research Service. Washington, DC. www.ers.usda.gov/briefing/rice/specialarticle/usricemarket.pdf.

Cole N. 2006. Rice farmers biggest losers over altered rice, exec says. Arkansas Democrat Gazette. www.nwanews.com/adg/News/171621 (accessed Nov. 16, 2006).

[CRC] California Rice Commission. 2010. GMO certification letter. http://calrice.thewebhounds.com/pdf/2010-GMO-Cert-Letter.pdf (accessed March 15, 2010).

Cronin Fisk M, Whittington J. 2010. Bayer loses 5th straight trial over US rice crops. Bloomberg News. www.bloomberg.com (accessed Dec. 5, 2010).

Cummings B. 2009. Rice trade issues for new US trade representative Kirk. Delta Farm Press. http://deltafarmpress.com/rice/rice-trade-issues-new-ustr-kirk.

Ellstrand NC. 2006. When crop transgenes wander in California, should we worry? Cal Ag 60(3):116–25.

[ERS] Economic Research Service. 2010. Adoption of Genetically Engineered Crops in the U.S. US Department of Agriculture. Washington, DC. http://www.ers.usda.gov/Data/BiotechCrops (accessed Nov. 1, 2010).

[FDA] US Food and Drug Administration. 2006. Statement on Report of Bioengineered Rice in the Food Supply. Washington, DC. http://www.fda.gov/Food/Biotechnology/Announcements/ucm109411.htm (accessed Feb. 6, 2011).

Fischer AJ. 2004. Comprehensive Rice Research 2004 Annual Report – Weed Control in Rice. Rice Experiment Station, Biggs, CA.

Fukuda H. 2002. Japan Grain and Feed Annual Report. USDA Foreign Agriculture Service. Washington, DC.

Fukuda H, Dyck J, Stout J. 2003. Rice Sector Policies in Japan. Electronic Outlook Report. US Department of Agriculture, Economic Research Service. RCS-0303-01. Washington, DC.

[GAO] Governmental Accounting Office. 2008. Genetically Engineered Crops. A Report to the Committee on Agriculture, Nutrition, and Forestry, US Senate. GAO 09-60. Washington, DC.

Gibson KD, Fischer AJ, Foin TC, et al. 2003. Crop traits related to weed suppression in water-seeded rice. Weed Sci 51(1):87–93.

GMO Contamination Register. 2010. www.gmcontaminationregister.org (accessed Nov. 28, 2010).

Goldberg G. 2000. Corn growers question need to sacrifice export markets due to GM crops. American Corn Growers Association. Washington, DC. www.biotech-info.net/acga_PR_3.html.

[ISB] Information Systems for Biotechnology. 2009. USDA Field Tests of GM Crops Database. www.isb.vt.edu (accessed May 6, 2009).

James C. 2009. China approves biotech rice and maize in landmark decision. International Service for the Acquisition of Agri-biotech Applications. Crop Biotech Update (Dec. 4, 2009). www.isaaa.org/kc/cropbiotechupdate/article/default.asp?ID=5112 (accessed Oct. 1, 2010).

Li Y, Wailes E, McKenzie A, Thomsen A. 2010. LL601 contamination and its impact on US rice prices. J Ag Applied Econ 42(1):31–8.

Linquist BA, Fischer A, Godfrey L, et al. 2007. Minimum tillage could benefit California rice farmers. Cal Ag 62:24–9.

Lu B-R, Snow A. 2005. Gene flow from genetically modified rice and its environmental consequences. Bioscience 55(8):669–78.

Marvier M. 2007. Pharmaceutical crops have mixed outlook in California. Cal Ag 61(2):59–66.

Moschini GC. 2006. Pharmaceutical and industrial traits in GM crops: Coexistence with conventional agriculture. Am J Ag Econ 88(5):1184–92.

O'Neill K. 2005. U.S. beef industry faces new policies and testing for mad cow disease. Cal Ag 59(4):203–11.

[RPC] Rice Producers of California. 2006. Biotechnology Position Statement. calriceproducers.org/html/biotech_position.html (accessed Nov. 15, 2006).

Salganik MJ, Heckathorn DD. 2004. Sampling and estimation in hidden populations using respondent-driven sampling. Sociolog Method 34(1):193–240.

Schultz B. 2006. LibertyLink 601 found in LSU foundation seed. Delta Farm Press. http://deltafarmpress.com (accessed Feb. 6, 2011).

Serapio M. 2010. After China, Philippines may approve GMO rice. Reuters. March 16. www.reuters.com/article/idUSTRE62F0T720100316 (accessed Nov. 28, 2010).

Song ZP, Lu B-R, Zhu YG, Chen JK. 2003. Gene flow from cultivated rice to the wild species under experimental field conditions. New Phytolog 15(7):657–65.

Sundstrom FJ, Williams J, Van Deynze A, Bradford KJ. 2002. Identity Preservation of Agricultural Commodities. UC Davis Seed Biotech Center Pub 8077. Davis, CA.

Taylor MR, Tick JS, Sherman DM. 2004. Tending the Fields: State and Federal Roles in the Oversight of Genetically Modified Crops. Pew Initiative on Food and Biotechnology. December. Washington, DC.

[UCCE] UC Cooperative Extension. 2001. Rice Project Survey Results. www.agronomy.ucdavis.edu/uccerice/NEWS/survey.htm (accessed Feb. 23, 2008).

[UCS] Union of Concerned Scientists. 2006. UCS uncovers lax USDA oversight of pharma crops. Washington, DC. www.ucsusa.org/food_and_environment.

Ueji M, Inao K. 2001. Rice paddy field herbicides and their effects on the environment and ecosystems. Weed Biol Manage 1(1):71–9.

Vermif P. 2006. EU and Japan block unapproved GM rice. Nature Biotech 24(10):1186.

Zerbe N. 2007. Risking regulation, regulating risk: Lessons from the transatlantic biotech dispute. Rev Policy Res 24(5):407–23.

RESEARCH ARTICLE

Switchgrass is a promising, high-yielding crop for California biofuel

by Gabriel M. Pedroso, Christopher De Ben, Robert B. Hutmacher, Steve Orloff, Dan Putnam, Johan Six, Chris van Kessel, Steven Wright *and* Bruce A. Linquist

Ethanol use in California is expected to rise to 1.62 billion gallons per year in 2012, more than 90% of which will be trucked or shipped into the state. Switchgrass, a nonnative grass common in other states, has been identified as a possible high-yielding biomass crop for the production of cellulosic ethanol. The productivity of the two main ecotypes of switchgrass, lowland and upland, was evaluated under irrigated conditions across four diverse California ecozones — from Tulelake in the cool north to warm Imperial Valley in the south. In the first full year of production, the lowland varieties yielded up to 17 tons per acre of biomass, roughly double the biomass yields of California rice or maize. The yield response to nitrogen fertilization was statistically insignificant in the first year of production, except for in the Central Valley plots that were harvested twice a year. The biomass yields in our study indicate that switchgrass is a promising biofuel crop for California.

Switchgrass is a grass native to North America that has been utilized primarily as a forage crop and groundcover. Because of its high biomass yields, switchgrass (*above*, in El Centro, Imperial County) is considered a good candidate for dedicated energy crops (biofuels).

Switchgrass is a perennial, warm-season (C4) grass native to North America. One of the dominant species of the North American tallgrass prairie, switchgrass (*Panicum virgatum*) grows naturally in remnant prairies and native grass pastures, and along roadsides throughout the continental United States, except in California and the Pacific Northwest (USDA 2006). Agriculturally, it has been used primarily as forage and for grazing and groundcover. Recently, however, it has emerged as one of the most promising cellulosic biofuel crops for ethanol production.

California consumes more ethanol than any other U.S. state. California gasoline contains about 6% ethanol by volume (since the substitution of MTBE [methyl tert-butyl ether] in 2004), resulting in annual ethanol consumption of nearly 1 billion gallons (3.78 million cubic meters). Of that, about 80% is maize-based ethanol transported by rail from the Midwest; 12% is sugarcane-based ethanol shipped from Brazil; and 8% is ethanol from maize grains produced in-state (CEC 2010). The proportion of ethanol blended in California gasoline is expected to increase to 10% by 2012, resulting in ethanol demand of 1.62 billion gallons (6.12 million cubic meters) per year if no gasoline consumption changes occur (CEC 2007). If in-state production does not increase, California will need to import more than 95% of its ethanol by 2012.

Currently, most of the ethanol used in California is produced by fermenting the sugar in Brazilian sugarcane and the starch in Midwestern grains (Macedo et al. 2008). Technology is being developed to produce ethanol from cellulose, the most abundant structural carbohydrate in plants; the cellulose content of switchgrass, for example, is about 40% (Isci et al. 2008). Cellulose cannot be directly fermented to produce ethanol; it needs to be broken down into more simple sugars. There are different processes of ligno-cellulose conversion into ethanol, such as strong acid hydrolysis followed by fermentation (SHF) and simultaneous saccharification and fermentation (SSF). Significant challenges remain and need to be overcome before the technology can be commercially used (CEC 2010).

Compared to maize grain–based ethanol, which is the only ethanol currently produced in California, cellulosic ethanol has higher productivity and net energy value, and lower net greenhouse-gas emissions (Adler et al. 2007). Cellulosic ethanol can also be produced from nonfood crops, waste and forest products, diminishing the possible inflationary effects on food prices if land used to produce food were diverted to ethanol crops.

Potential of switchgrass

There are many possible crop sources for cellulosic ethanol production in California, including agricultural and urban wastes, rice and wheat straw, wood

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chips from tree pruning and dedicated energy crops. Crops with high biomass yields, such as switchgrass, elephantgrass (*Pennisetum purpureum*) and miscanthus (*Miscanthus × giganteus*) are good candidates for dedicated energy crops. The advantages of switchgrass are its high yield potential, excellent soil conservation attributes and good compatibility with conventional farming practices (McLaughlin et al. 1999). Like most field crops, for example, switchgrass is established from seeds, whereas elephantgrass and miscanthus are established by transplanting billets and rhizomes. Also, switchgrass is no longer on the California Department of Food and Agriculture list of noxious weeds (CDFA 2010).

Under rain-fed conditions of the Midwest and southern United States, switchgrass biomass yields have ranged from 2.5 to 11 tons per acre (5.5 to 25 metric tons per hectare) (Fike et al. 2006; Heaton et al. 2004; McLaughlin et al. 1999; Schmer et al. 2008). The responses of switchgrass crops to nitrogen fertilizer have been variable and conflicting. Some studies report limited or no yield response (Christian et al. 2001; Thomason et al. 2004), while others have found significant yield increases due to nitrogen fertilization (Lemus et al. 2008; Muir et al. 2001; Stroup et al. 2003). Nitrogen response is an important area of study because nitrogen fertilizer is the main energy input and the main source of greenhouse-gas emissions during switchgrass cultivation (Adler et al. 2007; Schmer et al. 2008). Understanding how switchgrass responds to nitrogen will help researchers develop energy-efficient and environmentally benign production systems for biomass energy crops.

Because it can be used both as forage and as a biofuel crop, switchgrass may be well suited to California, a state with a large livestock industry and higher ethanol consumption than any other. However, there is little information about switchgrass production in California, nor in other irrigated regions. Irrigated Western regions are significantly different in climate and cropping patterns than the Midwest or southern United States, where most switchgrass research has been carried out. California's Mediterranean climate suggests greater yield potential but also higher water and nitrogen requirements.

Switchgrass can be separated into two ecotype groups: lowland and upland. Lowland ecotypes are found in floodplains and are taller (around 6 feet), coarser with a more bunch-type growth habit and may be more rapid growing than upland ecotypes. In contrast, upland ecotypes are found in drier upland sites and are finer stemmed, broad based and often semi-decumbent (Porter 1996). Usually, lowland ecotypes flower and mature later than upland ecotypes.

Switchgrass is not native to California, and no information has been available about the adaptability of lowland and upland ecotypes in California. In addition, California has different ecozones — areas defined by distinct climate patterns, landscapes and plant species. Therefore, it is possible that one ecotype is better adapted to one ecozone than another. The objectives of our research were to identify (1) how well the lowland and upland switchgrass ecotypes would adapt to the major ecozones in California, (2) the biomass yield potential for each ecozone and (3) the response of upland switchgrass to various nitrogen fertilizer rates.

Switchgrass ecotype trials

To identify the suitability of lowland and upland switchgrass ecotypes for California, and to test the adaptation of the crop itself, we established trials in July 2007 at four California locations with different climate characteristics and soil attributes (tables 1 and 2). Tulelake (Siskiyou County), the northernmost site on the border with Oregon, is typical of the intermountain regions of California and other parts of the Pacific Northwest. Davis (Yolo County) is situated in the Sacramento Valley, and Five Points (Fresno County) is in the San Joaquin Valley. El Centro (Imperial County) was the southernmost site and represents a low desert agricultural region typical of the Sonoran deserts of California, Mexico and Arizona.

In each location, we evaluated five lowland and five upland varieties. However, the lowland varieties slightly varied across sites, so we tested six lowland varieties total, but only five per site. Lowland ecotypes included two released varieties (Alamo and Kanlow) and four experimental varieties. The upland ecotypes included four released varieties (Trailblazer, Cave in Rock, Blackwell and Sunburst) and one experimental variety. The trials were a completely randomized block design with six replications. At all locations, the seedbed was prepared to provide a firm and fine soil surface. Switchgrass was drill seeded in July 2007 at a rate of 5 pounds per acre (5.6 kilograms per hectare) of pure live seeds, at a depth of

TABLE 1. Climatic characteristics of California ecozones used to evaluate switchgrass production, 2007-2008

Characteristics	Tulelake	Davis	Five Points	El Centro
Altitude (feet)	4,033	52	230	43
Latitude (°N)	41.7	38.5	36.4	32.7
Annual average max./min. temp. (°F)	62/31	74/46	77/48	89/56
Annual precipitation (inches)	10.9	17.6	6.9	2.7
Frost-free days	164	307	320	365

Source: CalClim 2009.

TABLE 2. Soil properties of California ecozones used to evaluate switchgrass production, 2007-2008

Soil attributes*	Tulelake	Davis	Five Points	El Centro
Clay (%)	32	28	31	42
Silt (%)	45	48	34	42
Sand (%)	23	24	35	16
pH	5.9	7.2	7.6	8
CEC (meq/100 grams)†	45.5	35.4	30.7	31.6
Olsen-P (phosphorus) (ppm)	62.5	13.6	7.4	10.7
Potassium (K) (ppm)	367	375	439	409
Organic carbon (%)	4.85	1.91	0.95	0.98
Nitrate-nitrogen (NO_3-N) (ppm)	26.5	9.9	10.6	8.8
Total nitrogen (%)	0.34	0.13	0.07	0.07

* Soil samples were taken before planting at average depth of 4 inches (10 centimeters).
† CEC = cation exchange capacity.

In the first full production year, plots of lowland switchgrass in El Centro yielded 17.6 tons per acre. The crop's productivity tends to increase through the third and fourth years.

0.25 inch (0.6 centimeter) and with 10 inches (25.4 centimeters) between rows. Plot size was 10 by 15 feet (3 by 5 meters). The plots were sprinkler irrigated after seeding to ensure good germination. No fertilizer was applied at planting, but at the three-leaf stage nitrogen (N) was applied in the form of ammonium sulfate at a rate of 50 pounds per acre (56 kilograms per hectare).

All fields were harvested in November 2007, after which the crop entered winter dormancy (table 3). The last harvests at Tulelake, Davis and Five Points were driven in part by the onset of the winter rains or snow; later harvests would have been impractical due to wet soils. Winter dormancy was observed at all sites, including El Centro. El Centro was the first site to break dormancy in early February, followed by Five Points in late February, Davis in early March and Tulelake in early May.

In Tulelake, only one lowland ecotype variety, Kanlow, survived the winter. Lowland ecotypes developed in the southern United States where winters are mild, although frost is not uncommon. Tulelake has average minimum temperatures of 22°F (–5.5°C) during winter and receives 21 inches (53.3 centimeters) of snow annually (CalClim 2009). Therefore, lowland ecotype varieties were generally expected to be unsuitable at this location, which was confirmed by the winter mortality of all except one.

In spring 2008, nitrogen, phosphorus (P) and potassium (K) fertilizers were applied. Nitrogen was applied in the form of ammonium sulfate at a rate of 100 pounds per acre (112 kilograms per hectare). Phosphorus (P_2O_5) and potassium (K_2O) were each applied at a rate of 50 pounds per acre (56 kilograms per hectare).

During the 2008 growing season, the number of switchgrass harvests varied among sites due to climatic differences. The plots were harvested once at Tulelake (October), twice at Davis and Five Points (July and October/November) and three times at El Centro (July, September and November). After the first and second harvests, 100 pounds nitrogen per acre (112 kilograms per hectare) was applied in the form of ammonium sulfate.

Flowering differences

In 2007, we recorded flowering differences among ecotypes and locations at harvest, because early flowering has been associated with lower yields (Hopkins et al. 1995). The upland varieties exhibited higher flowering percentages (percentage of flowering tillers) than the lowland varieties at all locations, and flowering percentages were higher in the southern locations due to the longer season and warmer temperatures. In Tulelake, 5% to 10% of tillers on average were flowering in the upland ecotypes across all varieties, and no flowering was observed in the lowland ecotypes. At Davis and Five Points, there was 15% to 25% flowering for upland and 0% to 10% for lowland ecotypes. The highest flowering percentages were found at El Centro, ranging from 50% to 75% for upland and 10% to 40% for lowland ecotypes.

In 2008, the upland ecotypes once again exhibited higher flowering percentages at the first harvest than the lowland ecotypes at all locations: average flowering percentages observed in lowland and upland ecotypes respectively were 2% and 48% at Davis, 4% and 66% at Five Points, and 6% and 70% at El Centro. At Tulelake, the single-harvest location, the only surviving lowland variety exhibited 30% flowering, while all the upland

TABLE 3. Management operations in 2007 and 2008, and switchgrass dormancy break in 2008

Year	Management	Tulelake	Davis	Five Points	El Centro
2007	Planting date	7/24	7/5	7/17	7/19
	N fertilization	3-leaf stage	3-leaf stage	3-leaf stage	3-leaf stage
	Harvest	11/8	11/19	11/13	11/26
2008	Dormancy break	Early May	Early March	Late February	Early February
	N, P and K fertilization*	5/5	4/9 7/21	3/25 7/25	3/27 7/14 9/8
	Harvest	10/1	7/18 10/30	7/23 11/19	7/11 9/5 11/6

* Nitrogen, phosphorus and potassium.

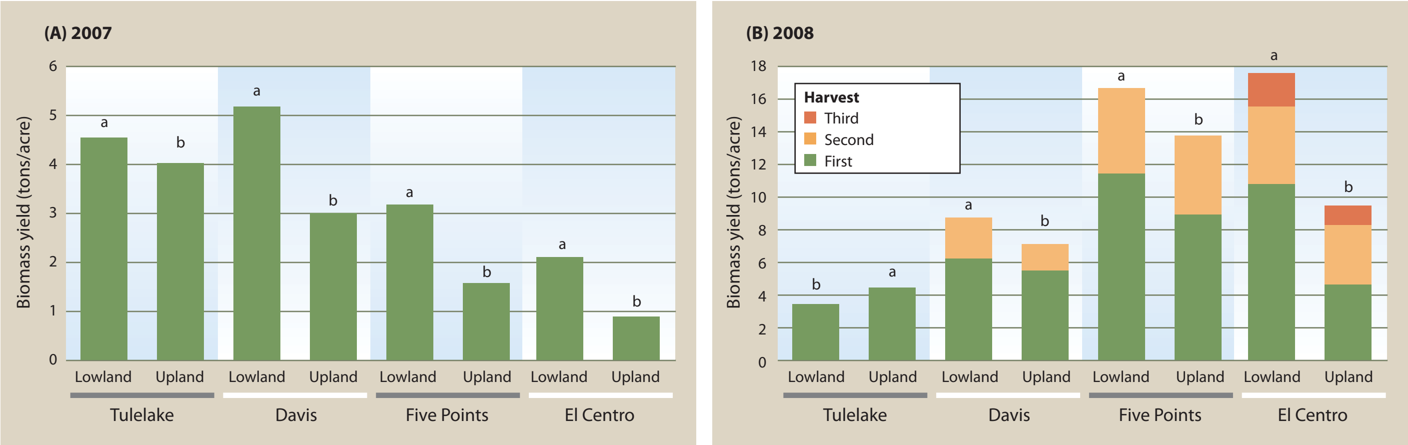

Fig. 1. Switchgrass yields during (A) establishment year (2007) and (B) first full production year (2008) by ecotype and ecozone. Each bar is mean of five varieties and six replications, except for the lowland ecotype at Tulelake, which represents one surviving variety. All locations were planted in July 2007. The same letter above an ecotype indicates that yields are not statistically different (Tukey at $P \leq 0.05$) within each location.

ecotypes showed 100% flowering. Only small differences in flowering among ecotypes were seen at the second harvest. Davis showed 47% and 35% flowering, Five Points 77% and 71%, and El Centro 29% and 8% for lowland and upland ecotypes, respectively. In our trials, early flowering was also correlated with lower yields, in accordance with other studies (Hopkins et al. 1995).

Biomass yields

In the 2007 establishment year, the lowland ecotypes yielded significantly more biomass than upland ecotypes at all locations, but these differences were less evident at Tulelake (fig. 1A). The highest biomass production was achieved by lowland ecotypes in Davis at 5.2 tons per acre (11.6 metric tons per hectare). El Centro had the lowest yield, with upland ecotypes producing only 0.8 ton per acre (1.7 metric tons per hectare). Biomass yields of switchgrass in the establishment year are expected to be lower than in subsequent years. Our establishment yields were similar to those reported in other U.S. studies (Muir et al. 2001) and in Mediterranean climates of Europe (Alexopoulou et al. 2008). We planted the switchgrass in July, and it is likely that an earlier planting date would have resulted in higher yields. Vassey et al. (1985) compared early, mid- and late-spring planting dates and found that the highest yields were achieved with the earliest planting dates.

In 2008, the first full production year, yields were generally higher than in 2007 (fig. 1B). The lowland ecotype yields were higher than upland ecotypes at all locations except for Tulelake, where only one lowland ecotype survived the first winter. Yields of lowland ecotypes averaged 8.7, 16.7 and 17.6 tons per acre (19.4, 37.4 and 39.4 metric tons per hectare) in Davis, Five Points and El Centro, respectively. The upland varieties were not well suited to the warmer locations, but in Tulelake all the upland varieties produced similar yields, which were higher than yields of the single surviving lowland variety.

At locations with multiple harvests, the first harvest produced significantly more biomass than subsequent harvests for all varieties. Of the total biomass, 73%, 67% and 57% was obtained in the first harvest at Davis, Five Points and El Centro, respectively (fig. 1B). At El Centro, the third harvest produced only 12% of the total annual biomass yield.

The 2008 yields achieved in our trials were substantially higher than those reported by Heaton et al. (2004) from 21 studies of mature switchgrass stands around the United States (3 years or older). In their studies, yields averaged 4.6 tons per acre (10.3 metric tons per hectare) and ranged from approximately 0.5 to 9.8 tons per acre (1.1 to 22 metric tons per hectare). Furthermore, we expect yields in our California plantings to increase in the following 1 to 2 years. Productivity tends to increase until the switchgrass stand reaches maturity and full yield potential at 3 or 4 years old (Sharma et al. 2003).

Nitrogen trials

Trials were conducted in the same four locations in 2008 to evaluate the yield response of the upland ecotype variety Trailblazer to different levels of nitrogen fertilizer. Nitrogen fertilizer was applied at each location at annual rates of 0, 70, 140, 210 and 280 pounds per acre (0, 75, 150, 225 and 300 kilograms per hectare) in Davis, Five Points and El Centro. In Tulelake, the nitrogen rates were half that of the other locations (0, 35, 70, 105 and 140 pounds per acre), due to the single harvest and shorter growing season. Five Points and El Centro received all nitrogen fertilizer in March and April, in two applications spaced 4 weeks apart. In Davis, the first nitrogen fertilizer application was in April and the second in July, after the first harvest. Tulelake received nitrogen fertilizer in one single application in May. The plots were adjacent to plots of the ecotype trials and were established at the same time in 2007 and harvested at the same time.

Overall yields were lowest at Tulelake and El Centro, averaging only 6.5 and 7 tons per acre (14.5 and 15.6 metric tons per hectare), respectively (fig. 2, page 172). Trailblazer is an upland variety, and in the ecotype variety trials it usually had lower yields than the lowland varieties (fig. 1B). Total annual biomass yields showed no response to nitrogen treatment at any location. This may be due to switchgrass's deep root system, reportedly up to 10 feet (3 meters), which is able to explore large amounts of soil for nitrogen (Parrish and Fike 2005).

While there was no response to nitrogen fertilizer in the first harvest yields at any location, the second harvest at both Davis and Five Points showed a

Nitrogen fertilizer will likely be needed for switchgrass crops to achieve their full yield potential. ***Above,*** **switchgrass is tested in Davis in June, about 1 month before the first harvest.**

With the high yield potential of switchgrass in California and consequent high nitrogen removal, California growers would most likely need to apply nitrogen fertilizer (and other nutrients) to sustain yields.

significant yield response when the two highest nitrogen treatments were compared to the plots that received no nitrogen. This suggests that over time switchgrass depleted the native soil's nitrogen reserves and required fertilizer nitrogen to achieve its yield potential. Muir et al. (2001) reported just such a situation: switchgrass depleted native soil nitrogen reserves when receiving no nitrogen fertilizer, and over time yield differences between unfertilized and nitrogen-fertilized switchgrass increased. Christian et al. (2001) found no yield response to nitrogen fertilizer during a 5-year study, but that was mainly because soil supply and deposition were adequate to support the low average yields of 4 tons per acre (8.9 metric tons per hectare), and the researchers affirmed that long-term management strategies would be necessary to avoid deficits in soil nitrogen. With the high yield potential of switchgrass in California and consequent high nitrogen removal, California growers would most likely need to apply nitrogen fertilizer (and other nutrients) to sustain yields.

Further research is still needed to improve nitrogen management, but it is likely that a switchgrass variety with higher yielding potential than Trailblazer would show a greater response to nitrogen fertilizer. We found that the plants were green at the first harvest, with high nitrogen content, resulting in high rates of nitrogen (and possibly other nutrients) removal from the soil, which in production fields would need to be replenished. Likewise, multiple-harvest systems are likely to require more fertilizers than single-harvest systems. In multiple-harvest situations, the crop's nutrient content is high at the first harvest, generally in midsummer. The last harvest (or the one harvest of single-harvest systems) takes place in the fall after the plants have senesced. During senescence, most nutrients, including nitrogen, likely retranslocate to the roots, becoming available for next year's growth. Retranslocation to the roots can increase nitrogen conservation within the plant-soil system and may reduce nitrogen fertilizer requirements in subsequent years. Further research is necessary to quantify nitrogen removal and develop nitrogen management strategies for single- and multiple-harvest crops.

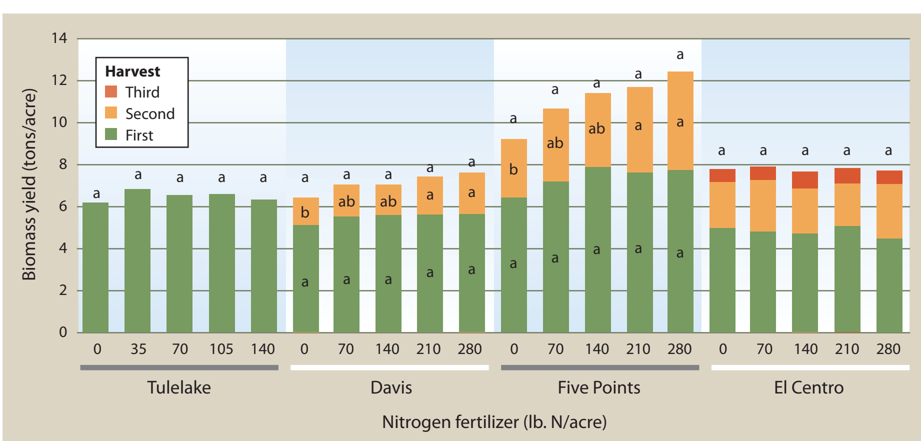

Fig. 2. Response of switchgrass variety Trailblazer (upland ecotype) to nitrogen fertilization in 2008. Letters above yield bars refer to total biomass for the full year, and letters inside bars refer to that harvest. The same letter indicates that yields were not statistically significant (Tukey at $P \leq 0.05$) within each location and harvest. No differences were seen in Tulelake or El Centro for each harvest or total biomass.

Promising biofuel crop

Our results suggest that switchgrass has high yield potential in California. Although its productivity in the state's cooler mountain regions is limited, productivity is considered good in the San Joaquin and Imperial valleys. Switchgrass had moderate yields in the establishment year and up to 17 tons per acre (38 metric tons per hectare) in the second year. By comparison, California maize and rice produce approximately 9 tons per acre (20.1 metric tons per hectare) of total biomass (grain plus stover), and alfalfa produces 7 to 8 tons per acre (15.6 to 18 metric tons per hectare). Therefore, the switchgrass yields reported here are promising both for forage and use as a biofuel crop.

Our results show that switchgrass requires little or no nitrogen in the establishment year, suggesting that it can efficiently use the native soil nitrogen pool; but switchgrass may require nitrogen fertilizers in multiple-harvest systems in the second and subsequent years in order to sustain high yields. In addition to the effect of multiple harvests on nitrogen removal, the harvesting and transportation costs (machinery, fuel and labor) of multiple harvests should be considered when evaluating the production and economic feasibility of switchgrass as a biofuel crop. Water use also elicits concern in California. Switchgrass is a C4 plant, and it is expected to show high rates of transpiration efficiency due to its more efficient photosynthesis pathway. Although not determined in these trials, we are currently researching water use in switchgrass production.

Productivity is dependent on ecotype varietal selection and proper fertility management. Upland varieties were best suited for Tulelake and the cooler mountain regions; most lowland varieties did not survive the first winter. For all other locations, where winter survival was not a concern, the lowland varieties were better adapted and achieved higher yields than the upland varieties.

While productivity in the cooler regions of California was limited, switchgrass did well in the warm San Joaquin and Imperial valleys. Average biomass yields were nearly double that of maize, rice and alfalfa. *Above,* Francisco Maciel shows the height of switchgrass at the El Centro field trial.

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References

Adler PR, Del Grosso SJ, Parton WJ. 2007. Life-cycle assessment of net greenhouse-gas flux for bioenergy cropping systems. Ecol Applic 17:675–91.

Alexopoulou E, Sharma N, Papatheohari Y, et al. 2008. Biomass yields for upland and lowland switchgrass varieties grown in the Mediterranean region. Biomass Bioenergy 32:926–33.

[CalClim] California Climate Data Archive. 2009. www.calclim.dri.edu/ (accessed May 29, 2009).

[CDFA] California Department of Food and Agriculture. 2010. Encycloweedia, Noxious Weed List – Section 4500 Food and Agriculture (pdf). www.cdfa.ca.gov/phpps/ipc/encycloweedia/encycloweedia_hp.htm (accessed May 12, 2010).

[CEC] California Energy Commission. 2007. Transportation Energy Forecasts for the 2007 Integrated Energy Policy Report. www.energy.ca.gov/2007publications/CEC-600-2007-009/CEC-600-2007-009-SF.PDF (accessed Jan. 8, 2010).

CEC. 2010. Statistics and Data on Ethanol and E85 as Transportation Fuels. http://energyalmanac.ca.gov/transportation/ethanol.html (accessed Jan. 8, 2010).

Christian DG, Riche AB, Yates NE. 2001. The yield and composition of switchgrass and coastal panic grass grown as a biofuel in southern England. Biores Technol 83:115–24.

Fike JH, Parrish DJ, Wolf DD, et al. 2006. Long-term yield potential for switchgrass for biofuel systems. Biomass Bioenergy 30:198–206.

Heaton E, Voigt T, Long SP. 2004. A quantitative review comparing the yields of two candidate C4 perennial biomass crops in relation to N, temperature and water. Biomass Bioenergy 27:21–30.

Hopkins AA, Vogel KP, Moore KJ, et al. 1995. Genotypic variability and genotype X environment interactions among switchgrass accessions from the Midwestern USA. Crop Sci 35:565–71.

Isci A, Himmelsbach JN, Pommeto AL III, et al. 2008. Aqueous ammonia soaking of switchgrass followed by simultaneous saccharification and fermentation. Appl Biochem Biotechnol 144:69–77.

Lemus R, Brummer EC, Burras CL, et al. 2008. Effects of N fertilization on biomass yield and quality in large fields of established switchgrass in southern Iowa, USA. Biomass Bioenergy 32:1187–94.

Macedo IC, Seabra JE, Silva JE. 2008. Greenhouse gases emissions in the production and use of ethanol from sugarcane in Brazil: The 2005/2006 averages and a prediction for 2020. Biomass Bioenergy 32:582–95.

McLaughlin S, Bouton J, Bransby D, et al. 1999. Developing switchgrass as a bioenergy crop. In: Janick J (ed.). *Perspectives on New Crops and Uses*. Alexandria, VA: ASHS Pr.

Muir JP, Sanderson MA, Ocumpaugh WR, et al. 2001. Biomass productions of 'Alamo' switchgrass variety in response to N, phosphorus and row spacing. Agron J 93:896–901.

Parrish DJ, Fike JH. 2005. The biology and agronomy of switchgrass for biofuels. Critical Rev Plant Sci 24:423–59.

Porter CL. 1996. An analysis of variation between upland and lowland switchgrass, *Panicum virgatum* L., in central Oklahoma. Ecology 47:980–92.

Schmer MR, Vogel KP, Mitchell RB, et al. 2008. Net energy of cellulosic ethanol from switchgrass. Proc Nat Acad Sci 105:464–9.

Sharma N, Piscioneri I, Pignatelli V. 2003. An evaluation of biomass yield stability of switchgrass (*Panicum virgatum* L.) cultivars. Energy Conver Manag 44:2953–8.

Stroup JA, Sanderson MA, Muir JP, et al. 2003. Comparison of growth and performance in upland and lowland switchgrass types to water and N stress. Biores Technol 86:65–72.

Thomason WE, Raun WR, Johnson GV, et al. 2004. Switchgrass response to harvest frequency and time and rate of applied N. J Plant Nutri 27:1199–226.

[USDA] U.S. Department of Agriculture. 2006. Plant Material Program. Plant Fact Sheet, *Panicum virgatum* (switchgrass). Natural Resources Conservation Service. Washington, DC. http://plants.usda.gov/factsheet/pdf/fs_pavi2.pdf.

Vassey TL, George JR, Mullen RE. 1985. Early-spring, mid-spring and late-spring establishment of switchgrass at several seeding rates. Agron J 77:253–7.

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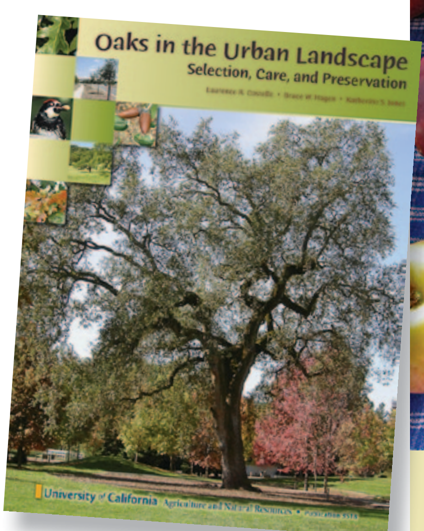

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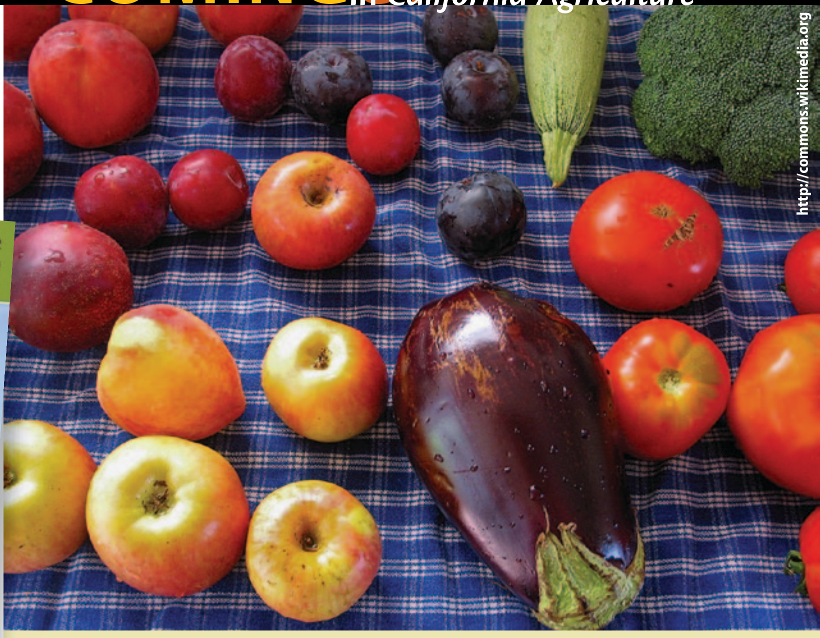

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WIC vouchers promote fruit and vegetable consumption

The federal Special Supplemental Nutrition Program for Women, Infants and Children (WIC) has begun distributing cash vouchers to low-income women and children to buy fruits and vegetables. With WIC reaching almost half of the infants and a quarter of all children under 5 years old in the United States, the vouchers provide an unparalleled opportunity to increase fruit and vegetable consumption among children. In 2010, UC Cooperative Extension researchers conducted a survey of WIC participants in Tulare, Alameda and Riverside counties, to guide development of a Farm-to-WIC program that would connect small local growers to the WIC market. In the next issue of *California Agriculture* journal, the researchers report on the survey results and identify specific kinds of produce that a new Farm-to-WIC program in California could target.