OCTOBER–DECEMBER 2012 • VOLUME 66 NUMBER 4

California Agriculture

Williamson Act cuts:
Survey finds ranch land at risk

University of California | Peer-reviewed Research and News in Agricultural, Natural and Human Resources

Long-term data at Research and Extension Centers to fuel new informatics program

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Understanding and managing the myriad environments that drive our natural world requires science that can illuminate the systems in play and how they interact, across time and spatial scales. There are efforts across UC and beyond to bring together such information, transforming our understanding of global change and enabling scientists to make predictions about how ecosystems will respond.

Such efforts use informatics, the convergence of biology, geography and computer science. The collection, analysis and visualization of complex data are now critical in research, business and government. Increasingly, we can uncover the meanings behind interrelated data sets and use them to make projections. But the models are only as good as the data. We need rich and extensive data, gathered from and usable across disciplines — whether by ecologists, geographers, hydrologists, managers, modelers, farmers or others.

Through a new statewide program, UC Agriculture and Natural Resources (ANR) will organize, digitize and make Web-accessible some of California's longest continuous data on agriculture and natural ecosystems, including weather and productivity related to management inputs — concrete data for modeling responses to change across the state.

Led by UC Cooperative Extension Specialist Maggi Kelly, housed at UC Berkeley, and Lisa Fischer, associate director of ANR's Research and Extension Center system, the new Informatics and Geographic Information Systems statewide program (IGIS) is now constructing databases and methodologies to ensure wide Web accessibility to decades of findings.

For the last 50 to 100 years, data has been carefully collected and recorded at nine RECs across the state. The centers span California from the Oregon border to Mexico, and represent a wide variety of geographic, topographic and climatic zones. Each includes land and facilities. There are two large (5,000-plus-acre) oak woodland–dominated sites with livestock grazing, and seven smaller (140- to 330-acre) sites dominated by intensively managed agricultural crops using a variety of cropping systems.

Over the years, baseline data collection (e.g., weather, soils and more) and research projects have generated a large body of findings. However, most of it is unavailable outside individual centers, and in many cases unavailable beyond the research team. This lessens the value of the projects, and by extension the RECs, to the larger academic and management world.

The new project will make REC research data available to scientists, managers and the public interested in understanding and modeling our complex world. This will enable scientists to make meaningful predictions of the agricultural and ecosystem responses to change, enhancing agricultural productivity in the future. Models alone do not yet provide an adequate basis for decisions about which crops are likely to do well or poorly, whether rangeland and forest productivity will increase or decrease, where rain and snowfall amounts and patterns are likely to change or where biodiversity shifts are likely to occur. But models gain predictive power through sufficient data, and the RECs' storehouse of data can make a strong contribution.

In addition, models based on multiple years of data can project trends, predict thresholds for agricultural land conservation efforts, inform policy to conserve prime agricultural land and help meet the demand for food, fiber, fuel and ecosystem services under changing economic, environmental and demographic conditions.

Complex data sets must be acquired from paper records at the RECs and from researchers willing to share their original findings, and then digitized, stored and made searchable, discoverable and accessible. One example of baseline data is the historical record of the centers' weather, vegetation type, soil type, soil fertility, and soil chemical analysis, all specified according to mapped plots, pastures and boundaries.

Specific to individual centers, data will be gathered on numbers of grazing animals by pasture, leaf analyses for tree fertility, fruit quality data and specific disease or invasive species issues. Other findings include raw field data collected for specific research projects, summarized plot data, written reports and journal articles, including those in *California Agriculture*, ANR's premier vehicle for research dissemination. Lastly, new data will be compiled at each center through a new instrumentation system, which includes an eddy covariance system tower, meteorological equipment and a soil sensor network compatible with national ecosystem observation networks to provide air and soil data.

This issue of *California Agriculture* reports research demonstrating the value of UC data collections: a survey of how Williamson Act cuts could affect private ranch land (page 131); an analysis of water use by oak woodlands and vineyards in Sonoma County (page 144); a review of how the United Nations' Clean Development Mechanism could help California achieve greenhouse gas reduction goals (page 137); a study of job mobility among dairy workers (page 153) and an evaluation of a new 4-H water education curriculum to improve science literacy (page 158).

The IGIS project will soon invite UC scientists to contribute their REC research data and include them in conversations about database construction and methodologies. Providing access to the wealth and breadth of data available from the UC ANR REC system will serve researchers, managers and the public for generations to come.

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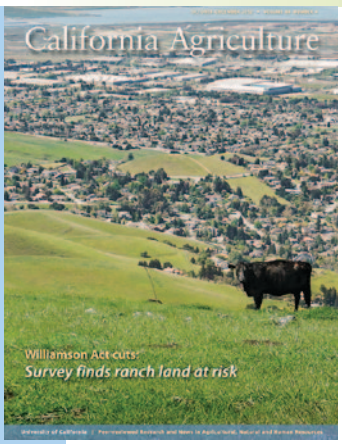

COVER: State budget cuts have dramatically reduced funding for the Williamson Act, the conservation law that provides property tax relief for the owners of 15 million acres of farms and rangeland. In a survey of Central Valley ranchers, researchers found that landowners planned to sell 20% of their total acres if Williamson Act contracts were eliminated (page 131); 76% of those owners predicted buyers would develop the land for nonagricultural uses. Shown is an Angus cow grazing in Mission Peak Regional Preserve, which overlooks the City of Fremont and the San Francisco Bay. *Photo by Sheila Barry*

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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, and the electronic journal logs about 5 million page views annually.

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; it includes printed and 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 and the SCIE databases), Commonwealth Agricultural Bureau (CAB), EBSCO (Academic Search Complete), Gale (Academic OneFile), 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 eScholarship repositories.

Authors and reviewers. Authors are primarily but not exclusively from ANR; in 2010 and 2011, 23% were based at other UC campuses, or other universities and research institutions. In 2010 and 2011, 33% and 40% (respectively) of reviewers came from universities, research institutions or agencies outside ANR.

Rejection rate. The rejection rate has averaged 34% in the last 3 years. In addition, associate editors and staff may send back 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.edu/submit.cfm.

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New insect-disease complex strikes Southland trees

RIVERSIDE, Calif. — UC Riverside scientists have identified a new insect-disease complex that is threatening avocado, coast live oak, box elder and other trees in Southern California. The complex includes a new shot hole borer and a symbiotic *Fusarium* species, which causes branch dieback. The same beetle and fungus have also been found in Israel, where the complex has caused severe damage to avocado trees since 2009.

Entomologists led by Richard Stouthamer proposed the name polyphagous shot hole borer (PSHB) for the tiny insect, an ambrosia beetle. Smaller than a sesame seed (the female is 0.1 inch), the insect was earlier misidentified as tea shot hole borer. Subsequent DNA sequencing by UCR scientists distinguished the insect as a different, potentially new, species.

G. Arakelian

Polyphagous shot hole borer

After it bores into a tree, the insect deposits the fungus, which causes branch dieback and eventual death of the tree. The yet unnamed *Fusarium* sp. was identified by Akif Eskalen, UC Riverside Cooperative Extension plant pathologist.

Eskalen has linked the insect-disease complex to the branch dieback and general decline of several avocado and landscape trees found in February and March this year in Los Angeles and Orange County residential neighborhoods.

The insect and fungus have a symbiotic relationship, Eskalen says. "When the female beetle burrows into the tree, it lays its eggs in galleries; the eggs develop into larvae, which feed on the fungus," he explains. "At the same time, the fungus attacks the vascular tissue of the tree, disturbing water and nutrient flow, and causing branch dieback and — if not stopped — the tree's death."

If infected branches are cut off early enough, trees can be saved. It is important that growers and homeowners not move infested avocado wood out of the infested area.

Photos: Eskalen Lab, UC Riverside

Symptoms in avocado include the appearance of white, powdery exudate in association with a single beetle exit hole on the bark of the trunk and main branches of the tree. This exudate could be dry, or it could appear as a wet discoloration.

If you suspect you have found the PSHB or seen symptoms of *Fusarium* dieback in your avocado grove or in other host plants, please contact your local farm advisor, county agricultural commissioner, or UC Riverside's Eskalen at akif.eskalen@ucr.edu or (951) 827-3499. — *Iqbal Pittalwalla and Janet White*

TO OUR READERS:

Managing editor Byron moves on

Janet Byron

After 13-plus years with *California Agriculture* journal, managing editor Janet Byron left in September to pursue a new career opportunity.

Byron was first hired in June 1999 as a special editor to help develop the journal's "Future in Focus: 2000–2025" editions, which were published in 2000. She became managing editor in February 2001.

When Byron started, *California Agriculture* was mailing out paper reviews, scanning slides and posting abstracts on its website.

"We have undergone a lot of changes to bring the journal into the digital age, but our commitment to publishing high-quality, peer-reviewed research in a beautiful, easily accessible format has never wavered," she said.

"Janet has been an unfailing source of creativity and inspiration in the challenging task of delivering sound science to a lay audience," said Janet White, executive editor. "She responds to challenges with optimism and new ideas. She has been a key collaborator in the team effort to make the journal widely accessible on the Web — and will be greatly missed."

During her tenure, the journal won numerous awards from the Association of Communication Excellence in Agriculture, Natural Resources, and Life and Human Sciences (ACE) for editing, writing, and technical and electronic publications.

"I have enjoyed working with everyone in ANR, especially the hundreds of scientists who have shared their research results and patiently submitted to editing over the years," Byron said.

Byron's new position is senior communications specialist for the Kaiser Permanente Division of Research in Oakland, where she will help disseminate medical research results. She can be reached at janetbyron@att.net.

Correction

In a letter from Dilipsinh M. Gaekwar published in the July-September 2012 issue, the year that Justin Smith Morrill began serving in Congress was incorrect. The correct year is 1855, not 1885.

UC Desert Research and Extension Center celebrates 100 years

When the UC Desert Research and Extension Center (UC DREC) was established in the Imperial Valley in 1912, water from the Colorado River was so available that dairies were plentiful in this desert region, along with feedlots for steers born to milk cows and fields of alfalfa to feed all those cattle.

While most of the dairies are long gone and the water supply has been tightened to meet urban demands on the Colorado River, the Imperial Valley's cattle feedlots and field crops have grown. In addition, farmers there have expanded into high-value crops such as winter vegetables and melons.

"The Imperial Valley is one of the largest agricultural areas in California," says Bill Frost, director of UC Agriculture and Natural Resources (ANR) Research and Extension Center (REC) system, which has nine centers spanning the state to support research tailored to local needs. "DREC is right in the middle of the desert, enabling the University to focus on locally relevant critical issues."

Agriculture in the Imperial Valley

Initially called the Meloland Field Station and later the Imperial Valley Field Station, UC DREC was the first addition to what became the ANR REC system. The 255-acre center is in the middle of an agricultural region called the low desert that encompasses California's Imperial and Coachella valleys, Arizona's Yuma Valley and Mexico's Mexicali Valley.

Courtesy of Bancroft Library, UC Berkeley

Walter Eugene Packard established UC's Meloland Field Station in the Imperial Valley in 1912 and served as superintendent until 1917. He lived in this house.

As a former Colorado River floodplain, the Imperial Valley has deep, rich soil. But rainfall averages less than 3 inches per year and summer temperatures can reach 120°F.

The winters, however, are sunny and mild, with highs in the 80s°F, allowing the year-round production that has helped make Imperial a top-10 agricultural county in California. The county had nearly $2 billion in gross agricultural production in 2011, and its top commodity groups are livestock, valued at more than $400 million; field crops, including alfalfa, wheat and sudangrass, at nearly $520 million; and melons and vegetables, including lettuce, broccoli and onions, at more than $900 million. About two-thirds of the vegetables eaten nationwide during winter are grown in Imperial County.

"We have perfect weather for winter vegetables. It's not too hot and hardly rains, so you can harvest all the time — the weather never gets in the way," says UC DREC superintendent Fernando Miramontes, who started there 33 years ago as a part-time field-worker and now oversees all research projects.

Alan W. Robertson and Bob Douthitt

The UC Desert Research and Extension Center is located in the heart of the Imperial Valley in southeastern California, on 255 acres. The area was formerly Colorado River floodplain, so its soils are deep and rich, but there is very little rainfall. Farming in this desert environment presents unique challenges.

UC DREC research contributions

DREC's research facilities include greenhouses, a plant- and soil-processing laboratory, an insect-rearing facility, a fully automated sprinkler area and a research feedlot cattle facility. The center has an annual operating budget of about $800,000 and research operations budget of over $500,000; with the help of more than a dozen administrative and field research support staff, scientists from UC as well as the USDA Agricultural Research Station in Salinas, more than 25 research projects are currently under way.

Over the past century of changes, UC DREC researchers have helped Imperial Valley farmers meet the many challenges of desert agriculture, including lack of water, extreme summer heat, and rampant pest

insects that devour crops and spread diseases. The center's major contributions (see timeline) include:

- Developing cattle feeds and shade structures to enhance feedlot production during the summer, when high temperatures hinder livestock weight gain.
- Developing plastic-tile drainage systems to maintain soil productivity by flushing salt from the root zone.
- Increasing the yields and pest resistance of desert-grown crops, from alfalfa and wheat to melons and lettuce.
- Testing thousands of rice lines from around the world for introduction to California.

In addition, today's UC DREC researchers are helping farmers prepare for the future by, for example, exploring the potential of sugar cane and other crops for biofuel feedstocks and by creating crop varieties that are adapted to climate change.

Feedlot cattle nutrition, care and production

UC DREC is a national leader in feedlot cattle research, with one of the largest university facilities, including a 700-head feedlot, more than 100 pens, a metabolism barn and a feedmill. Led by Richard Zinn, a UC Davis professor of animal science, the research focuses on optimizing feedlot cattle health and management in the extreme heat of the low desert summers.

In addition to helping cattle producers in the Imperial Valley, Zinn and colleagues collaborate with researchers at the Universidad Autonoma de Baja California (UABC), in Mexicali, Mexico, which is just over the border from UC DREC. Beginning with short courses in animal science at the UABC in 1984, this collaboration has grown to include Masters and PhD animal production programs there. Such programs offer students UABC faculty advisors coupled with research training and thesis work in UC DREC's comprehensive feedlot facilities. The collaboration has also led to UC DREC's participation in developing

Desert Research and Extension Center timeline

1912	UC establishes Meloland Field Station on 10 acres near El Centro.
1945	UC expands the station, by then called the Imperial Valley Field Station, to 255 acres.
1948	Results of first research on artificial shades for livestock published by N.R. Ittner and C.F. Kelly; research by V.E. Mendel, W.N. Garrett and others follows.
1940s & 1950s	Research to develop plastic-tile drainage led by James Luthin.
1960s & 1970s	Research to develop blue alfalfa aphid–resistant alfalfa led by William Lehman.
1962	Research milestones published, including development of 'Calmar' lettuce, which resists downy mildew, and the 'M-100' onion, which resists bolting in the heat.
1967	First sprinkler irrigation results published by F.E. Robinson, O.D. McCoy and G.F. Worker, Jr.
1970	Results of first rice lines tested for introduction to California published by W.F. Lehman, M.I. Peterson, C.R. Adair and others.
1973	'Signal' barley, a variety that has high yields in the low-elevation desert, released to growers.
1970s & 1980s	Research to develop 'CUF 101' alfalfa, which produces year-round in the low desert and is resistant to multiple pests, led by William Lehman.
1984	Richard Zinn and Juan Guerrero Cruz begin collaborating with the Universidad Autonoma de Baja California (UABC), in Mexicali, Mexico, leading to UABC Masters and PhD research in animal nutrition and production at UC DREC.
1990s	Whitefly-resistant alfalfa developed by Larry Teuber.
2001	Farm Smart agricultural education program established.
2006	Biofuel crop trials begun by Dan Putnam and David Grantz.
2012	Heat-tolerant lettuce and spinach trials begun by Beiquan Mou.
	October 25, 2012, Center celebrates 100th anniversary.

Courtesy of Imperial County Cooperative Extension

In October 1921, an Imperial Valley farmer and his mule created beds for onion seeding.

Courtesy of Imperial County Cooperative Extension

Throughout the 1920s and 1930s, the Imperial Valley Experiment Farm was staffed by one agronomist/superintendent. This picture of summer legumes was taken in 1924.

Farm Smart offers hands-on experience, insight into where food comes from

One of the highlights of UC DREC is an agricultural education program called Farm Smart, which was developed by former elementary school teacher Nancy Caywood. Also a farmer's daughter, Caywood got into agricultural literacy when she asked her 1st- and 2nd-grade students where food came from. "They said 'from the grocery store' and that really bothered me," Caywood recalls. "So I asked if I could bring my kids to the farm." The resulting field trips prepared Caywood for her next career as the Farm Smart outreach coordinator at UC DREC.

Established in 2001, Farm Smart provides K–12 agricultural outreach and education programs for just $3 per student. Funding also includes $50,000 annually from the Imperial Irrigation District as well as support from the Imperial County Farm Bureau and local seed companies. "The community makes this happen," Caywood says.

With a team of volunteers that includes her husband, Alan Robertson, Caywood offers more than 150 daylong agricultural education programs to nearly 8,000 students each year. The curriculum is aligned with the content standards for California public schools, covering topics including health and nutrition, bees and pollination, and natural and renewable natural resources. Designed to be fun as well as informative, the programs emphasize hands-on activities, from harvesting and eating winter crops to milking artificial cows and making butter, and also include hayrides and sing-alongs.

During January and February, Caywood offers a similar outreach program to the "snowbirds," retirees who flock from cold climates to the Imperial Valley. Called the Winter Visitor program, this Farm Smart component enrolls about 3,000 participants.

"Most people just don't know much about agriculture," Caywood says. "We help them learn where their food comes from." — *Robin Meadows*

Deidre DuBose

About 8,000 K–12 students visit DREC each year as part of the Farm Smart program. Activities include harvesting and sampling vegetables.

Nancy Caywood

During the winter, adults visit DREC to learn about natural and renewable resources in the Imperial Valley, including agriculture.

Deidre DuBose

Participants learned about soil types by playing interactive games led by Farm Smart outreach coordinator Nancy Caywood (center).

Deidre DuBose

During Fall Fest in November and December, students go on hayrides, grind corn and dance to traditional music. Other seasonal activities include ice-cream making in October, the USDA food pyramid in March and April, and insects in May; all students learn about irrigation and water.

and strengthening postgraduate animal science programs at several other Mexican universities.

Water conservation and quality

Because rain is so scarce, the Imperial Valley depends entirely on the Colorado River for irrigation water. While this water flowed freely for decades, today growers must contend with competing demands from Southern California cities.

"Water transfers between agricultural and urban areas put increased pressure on growers to conserve to meet the needs of the future," says Khaled Bali, UC DREC interim director and UC Cooperative Extension Imperial County irrigation/water management advisor. So far, transfer agreements have claimed about one-tenth the water once used for irrigation in the Imperial Valley.

The bulk of the irrigation water goes to field crops, which account for 80% of the 500,000 cultivated acres in Imperial County; most of the crops are primarily flood irrigated. UC DREC water conservation projects include lining irrigation canals, automating flood irrigation and developing strategies for using less water during the summer. "We are working to match water with crop needs," says Bali, who has worked at UC DREC for more than 20 years.

However, water conservation is complicated by local environmental factors. "One of the biggest issues is salinity," Bali says. "It's so hot that lots of the irrigation water evaporates, adding 7 tons of salt per acre per year." Most crops, particularly vegetables, are salt sensitive. But getting rid of salt means flushing the soil with even more water. "We're working to decrease runoff and optimize deep percolation, so there will be enough water to flush salts but not so much that there's waste," Bali says.

James D. McCreight

In field research at DREC conducted by USDA researchers, the melons from India on left show genetic resistence to cucurbit yellow stunting disorder virus; melons susceptible to the disease are on right.

Cathy Worker-Denton

UC agronomist George F. Worker served at DREC from 1953 to 1985. In the early 1980s, he pollinated sorghum for field trials.

Another difficulty is that agricultural wastewater is critical to the Salton Sea, which provides important bird habitat. "The Imperial Valley drains naturally into the Salton Sea, so more water conservation means less water for the Sea," Bali says. The influx of relatively fresh agricultural water is needed to counterbalance the salt-concentrating effects of evaporation, and the Salton Sea is already about 30% saltier than the ocean.

Low desert alfalfa

Alfalfa is the Imperial Valley's biggest water user, consuming more than a third of the available irrigation water. It is also the region's most extensive and valuable field crop, with nearly 120,000 acres in production and valued at $120 million in 2011. "Alfalfa has been important in the Imperial Valley from the very beginning," says Dan Putnam, a UCCE agronomist and forage specialist based at UC Davis. "There were thousands of small dairies in the early 1900s, and most grew alfalfa." Today, most of the region's alfalfa is shipped to dairies in Chino, San Bernardino County, which is among the state's largest milk-producing areas.

One of UC DREC's most important contributions is a variety of alfalfa developed in the 1970s by agronomist William Lehman. Called CUF 101, this alfalfa variety resists the blue alfalfa aphid and grows through the winter in the low desert rather than going dormant. "This saved the alfalfa industry because the aphid was decimating the crop in California," Putnam says. "CUF 101 also increased yields, revolutionizing alfalfa production in California as well as in Argentina, Australia, South Africa and the Middle East."

Putnam, who has worked on alfalfa for more than 20 years, tests varieties statewide to optimize local yields. "UC DREC is a terrific environment for testing for heat tolerance and long production seasons," he says. Thanks to winter growth in the Imperial Valley, today's alfalfa varieties produce up to 12 harvests per year, which is four times that in some parts of the state.

Developing new crop lines

UC DREC's winter growing season also speeds the development of new commercial crops. "It cuts the time of line development in half," Miramontes says. "We plant the lines in the winter, and our collaborators plant them in the summer."

Long-term projects include a 30-year collaboration on barley triticale with Canada's Alberta Agriculture and Rural Crop Development Center and a 35-year collaboration on carrots with the USDA. "We test more than 1,250 carrot varieties from all over the world in just an acre," Miramontes says.

Pest-resistant melons

But year-round production also has the downside of favoring crop pathogens such as powdery mildew and pest insects such as whiteflies, which feed on plant sap and spread diseases. "The Imperial Valley has had lots of trouble with whiteflies — there's always something for them to eat," says Jim McCreight of the USDA Agricultural Research Station (ARS) in Salinas, who has done field trials at UC DREC for a decade. "In some years, there can be such clouds of whiteflies that you have to be careful how you breathe."

Khaled Bali

A number of water conservation projects are under way at DREC. UCCE research assistant Daniel Buenrostro took infrared images of lettuce to determine crop vigor and irrigation needs.

Since the late 1970s, two new types of whiteflies have plagued the Imperial Valley, introducing four viral diseases. In addition, a new race of powdery mildew appeared in 2003. To help growers keep up with such constantly emerging pests and diseases, McCreight develops melons and other crops that are naturally genetically resistant. He discovered a cucumberlike cousin of cantaloupe from India that resists the new powdery mildew and three of the whitefly-transmitted viruses. He plans to breed these traits into the sweet cantaloupe preferred here. Maintaining crop resistance takes ongoing work, however. "It's common for pathogens to overcome resistance that's based on just one gene," McCreight says.

Biofuel crops

Several UC DREC researchers are evaluating the potential of high-yield crops for biofuel production in the Imperial Valley region, including switchgrass, sugarbeets and sugar cane. The most common biofuel worldwide is ethanol, which can be made by fermenting sugar from crop plants.

"One of the roles of the University is to test new possibilities," UCCE's Putnam says. "We provide independent data so growers can make informed decisions." Growth trials began in 2006, and so far sugar cane may be a promising candidate for low desert biofuel production.

Leafy greens and climate change

In another forward-looking project, plant geneticist Beiquan Mou of the U.S. Department of Agriculture's Agricultural Research Service in Salinas is working at DREC to create lettuce and spinach that can withstand the higher temperatures expected with climate change. Balmy winters have helped make Imperial Valley lettuce, valued at nearly $370 million in 2011, the leading commodity in the county. However, while the Imperial Valley is the nation's "winter salad bowl," the majority of California lettuce is now grown in the Salinas Valley, near Monterey, which currently has an ideal climate for this cool-season crop, with highs in the 60s and 70s°F. In addition, the Central Valley produces lettuce during the spring and fall.

"Climate change could change all of that," Mou says. "Some say the Salinas Valley could become a dust bowl." At temperatures above 80°F, lettuce tends to develop black tips and go to seed (bolt), and heat also makes its seeds go dormant.

Mou identified likely heat-tolerant varieties by growing them in the laboratory at 113°F last year and is now field-testing them at UC DREC and in the Central Valley. The results are already promising, including varieties that germinate at 100°F and do not bolt even at 110°F.

The benefits of heat-tolerant leafy greens go beyond preparing for climate change. "We also hope to extend the growing seasons in the low desert and Central Valley," Mou says. "This would save growers on land costs." Rental rates for farmland in these hot valleys are only one-fifth of those in Salinas Valley, which exceed $1,500 an acre per year.

Just as it has over the last century, UC DREC will continue providing research and outreach to meet the needs of Californians, from desert crop and livestock production to water conservation and environmental protection. "The farm economy is really taking off — Imperial Valley crops are at record highs right now," UC DREC interim director Bali says. "We want to one-make sure we keep supporting farmers in the future."

— Robin Meadows

For more information

UC Desert Research and Extension Center
http://ucanr.org/sites/desertresearch

UC ANR Research and Extension Center System
http://ucanr.org/sites/rec/About_Us

Asian citrus psyllid and huanglongbing disease threaten California citrus

Asian citrus psyllid is slowly spreading in California, and huanglongbing disease (also known as citrus greening) will likely become established in the state, requiring citrus farmers and residents with citrus in their landscapes to become accustomed to a new reality.

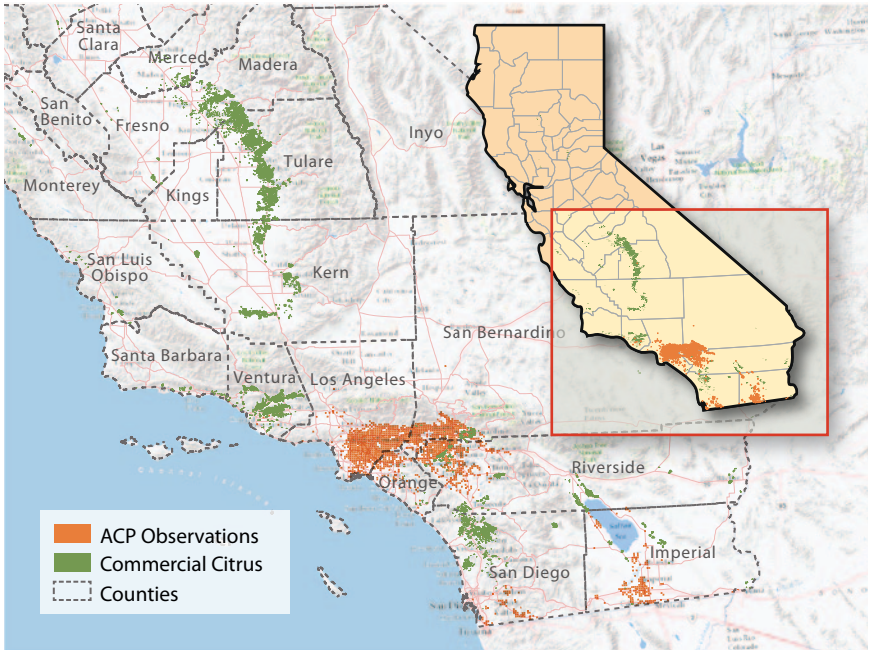
"Asian citrus psyllid and huanglongbing disease have played out this way around the world, including in Florida, Texas and other states," said UC Cooperative Extension specialist Beth Grafton-Cardwell. "There is no reason to believe California will be immune to the natural progression of this disease complex."

The aphid-sized Asian citrus psyllid was first identified in California in 2008 and is currently found in Imperial, San Diego, Los Angeles, Orange, Riverside, and San Bernardino counties. Asian citrus psyllid injects a toxin when it feeds on citrus leaves or stems, causing shoot deformation and plant stunting. Of greater concern is the fact that it vectors the bacterium associated with huanglongbing disease. Every tree infected with the pathogen will suffer a premature death, sometimes in as little as 3 years.

But that doesn't mean UC researchers and UC Cooperative Extension specialists and advisors are giving this serious citrus disease free rein in the Golden State. UC is working with officials from the citrus industry, U.S. Department of Agriculture and California Department of Food and Agriculture (CDFA) to wage an all-out battle.

Asian citrus psyllid carries the vector of huanglongbing disease, also known as citrus greening. One symptom of the disease is mottling and chlorosis of leaves.

They aim to contain psyllid populations, catch the infection early in order to rapidly remove infected trees, and monitor commercial citrus using geospatial technology. Meanwhile, scientists in university laboratories are exploring the trees, the pest and the pathogen at the molecular and genetic levels to find a long-term cure, while advisors are engaging and educating the public to help in the fight against the disease's spread.



Asian citrus psyllid total trap count, 2008–2012. The Geographic Information Systems Facility at the UC Kearney Agricultural Research and Extension Center in Parlier has entered a partnership with the Citrus Research Board and CDFA to develop a statewide citrus mapping database, enabling the citrus industry to make strategic responses to ACP and HLB outbreaks. To date, the database has mapped 29,865 Asian citrus psyllid detections.

Spread of the psyllid

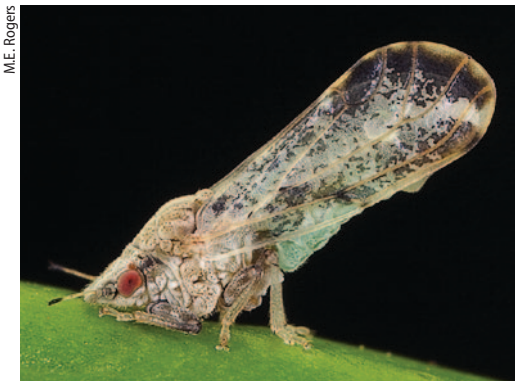
In March 2012, huanglongbing disease was detected in California for the first time. The multigrafted citrus tree in a Los Angeles County backyard was destroyed, but it is likely there are more infected trees nearby or in other areas. The disease is also spreading northward in Mexico toward California.

The psyllid and disease together present a grave threat to California's $2.1 billion citrus industry, the livelihood of citrus farmers and thousands of farmworkers, and the fragile economies in California's rural citrus belt, extending from San Diego through interior and coastal Southern California and up into the San Joaquin Valley. Their presence prevents exports to countries that do not have this pest and disease. The loss of citrus trees in urban areas of

California due to the disease will change the face of the landscape and reduce the availability of local fruit.

Ensuring pathogen-tested plant material

M.E. Rogers



UC researchers are pursuing a number of approaches to limit the spread of Asian citrus psyllid (*above*, feeding). By keeping populations low, they hope to limit the chances of psyllids picking up the huanglongbing pathogen.

The state of California has strict regulations in place to ensure that citrus trees are produced with pathogen-tested propagative material. However, the general public does not always understand the importance of these regulations, and people sometimes unknowingly bring diseased plant material into California and graft their own trees. The UC Citrus Clonal Protection Program (CCPP), housed at UC Riverside, is the gatekeeper of California citrus. Directed by Georgios Vidalakis, UCCE specialist in the Department of Plant Pathology at UC Riverside, CCPP is one of three programs authorized nationwide to import citrus budwood from overseas. CCPP services include disease diagnosis, pathogen detection and elimination, and the distribution of true-to-type citrus propagative material of fruit and rootstock varieties to nurseries and private individuals.

In the face of the current citrus threat, scientists at UC Riverside are developing a legal source of plant material for popular noncitrus hosts of the psyllid, such as bael tree, a native food plant of India also used for traditional medicine, and Indian curry leaf, a flavoring common in the cuisine of India, Pakistan, Bangladesh and other Southeast Asian countries. The program — run by Tracy Kahn, principal museum scientist, and David Karp, associate in the Agricultural Experiment Station, in the UC Riverside Department of Botany and Plant Sciences — will provide clients with pathogen-tested plants, reducing the incentive for smuggling plants and plant material into California that potentially harbor Asian citrus psyllid or huanglongbing disease.

Photos: M.E. Rogers

When psyllids feed on citrus leaves, the leaves become distorted and malformed. Psyllids extract large amounts of sap from trees and produce honeydew, which can cause sooty mold.

Managing the psyllid

Asian citrus psyllid is currently found only in Southern California. The majority of commercial citrus is grown in Central California. If its spread northward can be slowed, it minimizes quarantine and export issues and reduces the threat to Central Valley citrus production. If psyllid populations are kept low wherever they are found, then their chances of picking up the huanglongbing pathogen are reduced and spread of the disease is slowed. UC is actively mapping, monitoring and finding the best way to treat

M.E. Rogers

M.A. Hoy

Jack Kelly Clark

Left, **psyllid nymphs produce waxy tubules. Two biological controls that target the nymphs have shown promise in Florida. *Center*, the parasitic *Tamarixa radiata* (Waterson) wasp, from Taiwan and Vietnam, lays eggs underneath the nymph, and the wasp larvae will feed on and kill the psyllid. *Right*, lady beetles, *Harmonia axyridis* Pallas, feed on psyllid nymphs.**

Asian citrus psyllid to keep the Southern California populations in check.

Frank Byrne, an associate research entomologist, and Joe Morse, a professor in the Department of Entomology at UC Riverside, are studying the efficacy of the systemic pesticide imidacloprid to protect citrus trees in nurseries. "The treatments can protect the young trees for up to 3 months," Byrne said.

Scientists with UC Cooperative Extension are developing treatment options for homeowners and farmers who do not use synthetic pesticides on their citrus. The current recommendation for organic growers is to spray a low rate of horticultural spray oil on trees at 14-day intervals. Grafton-Cardwell is evaluating the effect of this treatment on citrus health, productivity and fruit quality for San Joaquin Valley navel oranges. Jim Bethke, UCCE advisor in San Diego County, is screening additional organic insecticides on a greenhouse colony of Asian citrus psyllid to find products that may have greater persistence and efficacy.

Mark Hoddle, UCCE specialist in the Department of Entomology at UC Riverside, collected two natural enemies of Asian citrus psyllid in Pakistan. The first is a tiny wasp, *Tamarixia radiata,* which lays eggs underneath late-stage nymphs. The hatching larvae eat the nymphs, killing them. The other, *Diaphorencyrtus aligarhensis,* is a small wasp that lays eggs in younger psyllid nymphs. *Tamarixia* is being released in urban areas of Southern California to help reduce Asian citrus psyllid populations.

At the UC Kearney Agricultural Research and Extension Center in Parlier, a geospatial map is being developed by the geographical information systems (GIS) team, led by Kris Lynn-Patterson, academic coordinator. The citrus map will be enriched with details about the California citrus groves — types of trees, whether conventional or organic, ownership, management and who is packing the fruit. Another layer on the database will identify factors that could influence the direction and speed of Asian citrus psyllid spread after an infestation is detected, such as weather patterns and traffic corridors.

Detecting infected trees

Finding trees infected with huanglongbing disease and eliminating them before the Asian citrus psyllid picks up the pathogen and spreads it to neighboring trees is a major challenge. The pathogen in the tree cannot be detected by lab testing for several months, and the symptoms — yellowed leaves, small and bitter fruit — may not show up for a year or more after infection. Meanwhile, the disease can be spread by the psyllid. Research is under way to develop early disease detection so that infected trees can be rapidly removed.

Cristina Davis, professor in the UC Davis Department of Mechanical and Aerospace Engineering, and Abhaya Dandekar, professor in the UC Davis Department of Plant Sciences, are refining a mobile chemical sensor that can rapidly discriminate between healthy and diseased citrus trees by sniffing their volatile organic compounds (VOCs). The researchers collected samples of VOCs emitted from trees infected with huanglongbing disease in Florida every month for a year in order to train the mobile sensor to recognize its smell. "The idea is to extract a group of compounds that creates the signature for the

Monique Gamier, INRA, France

A.R. Lee, USDA/ARS

George Vidalalakis

Leaves with huanglongbing symptoms, *top*. Note the yellow areas to one side of the midveins and the dark green areas directly opposite. Citrus trees with the disease often have, *top inset*, excessive and premature fruit drop, or, *above*, citrus fruits that are small, hard and misshapen or have rinds that do not color properly. Such symptoms may not show up in the tree for a year or more after infection. Research is under way to detect the disease earlier so that infected trees can be removed.

presence of huanglongbing disease," Dandekar said. A software program develops an algorithm that lets the machine know it is detecting the disease.

Carolyn Slupsky, UC Davis assistant professor with a split appointment in the Department of Nutrition and Department of Food Science and Technology, is looking at the metabolism of citrus trees infected with the pathogen associated with huanglongbing disease. Hailing Jin, associate professor in the Department of Plant Pathology and Microbiology at UC Riverside, is working to identify the huanglongbing-induced small RNAs that will indicate whether a citrus tree is infected with the disease. Wenbo Ma, associate professor of plant pathology at UC Riverside, believes pathogen-specific proteins in the tree's phloem, the food-conducting tissues of the plant, could be used as a more reliable disease detection tool than the pathogen itself.

In addition to careful visual monitoring for all stages of Asian citrus psyllid, yellow sticky cards can be used to detect adults.

Finding long-term solutions

Managing psyllids with insecticides and biological control doesn't eliminate the entire pest population, and it is difficult to remove infected trees fast enough to stay ahead of the disease's spread. Long-term solutions are needed to develop a citrus tree that can resist or withstand the bacterium and produce good-tasting, abundant fruit, or confound the psyllid so that it cannot transmit the disease.

Dandekar and his colleagues are experimenting with gene fusion to make citrus plants more effective at fighting the disease. "Many disease-causing microbes can evade one defensive action by a host plant, but we believe that most microbes would have difficulty overcoming a combination of two immune-system defenses," Dandekar said.

In Florida, researchers have found that trifoliate orange rootstock has some natural resistance to huanglongbing disease. They have enlisted their long-time collaborators in California to help determine the mechanism of this partial resistance and, eventually, to transfer it to edible citrus varieties. Mikeal Roose, professor in the Department of Botany and Plant Sciences at UC Riverside, and his colleagues are assisting in the genetic analysis of about 200 hybrid crosses between sweet orange and trifoliate orange, a species used as a rootstock. "We are sequencing a large number of genome fragments to find particular fragments that are associated with resistance," Roose said.

Engaging and educating the public

The ability to keep Asian citrus psyllid and huanglongbing disease at bay depends in large part on the active involvement of commercial citrus growers and California residents with citrus trees in their home landscapes. They need to understand the impact of the disease on their trees and participate in the management program. Grafton-Cardwell has pulled together a team of scientists to develop large-scale extension activities and aggressive management programs to stave off devastating commercial and residential losses in California. The project is funded with a 5-year grant from UC Agriculture and Natural Resources.

A team of USDA and UC scientists are producing a palm-sized flipbook that will give CDFA inspectors ready access to pictures and the identifying features of 25 plants that are hosts of Asian citrus psyllid. The California Citrus Research Board, which is funding much of the current university research, will publish the flipbook. Matt Daugherty, UCCE specialist in the Department of Entomology at UC Riverside, will be researching the plant management practices used in retail nurseries and garden centers, such as irrigation frequency, soil type and pot size. Pam Giesel, UCCE academic coordinator for the UC Master Gardener program, is working with Daugherty on a statewide effort to engage UCCE's 5,500 volunteer master gardeners in an education program. Scientists will train master gardeners and provide curriculum and other learning materials so they can convey information about the pest and its management to residents they serve.

Karen Jetter, associate project economist with the UC Agricultural Issues Center in Davis, is developing economic models to estimate the costs of Asian citrus psyllid and management in backyard citrus and commercial orchards, and linking the information to a geospatial database. "The tool will include all the information necessary for a homeowner, grower or pest control adviser to determine the most effective and affordable pest management for his or her situation," Jetter said.

Sustainable citrus production in California in the presence of Asian citrus psyllid and huanglongbing disease will depend upon a combination of tactics, including genetic engineering as well as applied pest and disease management strategies, Grafton-Cardwell said.

"Scientists at UC and around the world are working to develop solutions," she said.

— Jeannette Warnert

Analysis reveals potential rangeland impacts if Williamson Act eliminated

by William C. Wetzel, Iara L. Lacher, Daniel S. Swezey, Sarah E. Moffitt *and* Dale T. Manning

California budget cuts have resulted in dramatic reductions in state funding for the Williamson Act, a land protection program that reduces property taxes for the owners of 15 million acres of California farms and rangeland. With state reimbursements to counties eliminated, the decision to continue Williamson Act contracts lies with individual counties. We investigated the consequences of eliminating the Williamson Act, using a geospatial analysis and a mail questionnaire asking ranchers for plans under a hypothetical elimination scenario. The geospatial analysis revealed that 72% of rangeland parcels enrolled in Williamson Act contracts contained habitat important for statewide conservation goals. Presented with the elimination scenario, survey respondents reported an intention to sell 20% of their total 496,889 acres. The tendency of survey participants to respond that they would sell land was highest among full-time ranchers with low household incomes and without off-ranch employment. A majority (76%) of the ranchers who reported that they would sell land predicted that the buyers would develop it for nonagricultural uses, suggesting substantial changes to California's landscape in a future without the Williamson Act.

Sarah E. Moffitt

The Williamson Act reduces property taxes for private owners of California farmland and rangeland. In a survey, ranchers were asked what their plans would be for their land if the tax benefit were eliminated. *Above*, cattle graze near Santa Rosa.

Ranching provides broad social, economic and environmental benefits to the state of California (Huntsinger and Hopkinson 1996; Knight et al. 1994, 2002). Properly managed rangeland can conserve important ecosystem services, including the delivery of fresh water and maintenance of habitats vital for native flora and fauna (Barry and Huntsinger 2002; Marty 2004). California ranching has faced an increasingly volatile economic climate in recent years (Andersen et al. 2002). The rate of rangeland development in California for nonagricultural uses exceeds the landscape conversion rate for both forest and croplands, and this accelerating development is predicted to continue for rangelands surrounding California's Central Valley (CDF-FRAP 2010). This development pressure threatens both the ranching industry and the native species that depend on rangeland for survival.

The economic success of ranching in California is intertwined with the California Land Conservation Act of 1965 (known as the Williamson Act), one of the nation's oldest agricultural conservation programs. The goal of the Williamson Act is to preserve agricultural and open space lands by encouraging landowners to stay in agricultural production through reduced property tax rates. Under the Williamson Act, landowners voluntarily commit to maintaining their land in agricultural production under a local county contract for a minimum of 10 years. In return, landowners receive a reduction in their annual property taxes. Under the original program, contract-holding counties received annual subvention payments from the state in proportion to their enrollment and to the productivity of the enrolled lands. These funds helped compensate for the tax revenue losses counties faced due to their participation in the program. Since 1965, thousands of California ranchers and 53 of the 58 counties in California have enrolled in the Williamson Act program.

Beginning in budget year 2008-2009, California drastically reduced subvention reimbursements to counties as part of a plan to phase out the program. In 2009-2010, California Governor Arnold Schwarzenegger cut state subvention funding to $1,000, essentially eliminating state support. In 2008, before subvention payments were cut, state reimbursements to counties ranged from $5.2 million in

Online: http://californiaagriculture.ucanr.edu/landingpage.cfm?article=ca.v066n04p131&fulltext=yes

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heavily agricultural counties (e.g., Fresno, Kern, Tulare) to less than $12,000 in more urbanized counties (e.g., Orange, San Bernardino). In 2010, in response to subvention payment loss, Imperial County ended its participation in the program, nonrenewing (allowing contracts to expire) contracts countywide. Under mounting budget deficits, a number of counties placed a moratorium on new contracts because of uncertainty surrounding the future of subvention payments (Sokolow 2010).

Williamson Act savings may make a critical difference in turning a profit versus taking a loss for the majority of California ranchers.

Assembly Bill 1265 (passed in 2011) offers counties the option to continue Williamson Act contracts while giving them an opportunity to recoup some lost tax revenues. Under AB 1265, a county can shorten Williamson Act contracts by 10% and increase the assessed value of land by 10% of the difference between Proposition 13 values and the Williamson Act assessed value. This option becomes available if state subvention payments fall below half of a county's actual foregone general fund property tax revenue. This increased property tax revenue is allocated exclusively to counties; for many counties this is projected to compensate for lost state subvention payments. If landowners agree to enter into the shorter contracts, counties would presumably be encouraged to stay in the program because they avoid losing property tax revenue. Because the state has not approved funding for future subvention payments, the decision to continue the program under this new structure has fallen into the hands of individual counties.

Using a mail survey and landscape analysis, we explored the economic and ecological impacts if counties decided to eliminate Williamson Act contracts.

Survey design and delivery

In 2010, we collaborated with the California Cattlemen's Association (CCA), a ranching membership association, to randomly survey 702 CCA members from 33 counties of California's Central Valley and surrounding foothills. We used stratified random sampling to select 62% of the region's CCA members. We chose these counties because they overlapped with a California Rangeland Conservation Coalition study of sensitive rangeland habitats (CRCC 2007b). In a few cases, respondents owned additional land in counties not included in the CRCC study. We used the Dillman (2000) method for mail questionnaires to ask ranchers about their Williamson Act contracts, ranching operation finances, attitudes toward the Williamson Act and future ranching plans. The questions forming the core of our analysis asked ranchers for their plans in the hypothetical event that their Williamson Act–sponsored tax reductions were eliminated. Additional demographic, fiscal and geographic information was also collected.

Survey responses to hypothetical scenarios are typically subject to biases (List and Gallet 2001). In our survey, respondents had a potential financial interest in maintaining Williamson Act funding and thus may have perceived an incentive to report exaggerated consequences of contract elimination. We deal with this potential bias by interpreting results as relative vulnerabilities instead of as exact predictions of future behavior and land use. Comparisons of relative vulnerabilities are justified because ranchers in all socioeconomic categories benefit from their Williamson Act contracts and all may have perceived an incentive to respond in ways that protect the Williamson Act. Where we discuss absolute sizes of reported impacts, we interpret them as upper limits for rancher responses to the loss of Williamson Act contracts.

We received responses from 52% of the 702 ranching businesses randomly selected for our survey. Of the 364 returned surveys, 294 (84%) reported ownership of rangeland in California and 57 (16%) responded that they exclusively leased land for their livestock operations. Of the landowners, 244 (83%) indicated that they held Williamson Act contracts. Not all 244 respondents answered every question, so sample sizes varied by question.

We used an exploratory data analysis approach to summarize relationships in the survey responses. Our approach involved graphing response and independent variables followed by a visual assessment of any relationships conforming to particular hypotheses. The strength of this approach is that it is robust to nonlinearity and outliers because it makes few

Sarah E. Moffitt

Under a hypothetical elimination scenario for Williamson Act contracts, ranchers predicted that about three-quarters of the land sold in response would be commercially developed. Conversely, 80% said that their heirs would continue grazing the land if the contracts continued.

assumptions about shapes of curves and distributions of data (Bolker 2008).

Landscape analysis

We used ArcGIS software to calculate the percentage of nonprime Williamson Act contract parcels in the 33 counties that overlapped with sensitive habitat on the CRCC's biological prioritization map (CRCC 2007b), which identifies areas of privately owned rangeland that "have high biodiversity value and require conservation action in the next 2 to 10 years" (CRCC 2007a). We chose nonprime parcels because they are primarily rangeland. The Williamson Act defines prime and nonprime land based on per-acre production value.

We based the analysis on the percentage of parcel overlap instead of area of overlap because a large portion of publicly available county data contained insufficient acreage data. We obtained the Williamson Act parcel data from county websites. San Benito and San Joaquin counties did not have prime/nonprime designations in their publicly available Williamson Act parcel data. For these two counties, we used data on the distribution of grazing land from California's Farmland Monitoring and Mapping Program (FMMP) to deduce the Williamson Act categories of unlabeled Williamson Act parcels. This was done by extracting parcels within the county that were also designated as grazing land by the FMMP. Therefore, for these counties we assume grazing Williamson Act land is also nonprime Williamson Act land.

Importance of property tax reductions

Opinions and perceptions. The majority of ranchers (91% of 237) reported that the Williamson Act was "very important" or "extremely important" for the "long-term viability of their cattle and rangeland operations" and for "ranching in California as a whole" (96% of 240); the rest said it was "slightly," "somewhat," or "not at all" important for their ranch and ranching in California as a whole. Enrolled ranchers estimated a $10,000 median annual property tax reduction through their participation in Williamson Act contracts (with a range from $1,000 to $120,000), which fits with county estimates of rancher savings over their Proposition 13 property taxes (e.g., in 2003 Yolo County estimated a per-acre savings of $6 to $15; Sokolow and Bennett 2004).

The proportion of ranchers who reported that the Williamson Act was important for the long-term viability of their rangeland operations decreased with increasing household income level. Those who identified as part-time ranchers, or as ranchers who were additionally employed off-ranch, also placed reduced overall importance on the Williamson Act. Opinions regarding the importance of the Williamson Act did not vary by ranch acreage, years spent ranching, estimated land values, estimated ranch profit, rancher age or previous land sale history. The result that Williamson Act importance varies with household income but not with ranch profit is also true for vulnerability to selling.

Profits and savings. Seventy-three percent of respondents reported that in 2009 they earned less than $10,000 in annual profit from their ranching businesses (fig. 1) and 71% reported that their annual profit was equal to or less than their Williamson Act savings. Ninety-three percent of ranchers earning less than $10,000 in annual profit reported that their Williamson Act savings exceeded their profit in 2009. These results indicate that Williamson Act savings may make a critical difference in turning a profit versus taking a loss for the majority of California ranchers.

Propensity to sell land

On average, ranchers said they would sell 29% ± 3.2% (mean ± standard error) of their owned rangeland under the hypothetical scenario of Williamson Act contract elimination. Ranchers tended to plan to sell all or none of their ranch with relatively few planning to sell parts of

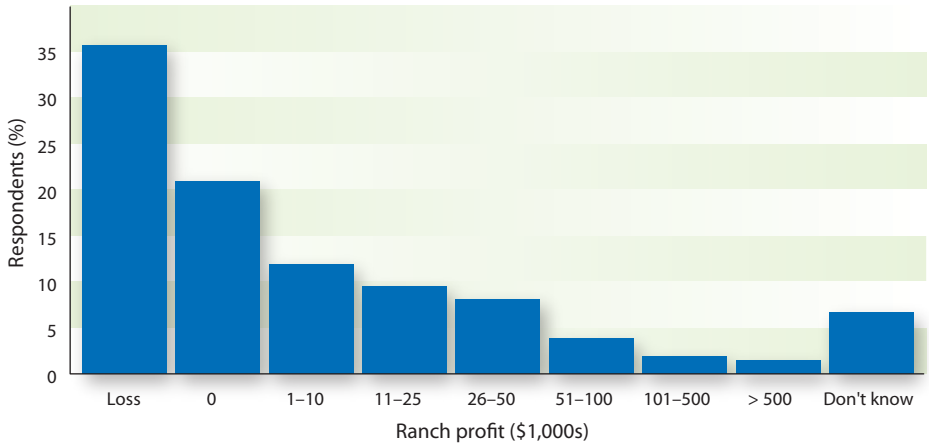

Fig. 1. Ranching operation profits reported by survey respondents who had land enrolled in Williamson Act program, 2009 (*n* = 196).

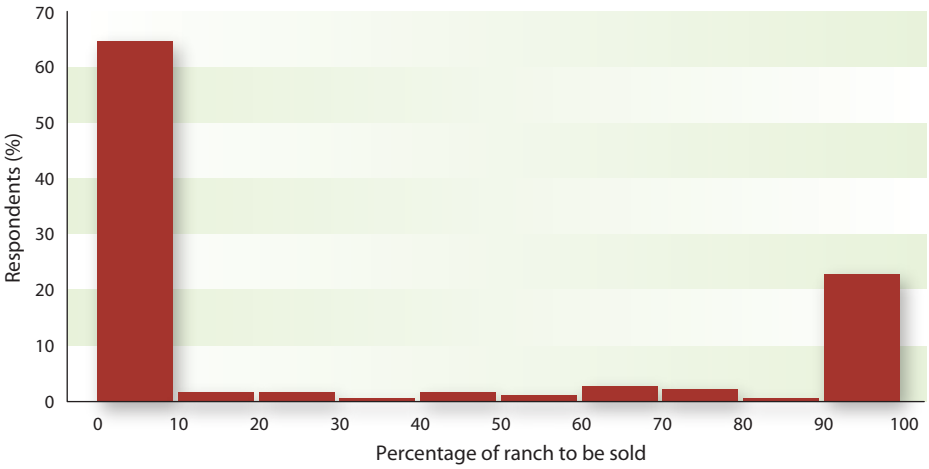

Fig. 2. Rancher estimates of percentage of rangeland they would attempt to sell given elimination of Williamson Act contracts (*n* = 175). Answers are binned into 10% increments.

ranches (fig. 2). Only 18% of respondents reported that they would sell a portion of their ranch, whereas 19% planned to sell all and 63% planned to sell none. Respondents intended to sell a total of 99,137 acres, or 20% of the total owned acreage reported.

These numbers give an indication of rancher-stated intentions, not the true amount of land that would be sold. We interpret them as upper bounds on the true values for two reasons. First, not all intentions to sell land translate into land sales; it can often be difficult to find buyers. Second, this is a hypothetical scenario and responses on reported intent to sell could be exaggerated.

Williamson Act parcel vulnerability

We used two metrics to assess a ranch's vulnerability in the Williamson Act contract elimination scenario: the estimated probability of selling a ranch (on a scale from 1 to 5), and the estimated percentage of ranch acreage respondents would intend to sell. The choice of metric did not change the conclusions of the analysis, so we present results only for the estimated percentage of ranch acreage intended to be sold. The vulnerability metrics varied most strongly with household income, off-ranch employment and additional operational income from ranch sources other than livestock production (e.g., tourism, hunting, firewood operations). There was no clear relationship between vulnerability and other rancher or ranch enterprise characteristics (analysis not shown), including years spent ranching, estimated land sale price, ranch distance from town and history of nearby development, among many others. Our results may exaggerate the absolute value of vulnerability, but only the relative value of vulnerability matters for these comparisons.

Household income and ranch profit. There was a strong negative relationship between household income and ranch vulnerability (fig. 3) but no relationship between ranch profit and vulnerability. Respondents with off-ranch employment or identifying as part-time ranchers tended to have higher household incomes. Ranchers with diversified ranch activities other than cattle production also intended to sell less land (23% of total land owned) on average compared to ranchers whose sole ranch income came from cattle production (33% of total land owned). In contrast, there was no relationship between ranch profit and vulnerability. The one exception to this trend was that none of the ranches earning over $100,000 in profits intended to sell any land in the Williamson Act termination scenario.

Future land use. Predictions made by ranchers regarding the future use of their land showed a potential for loss of open space and rangeland in California if Williamson Act tax reductions ended. Ranchers predicted that 76% of the land sold in response to Act elimination would likely be developed commercially for nonagricultural, nonopen space uses including housing developments (fig. 4). Only 15% of these same ranchers listed continued grazing as a likely future land use after sale. In contrast, the majority of respondents (78%) reported that their heirs would continue grazing their land if Williamson Act contracts continued. Fewer than 2% reported that heirs would develop their rangeland for urban or suburban use. While these numbers do not directly translate to an estimate of the total acreage that would be developed, they do suggest that land passed to heirs might have a greater chance of escaping development than land put up for sale in the event of Williamson Act elimination. Commercial development is only one of several possible outcomes for land sold by ranchers, but the fact that this was the most commonly predicted outcome is alarming.

Trends in ranch vulnerability. Household income played the strongest role in determining the probability that a rancher would intend to sell land, with higher income groups intending to sell less land

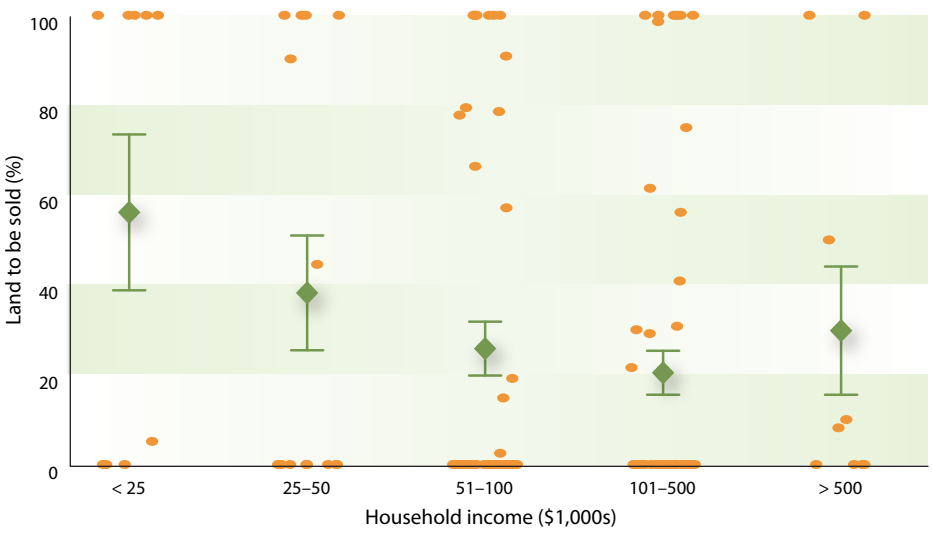

Fig. 3. Percentage of owned ranchland that respondents in different household income categories reported they would attempt to sell given elimination of the Williamson Act (*n* = 134). Green diamonds are the average percentage of ranchland to be sold; green lines show one standard error above and below the mean; orange points show actual data points spread out horizontally within each household income category.

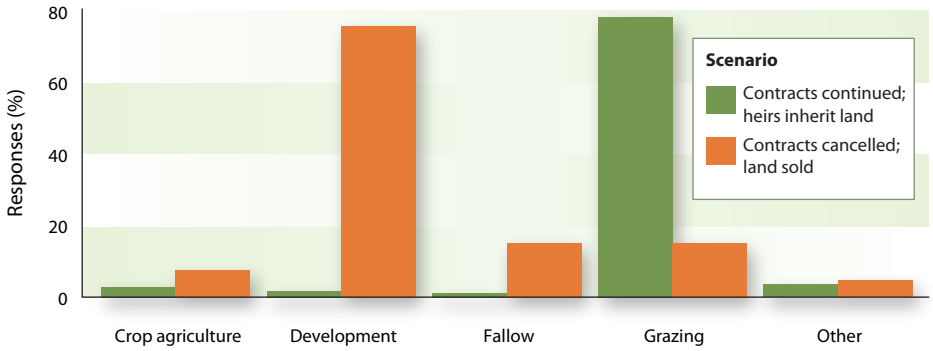

Fig. 4. Rancher predictions for future use of their land under ownership of heirs if Williamson Act contracts continued, and if they were eliminated and the land was sold.

than low-income ranchers. Interestingly, 5% of ranchers earning $100,000 or more in annual household income reported that they did not know their ranching operational profit from 2009. This finding suggests that among wealthier owners, ranching profits play a small role in land sale decisions. The 5.6% of respondents who reported annual household incomes of less than $25,000 and profits less than $10,000 were the group with the greatest vulnerability. Diversification away from sole dependence on conventional ranching activities is an emergent trend in the economic landscape of California ranching (Rilla et al. 2011). Survey respondents who were part-time ranchers, had off-ranch employment or earned ranch income from sources other than cattle (e.g., agritourism) reported far lower ranch vulnerabilities. That ranch diversification decreases economic vulnerability should be an important lesson for ranchers and conservationists in California.

Development pressure. Most ranchers who intended to sell land in the Williamson Act elimination scenario indicated that they believed it would be developed for nonagricultural use. This trend suggests that many ranchers perceive significant development pressures in the areas surrounding their parcels. The location of rangeland parcels will determine the scale of property tax increases in the absence of the Williamson Act savings and obviously influence the degree of development pressure and the land's resale value. If development across California follows previous models for the Mojave Desert regions, land located close to cities and other development is more likely to develop first (Gomben et al. 2012) and thus may see a larger increase in property taxes without the Williamson Act. Land sale by economically vulnerable ranch households may be more likely in these areas.

Heirs. A major finding of our study was that a majority of ranchers believed their heirs would continue to commercially graze their properties when land is passed to them (fig. 4). This suggests that if the Williamson Act remains in place, ranching communities and rangeland in California may be protected in the near future, and that the Williamson Act is meeting its goal of preserving agricultural communities and ranching landscapes in California.

Conservation value of nonprime parcels

Out of 102,384 nonprime Williamson Act parcels within the CRCC study region, 43,639 were located within CRCC "critical" habitat, and 29,672 were located within CRCC "important" habitat (fig. 5). Thus, 43% of nonprime Williamson Act parcels in our study area were classified as CRCC "critical," with an additional 29% classified as "important." A future without the Williamson Act in place may see increasing development and conversion of rangeland that is critical or important for conservation, putting ecologically valuable habitats at risk.

The large majority of nonprime Williamson Act parcels in our study area were located in the foothills encircling the Central Valley. CRCC habitats designated as either critical or important were scattered throughout the lower elevations of the foothills, with a patchy distribution spanning multiple habitat types generally dominated by oak savannas and grasslands (CRCC 2007b; LandFire 2010). These grassland habitats are home to native plants and animals and threatened vernal pool ecosystems and associated organisms, at least some of which benefit from moderate grazing (CRCC 2007b; Marty 2004).

An important land management tool

The Williamson Act has served as a land management tool for close to half a century by encouraging the conservation of agricultural lands, open spaces and rural communities throughout the state. Under the current state budget crisis, AB 1265 means that counties now must decide if they want to continue honoring Williamson Act contracts through the shortening of contract duration and the reduction of tax benefits to landowners. Many counties will likely continue with the modified version of the Williamson Act because the benefits are popular with property owners and the increase in revenue can compensate for the loss of state subvention payments. Some counties with major budget shortfalls, like Fresno,

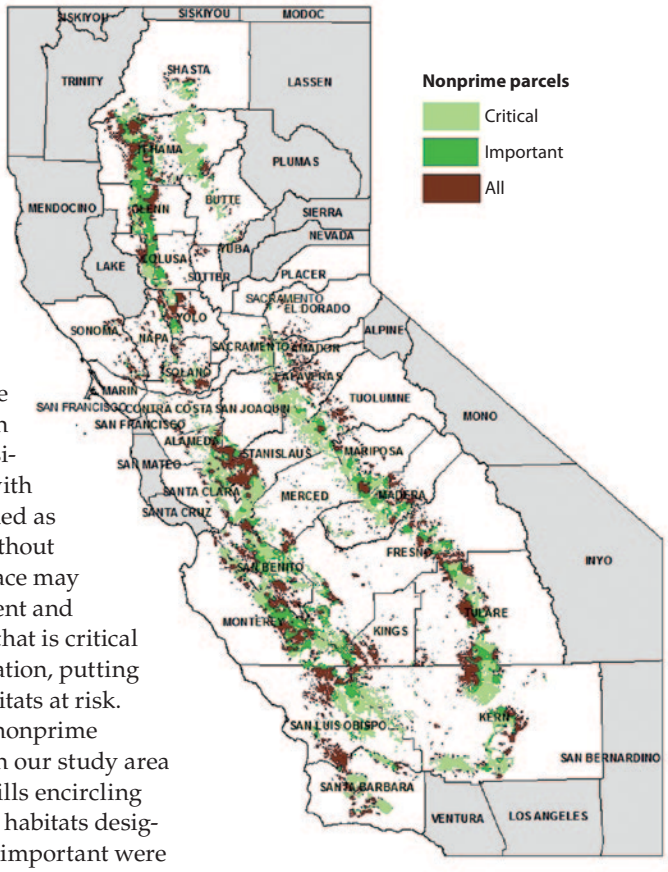

Fig. 5. Conservation designation of all nonprime Williamson Act parcels within California Rangeland Conservation Coalition (CRCC) study area, showing high overlap between nonprime Williamson Act parcels and CRCC conservation habitat (CRCC 2007b).

have already gone down the road of reducing benefits to landowners. Beyond politics, a fundamental question is what will happen to rangeland and ranching in California if counties begin to eliminate Williamson Act contracts (fig. 6).

Results of this study show that ranchers perceive the Williamson Act to be a critical component of their ranching businesses. Ranching is a low-profit venture nationally (Gosnell and Travis 2005). Our study confirms this for California: 71% of Williamson Act–enrolled ranchers reported a net annual profit equal to or less than their Williamson Act property tax savings in 2009. Williamson Act tax reductions make the difference between profit and loss for the majority of California ranchers in the Central Valley and surrounding foothills. Ranchers with high annual household incomes, typically earned from off-ranch employment, seemed less likely to be influenced by a decrease in profits or changing property

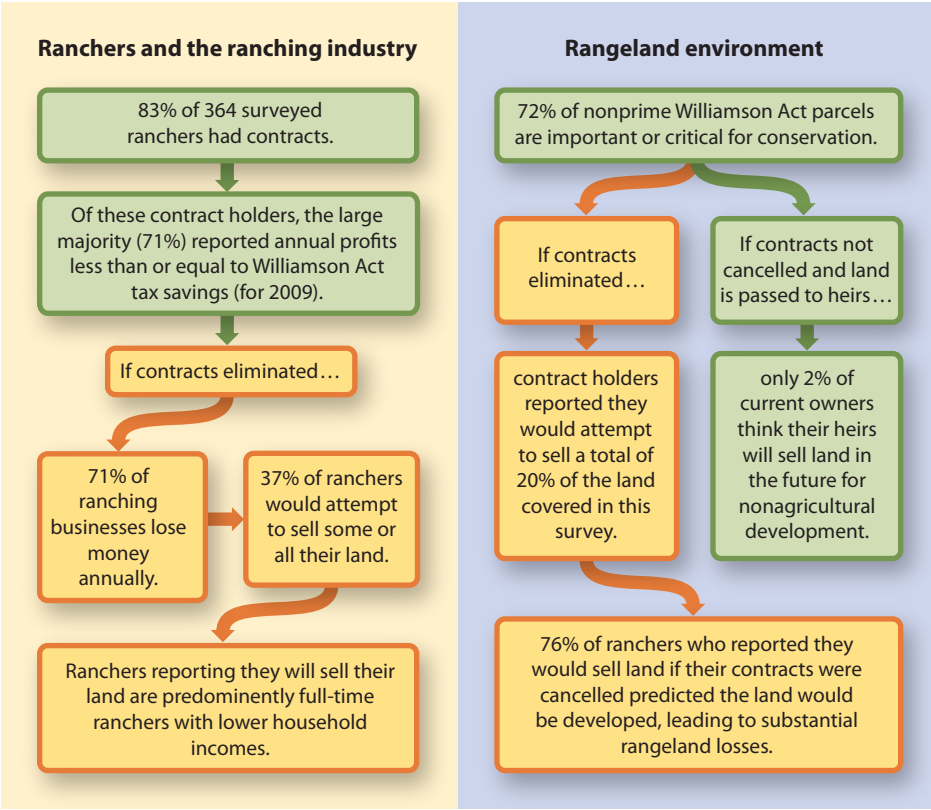

Fig. 6. Possible consequences of eliminating Williamson Act contracts and property tax savings for ranching landowners.

tax burden. On the other hand, full-time ranchers with low annual household incomes frequently reported that they intended to sell land if they had to pay full property taxes in the absence of the Williamson Act. Our results indicate that the Williamson Act program buffers low-income, full-time ranchers from fiscal insolvency. The likelihood that ranchers who lose their Williamson Act contracts would attempt to sell land increases among our survey population as household income decreases.

Nonrenewal of Williamson Act contracts could make large areas of rangeland throughout the state vulnerable to sale, and ranchers indicated that these lands would likely be commercially developed. These lands have important conservation value and host numerous rare and endangered plant and animal species (CRCC 2007b). New conservation grazing and sustainable rangeland management practices (Brunson and Huntsinger 2008) hold significant promise as tools for integrating ecological conservation with agricultural production and preserving the integrity and beauty of the California landscape. Careful consideration of how policymakers can protect rangeland and its diverse habitats is of utmost importance in the years to come.

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Clean Development Mechanism agricultural methodologies could help California to achieve AB 32 goals

by Ariel Dinar, Donald F. Larson *and* J. Aapris Frisbie

California Assembly Bill 32 (AB 32), passed in 2006, mandates reductions in California's greenhouse gas emissions to 1990 levels by 2020. Charged with implementing the bill, the California Air Resources Board has identified emission reduction strategies, including nine for agriculture. The goals set for agriculture are voluntary, but because the agricultural sector represents a significant portion of both the state's economy and its greenhouse gas emissions, it offers considerable opportunities for mitigation activities. To reduce compliance costs, the Board's plan includes a cap-and-trade program that allows for offsets to be purchased from nonregulated firms that undertake mitigation in or outside the state. However, methodologies are needed to assess the impact of mitigating activities. Without them, emission reductions are expected to fall far short of potential. We review an existing international mechanism — the Kyoto Protocol's Clean Development Mechanism (CDM) — that offers a framework for evaluating offset projects and advanced methodologies that could facilitate AB 32 implementation in California.

Ariel Dinar

The U.N. Clean Development Mechanism promotes projects that reduce greenhouse gas emissions in developing countries. Its methodologies can help inform the implementation of California's AB 32. *Above*, crop material is transported for processing as biofuel in Marrakesh, Morocco.

Greenhouse gas emissions change in response to population and economic growth. Net emissions in California rose between 2000 and 2004 from 459.2 to 484.0 million metric tons of CO_2 equivalent (million $MtCO_2e$) before declining to 453.0 million $MtCO_2e$ in 2009 as the economy slowed (ARB 2012) (fig. 1). Agricultural emissions, as a fraction of total net emissions, are also gradually increasing, from 6% in 2000 to 7% in 2009.

In 2006, the California legislature passed Assembly Bill 32 (AB 32), the Global Warming Solutions Act of 2006 (ARB 2006), which requires California to reduce greenhouse gas emissions to the 1990 level of 427 million $MtCO_2e$ by 2020. This amounts to a 15% reduction in 2008 levels and a 30% reduction in levels that would occur by 2020 if no actions were taken. AB 32 directs the California Air Resources Board (ARB) to develop a plan for reducing greenhouse gas emissions, which the agency completed and made available for public comment (ARB 2008, 2010a). The plan identifies emission reduction strategies targeting emission sources for different sectors; nine focus on agriculture (CAT 2008). The reductions are mandatory for some sectors, such as industrial enterprises and electrical power operations, but for agriculture they are voluntary.

Agriculture represents a significant economic sector in California; it uses 25% of the state's land and consumes about 75% of its water resources (Hanak et al. 2011; USDA 2007). California agriculture produced approximately $34.8 billion in revenue in 2010 (Agricultural Statistical Review 2010) and ranks number one among states in agricultural cash receipts (CAT 2008). In terms of greenhouse gas emissions, agriculture accounted for about 7.1% of California's total in 2009 (table 1).

What is a metric ton of carbon dioxide?

Driving from Los Angeles to Washington, D.C. — assuming that a full tank of gasoline yields an average of 300 miles — produces the equivalent of about 1 metric ton of carbon dioxide ($MtCO_2e$) in emissions (Ha 2012).

Cap-and-trade program

The Air Resources Board plan for achieving AB 32 goals includes a combination of direct regulations,

Online: http://californiaagriculture.ucanr.edu/landingpage.cfm?article=ca.v066n04p137&fulltext=yes
DOI: 10.3733/ca.v066n04p137

performance-based standards and market-based mechanisms. The centerpiece is a cap-and-trade program, which would initially target certain production or distribution processes, including cement production, oil refining, and other significant users of fossil fuels. The program is designed to potentially be linked to similar programs, in particular to an envisioned regional cap-and-trade program that includes New Mexico, British Columbia, Quebec and Ontario.

Under California's proposed cap-and-trade program, regulated firms would be given allowances for greenhouse gas emissions once a year beginning in 2012, declining 2% to 3% per year to match emission reduction targets. Firms with surplus allowances could sell or save (bank) them for future use. Firms unable to reduce their emissions or looking to increase emissions could enter the market to purchase surplus allowances (ARB 2010a).

These trading features of the proposed program (LAO 2012) are standard components of cap-and-trade systems, including those pioneered in California to reduce air pollution (Larson and Parks 1999). The Board's proposed program is also innovative because it would be open to additional private or public mitigation activities that reduce emissions or sequester greenhouse gases. Firms or groups in noncapped sectors may undertake mitigation activities and then be credited with offsets. Regulated firms can buy these and use them in lieu of government-issued allowances to meet a portion of their regulatory requirements (ARB 2010b). Firms in capped sectors could also theoretically undertake mitigation activities beyond their quota, depending on their marginal abatement cost.

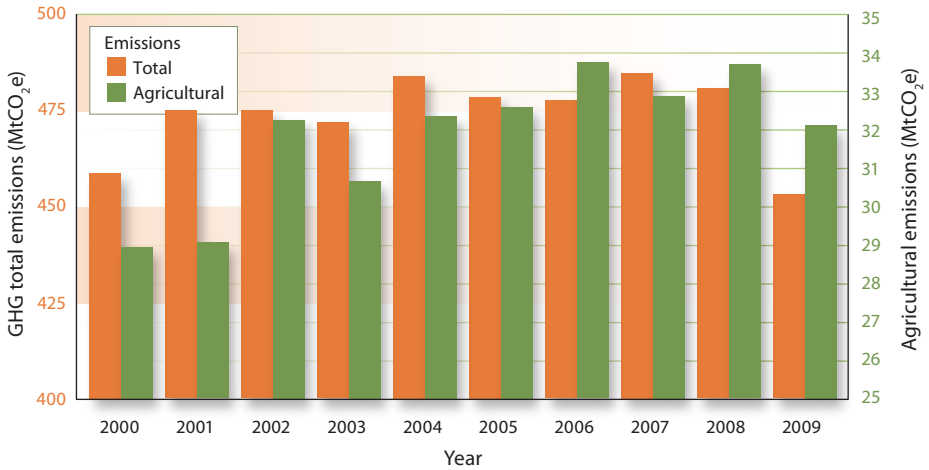

Fig. 1. California net greenhouse and agricultural emissions 2000–2009, in million metric tons CO_2 equivalent ($MtCO_2e$). Carbon dioxide equivalent (CO_2e) measures emissions based on global warming potential. Source: ARB 2012.

TABLE 1. Agriculture's contribution to greenhouse gas emissions in California, 2009

Source	Emissions
	*million $MtCO_2e$**
Agriculture (all subsectors)	**32.13**
Livestock	19.64
Enteric fermentation	9.30
Manure management	10.35
Crop growing and harvesting	9.84
Fertilizers	8.44
Soil preparation and disturbances	1.32
Crop residue burning	0.07
General fuel use in agriculture	2.65
Forestry	0.19
Calif. total gross emissions	**456.77**
Forestry net emissions	−3.80
California total net emissions†	**452.97**

Source: ARB 2012.

* Million metric tons CO_2 equivalent; based on Smith et al. 2007.

† Total emissions of greenhouse gases in California for 2009 included emissions from these sources and sectors: transportation (172.92 million $MtCO_2e$), electric power (103.58 million $MtCO_2e$), commercial and residential (42.95 $MtCO_2e$), industrial (81.36 million $MtCO_2e$), recycling and waste (7.32 million $MtCO_2e$) and high global warming potential (GWP) gases (16.32 million $MtCO_2e$).

Trading under the cap, and potentially supplementing allowances with offsets, are both expected to reduce compliance costs, an objective of the Board's plan. The two mechanisms are complementary: trading creates price signals that motivate regulated firms to seek low-cost mitigation opportunities, and the opportunity to earn credits that can be sold encourages regulated and nonregulated firms and groups to seek low-cost mitigations in sectors where emissions are not capped.

To work, the program requires a comprehensive set of standards and regulations that details how emissions are measured and offsets created, especially if it is to be part of a regional cap-and-trade system. The standards and regulations must rigorously protect the environmental benefits associated with emission reductions, because regulated emitters have incentives to under-report emissions, and both buyers and sellers of offsets benefit from exaggerated mitigation claims (Chomitz 1999). Initially, the Board plan envisions four sets of rules, called compliance offset protocols, for offset-generating projects, including one for livestock projects.

Livestock production is the agricultural subsector with the highest emissions and in turn with the highest potential for mitigation (table 1). It uses approximately 37% of the state's agricultural land (USDA 2007), and it generated 61% of California's agricultural greenhouse gas emissions in 2009. The remaining 63% of agricultural land is used for field, fruit and nut crops; these crops generated 30% of the state's agricultural emissions in 2009 due to fertilizer use, soil preparation and disturbances, and the burning of crop residue. Fuel used for agricultural activities contributed the remaining 8%.

Since agriculture represents a significant portion of both the state's economy and greenhouse gas emissions, it is not surprising that it offers considerable mitigation opportunities. The Climate Action Team (CAT), the government agency responsible for implementing California's global warming emission reduction programs, estimated that agriculture's annual greenhouse gas emissions could be reduced by 9.1 million $MtCO_2e$ per year if the emission reduction strategies were fully implemented (CAT 2006, 2008).

Nine strategies for agriculture

The mitigation potential for agriculture is comprised of nine strategies, each of which contains identified activities for implementation (table 2). The most significant strategies concern the uses of biomass: Converting manure to energy could generate annual reductions of 1 million

$MtCO_2e$ and using other types of agricultural biomass another 2.3 million $MtCO_2e$.

Other important strategies concern carbon sequestration. When plants photosynthesize, they remove carbon dioxide from the atmosphere and convert it into organic carbon, which is used in the production of plant biomass; for example, leaves, wood, roots or root exudates. When leaves fall, roots secrete or plants die, this carbon can be removed from active cycling and stored, or sequestered, in the soil if it is protected from microbial decomposition (Jastrow et al 2007). Consequently, carbon sequestration can be achieved by farmscaping — planting trees, shrubs and grasses in hedgerows, which removes carbon dioxide out of the atmosphere and contributes to the formation of soil complexes that fix carbon. Carbon sequestration in soils and plants could save 2.5 million $MtCO_2e$ — 1.5 million $MtCO_2e$ from farmscaping (CAT 2008) and another 1.0 million $MtCO_2e$ in soils (table 2).

Although the Board proposed a livestock protocol and rules on fuel use that might support several strategies, significant hurdles prevent implementation of many of the strategy activities. In its AB 32 analysis, the Climate Action Team noted that methodologies for more than half of the agricultural strategies were not in place, in part because of a lack of scientific research (CAT 2008). This situation accounts for much of the difference — approximately 25%, or 2.8 million $MtCO_2e$ — between potential reductions for 2020 if the strategies were implemented and reductions deemed feasible by that year (table 2).

The Clean Development Mechanism

The challenges facing the Air Resources Board are not completely uncharted. There has been considerable experimentation on how to structure agricultural projects that reduce emissions or sequester carbon, beginning with voluntary pilot projects under the auspices of the United Nations (Larson and Breustedt 2009). Particularly relevant are thousands of projects operating under the Clean Development Mechanism, which promotes technology transfer and private and public investments in emission reduction and sequestration projects in developing countries.

The Clean Development Mechanism is a project-based provision of the Kyoto Protocol, an international agreement linked to the U.N. Framework Convention on Climate Change (UNFCCC), which aims to reduce greenhouse gas emissions and enhance welfare in developing countries. Credits generated by these projects can be used to meet pledged emission reduction commitments under the UNFCCC. The structure is analogous to the California Air Resources Board's proposed program, which allows independent entities to create offsets that regulated firms can use. For example, since agriculture is an unregulated sector under the California program, a livestock farmer could potentially capture livestock methane emissions, receive offset credits for the voluntary emission reduction, and in turn sell them to a regulated entity such as a concrete manufacturing facility in need of additional carbon allowances. Central to the Clean Development Mechanism are its technical blueprints, called methodologies, which lay out rules for calculating the number of credits granted for specific mitigation activities.

Overall, the Clean Development Mechanism has successfully attracted project investments (Rahman et al. 2010), though it has been more effective in some agricultural mitigation activities than others (Larson et al. 2011). Agricultural mitigation projects, those that convert organic waste products to energy and limit methane emissions, have been successful under the Clean Development Mechanism, but land-use projects have not been successful under the Clean Development Mechanism in its current form. Land-use projects are defined as the total human arrangements, activities, and inputs undertaken in a certain land cover type to achieve purposes for which land is managed, such as crop production, grazing, timber extraction and conservation. Land-use forestry projects are those associated with decreasing emissions through avoiding deforestation, improving forest management

In California, dairies such as Straus Family Creamery overlooking Tomales Bay are reducing greenhouse gas emissions by converting cow manure into energy in methane digesters. Under the tarp, the liquid manure is transformed by bacteria into biogas, which powers an engine that fuels an electric generator.

TABLE 2. Emission reduction proposals for California agriculture

Strategies	AgCAT* estimate of maximum possible annual reduction with 100% implementation of strategy	AgCAT estimate of annual reductions deemed feasible by the year 2020	Subsectors with potential for reduction (table 1)
	million $MtCO_2e$		
Agricultural pump efficiency	0.2	0.2	Crop growing and harvesting
Tractor tire inflation	0.1	0.1	Soil preparation and disturbances
Manure to energy facilities	1.0	1.0	Manure management
Fertilizer use efficiency	1.0	1.0	Fertilizers
Agricultural biomass utilization	2.3	0.6	Crop growing and harvesting
Dedicated biofuel crops	1.0	1.0	Crop residue burning
Soil carbon sequestration	1.0	1.0	
Farmscape sequestration	1.5	0.5	
Enteric fermentation	0.2	0.1	Enteric fermentation
Total, annual	**9.1**	**6.3**	

Source: CAT 2006.

* AgCAT = Agricultural Working Group of the Climate Action Team.

and increasing the uptake of carbon (IPCC 2000). The Clean Development Mechanism has an extensive agricultural project base with a set of established standards and rigorous, peer-reviewed methodologies to ensure that the offsets are real, additional and verifiable (UNFCCC 2010).

This large stock of already completed methodologies can provide guidance as the Air Resources Board and Climate Action Team develop California's implementation rules and protocols. In particular, it could hasten their progress by providing methods of quantification for particular processes that would otherwise need extensive research. For example, one of the hurdles for implementing farmscape sequestration is uncertainty about its potential to sequester carbon and whether this potential is significant enough to merit the development of a measurement methodology (CAT 2008). In addition, the analysis cites the difficulty in quantifying the carbon content of woody shrubs as an obstacle to including the simple practice of planting shrubs in hedgerows between crops as an AB 32 strategy.

The Clean Development Mechanism has an approved baseline and monitoring methodology (AR-AM0006) for reforestation and afforestation, defined as the establishment or re-establishment of forest cover (Zomer et al. 2008). And it has researched the carbon sequestration potential of planting trees and shrubs in hedgerows and states that the resulting carbon pools are significant (CDM 2006). The methodology contains equations for woody shrubs as well as equations for measuring net greenhouse gas removal by sinks, another scientific hurdle mentioned by the Climate Action Team in regard to implementing agricultural carbon sequestration projects (CAT 2008).

Adeel Halim, UNFCCC/CDM Project: 0826

In northern India, the Clean Development Mechanism helped develop a project that is converting bagasse fiber — a waste product of sugar cane manufacturing — into fuel. The project has reduced carbon emissions by about 90,000 tons while providing increased income for local sugar cane farmers.

Soil carbon dynamics is an ongoing research topic, and its biological and physical mechanisms are not well understood (Post and Kwon 2000), but the Clean Development Mechanism project methodologies could help California realize its 2020 regulatory targets. Agricultural projects in the Kyoto Protocol include implementation opportunities and solutions to hurdles that are relevant to tapping mitigation potential in California agriculture.

How the CDM works

Those charged with implementing AB 32 must find instruments that are both economically efficient and environmentally effective. In the case of the Clean Development Mechanism, environmental integrity is subject to specific supervision rules and a series of checks along the project cycle by the UNFCCC Secretariat. To start, an international supervisory group, known as the CDM Executive Board, must approve methodologies for establishing baselines on behalf of the UNFCCC. Approved methodologies are published, and project developers can consult them. However, projects relying on new methods face the additional task of gaining approval. In either case, whether new or established methods are employed, developers must also convince the CDM Executive Board that their project methodology has been appropriately applied.

The project cycle also contains checks carried out by an independent firm or organization that has been accredited by the CDM Executive Board. This entity, known as a designated operational entity (DOE), initially validates the baseline design and the project's plan to monitor and measure outcomes. This occurs before the project is registered — that is, officially recognized by the CDM Executive Board. For large projects, a separate independent entity carries out the project's monitoring protocol, the process by which emissions or sequestrations are measured.

TABLE 3. Number of Clean Development Mechanism projects using selected methodologies by project start year*

Methodology	Description	2004	2005	2006	2007	2008	2009	2010	Total
ACM010†	Manure management	5	40	7	5	1	0	2	60
ACM003†	Biogas from manure or composting	0	7	1	5	5	2	6	26
ACM006‡	Biomass residue from agriculture used for electricity generation	3	35	51	22	54	34	21	220
AMS-I.B‡	Renewable energy generation units supplied by irrigation	3	0	1	0	0	0	0	4
AMS-I.C‡	Renewable biomass burning	0	12	18	24	50	32	51	187
AMS-I.D‡	Biomass from feedstock	2	47	63	51	31	29	29	252
AMS-III.D†	Methane recovery from manure	0	14	84	29	28	24	12	191
AMS-III.E†	Methane avoidance from agricultural biomass	0	2	12	4	4	2	4	28

Sources: Risoe (2010) and authors' calculations.

* Some projects employ more than one methodology. For description of projects, see Dinar et al. (2011), Annex 1.

† Methodologies involve reducing methane and other greenhouse gases via anaerobic decomposition systems for manure or other organic matter.

‡ Methodologies involve replacing fossil fuels with alternative fuels from agricultural biomass or processes.

CDM agricultural projects

In the context of the Clean Development Mechanism, we define an agricultural project as one that uses agricultural residuals, outputs or processes to directly or indirectly reduce greenhouse gas emissions (FAO 2010). This includes projects that sequester carbon in soils.

We studied a dataset described by Larson et al. (2011) that covers 5,824 projects (as of Dec. 1, 2010), based on data reported by Risoe (2010). Of these, 1,022 projects (17.5%) were classified as agricultural, land-use or forestry projects. Examples of such projects include the Assisted Natural Regeneration of Degraded Lands in Albania (World Bank 2009, 2011) and the Moldova Soil Conservation Project (World Bank 2004, 2011). The Albania project was designed to transform badly eroded lands into broadleaf forests of native species. The primary objective of the project in Moldova is to conserve and improve the productivity of agricultural soils by planting shrubs and trees. The project is expected to generate other benefits, including global biodiversity and fuelwood and other forestry products for nearby communities.

Based on Risoe's analysis, the agricultural projects are expected to reduce business-as-usual emissions by nearly 220 million $MtCO_2e$ by 2012 and 582 million $MtCO_2e$ by 2020. Available estimates of CO_2 emissions (WRI 2011) suggest that total global annual emissions were 30.0 and 37.8 $GtCO_2e$ (1 gigaton [Gt] CO_2e = 1 billion metric tons CO_2e) in 1990 and 2005, respectively.

The main methodologies used for these 1,022 projects were extracted from Risoe's project data and can be found in Dinar et al. (2011). The projects rely on 33 approved methodologies (Larson et al. 2011), but the eight most frequently used methodologies account for 80% of the projects (table 3). While each project must meet the specific criteria stated in each methodology, a closer look at the most widely used methodologies suggests that they are composed of variations around a small set of core mitigation activities.

The most widely used mitigation activity displaces fossil fuels with alternative fuels from agricultural biomass or processes. Examples include the generation of electricity by burning agricultural waste and the generation of mechanical energy via irrigation. The second most widely used mitigation activity is avoiding the release of methane and other greenhouse gases, or recovering them by modifying anaerobic decomposition systems for manure or agriculturally derived organic matter (Dinar et al. 2011, Annex 1).

These two core mitigation activities already in place on a number of the state's farms could be adopted in California. They would encourage better management of manure, as well as the displacement of fossil fuels. However, Clean Development Mechanism methodologies are less well developed in areas associated with other important AB 32 strategies, including crop growing and harvesting, and soil preparation and disturbances. Consequently, methodological hurdles will remain in the short run, making it difficult to tap mitigation opportunities in these areas.

When combined with emission caps and markets in tradable allowances, offset programs can encourage private and public investment in mitigation activities.

Mitigation potential

Missing methodologies are also holding back international mitigation efforts. The Clean Development Mechanism taps only a small portion of the mitigation potential in the agricultural sectors of developing countries. For example, Larson et al. (2011) calculated that the 1,022 agricultural and land-use forestry projects studied amounted to a little more than 3% of the mitigation potential identified in the most recent Integovernmental Panel on Climate Change (IPCC) report (Smith et al. 2007). Larson et al. (2011) note several generous assumptions in their calculations and surmised that their estimate represents an upper bound.

In the case of the Clean Development Mechanism, much of the mitigation gap likely arises from missing methodologies for land-use projects. Mitigation activities for these projects include the restoration of degraded land, better management of crop and pasture land, and the appropriate use of fertilizers. Research summarized by the Intergovernmental Panel on Climate Change (Smith et al. 2007) suggests that these activities have the largest mitigation potential for the agricultural sector globally and thus for achieving AB 32 goals as well.

Land-use projects

The appropriate roles for land-use projects in international mitigation efforts were contentiously debated as the Kyoto Protocol and the Clean Development Mechanism were crafted (Larson et al. 2008). And, in the rules that eventually emerged, the projects faced special limitations, in large part because of the nature of land-use mitigation. The activities are mostly straightforward and readily observed, for example, the adoption of conservation tillage methods or the addition of organic material to degraded soils. The likely benefits and processes generating them are easy to list as well. But measuring precisely the net effects, which are needed to assign credits, is challenging, and the related science is complex. Moreover, even well-measured effects are potentially reversible under many settings. For example, the mechanisms controlling soil organic carbon (SOC) dynamics are imperfectly understood (Sollins et al. 1996), so even meticulously inventoried carbon stocks have the potential to be re-emitted back into the atmosphere if temperature, precipitation or any other of the myriad variables affecting soil organic carbon dynamics happen to change. This difficulty creates skepticism about the environmental integrity of land-use projects and increases monitoring

California's Climate Action Team estimates that the state's agricultural sector could reduce emissions by 6.3 million $MtCO_2e$ in 2020 by expanding practices such as composting.

The Clean Development Mechanism funds programs such as the Lages Methane Avoidance Project, which teaches children to grow vegetables using biomass ashes as fertilizer.

costs, which encourages potential investors to favor alternative projects.

Land-use projects fit uneasily in an offsets framework for another reason, which concerns their positive externalities (spillover benefits not reflected in price and affecting outside parties). In some cases, they generate important environmental benefits (cobenefits) in addition to benefits that are part of the mitigation plan. For example, landscape management practices that reduce soil erosion build up pools of carbon sequestered in stabilized soil, a mitigation activity that could be part of an offsets program; but the mitigation also can lead to cleaner streams, giving better protection to watersheds and cleaner water for downstream consumers. When public cobenefits are significant and entail additional cost, assigning credits for sequestration activities alone may not be sufficient incentive to encourage investors. Ideally, program incentives would be sufficient to promote the production of both mitigation benefits and public cobenefits. In the Clean Development Mechanism, payments are based on mitigation outcomes, and cobenefits are not financially rewarded. A further disincentive to investors is that coordination among landowners is often needed to fully capture land management benefits, which can drive up transaction costs.

Project-based mitigation works well on a global scale for certain types of agricultural projects, mostly those that manage organic wastes or use byproducts to produce energy. Land-use projects are less suitable due to the complex and location-specific biochemistry of carbon sequestration in soils, the frequent need to coordinate actions across a large number of landowners and the additional complication of accounting for cobenefits.

Implications for California

The Clean Development Mechanism offers encouraging lessons for the implementation of AB 32. First and foremost, it shows that when combined with emission caps and markets in tradable allowances, offset programs can provide incentives for private and public investment in mitigation activities. Second, some of the agricultural mitigations envisioned by the Air Resources Board are practicable. And third, the methodologies that have been built up in recent years in the Clean Development Mechanism could help accelerate the establishment of AB 32 protocols.

Other lessons concern the future inclusion of California's cap-and-trade program into a regional program. Current rules preclude California cap-and-trade program participants from trading in carbon reduction credits with non-U.S. producers. However, the Air Resources Board notes that projects outside of California can help lower the compliance costs for regulated entities in California, and they can reduce greenhouse gas emissions in regions that would otherwise lack the resources for such projects. The Board refers in particular to projects along the Mexican border as potentially benefiting both California and Mexico (ARB 2008). Building on Clean Development Mechanism methodologies already in use in Mexico could smooth a regional expansion of the California program.

Furthermore, the trading and offset provisions of the proposed California program are designed to contain the costs of meeting emission reduction objectives, and the Clean Development Mechanism could provide important guidance and inspiration for their implemetation. Broadly speaking, the effects of carbon emissions on climate are the same regardless of where the emissions occur, which is why some countries have used Clean Development Mechanism offsets in other countries to supplement their own mitigation activities. For example, the European Union's Emission Trading Scheme allows firms to meet a portion of their regulatory requirements with Clean Development Mechanism credits, though that arrangement terminates this year, and the future is not clear.

If project-based crediting continues under the UNFCCC, as many expect it will, the California system could be opened, partly or fully, to UNFCCC tradable offsets as a way to contain costs. And to the extent that lower-cost emission reductions could be found in other countries, the California system could have a larger impact on climate change for a given cost.

The Clean Development Mechanism offers a few off-the-shelf methodologies for quantifying the impact of land-use projects, but more scope remains for California to develop a soil sequestration protocol of its own. The UNFCCC has moved recently to create incentives that slow deforestation, but similar mechanisms to protect carbon pools in soil are still missing. To make progress in the farmscape and soil carbon sequestration strategies, California must find a way to fit land-use project incentives into future protocols or devise other instruments.

Prospects for California agriculture

For California to meet its 2020 emissions reductions targets, the Market Advisory Committee (MAC) to the California Air Resources Board recommended a phased approach, in which standards would be set for an initial group of offset categories around which there was a high degree of confidence in their environmental integrity (MAC 2007). For out-of-state offsets, California would sign contracts with other states or countries to adequately ensure a similar level of environmental integrity and accountability.

Agriculture is an important sector of California's economy with much untapped potential for carbon offsets. The Economic and Technology Advancement Advisory Committee (ETAAC) was formed to advise the Air Resources Board on activities that will facilitate investment in and implementation of technological research and development opportunities. ETAAC identified the technical potential to derive about 17 million $MtCO_2e$ of climate change mitigation benefits from California production agriculture, which is about 10% of the total goal for 2020 (ETAAC 2008, Table 6-1).

The Market Advisory Committee's call for working with other regions

or countries — perhaps developing ones — to invest in agricultural projects opens a window of opportunity for cost-effective carbon abatement. The Clean Development Mechanism provides a framework for organizing offset projects and methodologies to assess their impact. Within the agricultural sector, it has been an effective conduit for mitigation projects backed by private and public funding that use residual agricultural organic matter as an alternative fuel source, as well as those that manage methane from composting and manure.

Strategies for using the CDM

How can California become a player in this arena and use the Clean Development Mechanism to its immediate advantage? ETAAC (2008) suggests several strategies that could also be applied in a Clean Development Mechanism context. One is to identify and provide financial incentives for the low-hanging fruits ("early action" areas) with credits that can be clearly defined. Agriculture is considered an "early action" area. Another strategy calls for the creation of a trust for public funding, which would direct investments in research, development and demonstration (RD&D) and finance technology pilot projects. Another strategy calls for fostering international and domestic collaborations to learn from others who have already implemented climate change policies (ETAAC 2008).

Our work suggests that California could benefit from reviewing the existing Clean Development Mechanism methodologies and adapting them for its specific needs. In addition, California could create policies and rules that reflect the true value of land-use carbon credits, which in turn would provide incentives for investors to engage in agricultural land-use projects.

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RESEARCH ARTICLE

Converting oak woodland or savanna to vineyards may stress groundwater supply in summer

by Mark Grismer *and* Caitlin Asato

Water resources are important to land-use planning, especially in regions where converting native oak woodlands or savannas to wine grape vineyards may affect the amount of water available for restoring salmon runs. Research has shown that woodland conversion to grasslands (for possible rangeland grazing) leads to greater and more sustained stream flow and groundwater recharge; however, little information is available about woodland conversion to vineyards. To inform resource managers and planners, we developed a water balance model for soil and applied it to vineyards, native oak woodlands and annual grasslands to evaluate their relative use of groundwater. We applied the model to Sonoma County, using climate data from 1999 to 2011, and determined that oak tree canopy coverage of 40% to 60% results in annual groundwater extraction equivalent to that of an established irrigated vineyard. However, vineyard groundwater use far exceeded that of oak woodlands in late summer to early fall, which could further stress already affected groundwater resources. We also evaluated the prediction sensitivity of the model to key parameters associated with rain levels, soil water–holding capacity and irrigation management.

YinYang/iStockphoto

In areas where oak woodlands are converted to vineyards, the recharge of groundwater to streams may change. The authors developed a water balance model for soil, which they applied to vineyards, oaks and grasslands.

Wine grape production in California coastal counties has increased steadily during the past few decades, often resulting in the conversion of native oak woodlands or savannas into vineyards. Generally, oak woodlands have tree canopy covers greater than about 40% by area, while oak savannas are predominantly grasslands interspersed with oaks. Concerns about oak woodland and savanna conversions have been raised in terms of losses in landscape ecological diversity (Heaton and Merenlender 2000), adverse impacts on soils (Jackson et al. 1990), soil erosion, water quality (Hinckley and Matson 2011) and water quantity. One community concerned about vineyard expansions referred to them as the "tentacles of the wine-grape octopus" (Parrish 2011), and local scientists in Sonoma County have raised concerns about biodiversity (Community Foundation 2009). These concerns are amplified by climate change, which increases plant water demands, possibly resulting in decreased groundwater availability. And yet, wine grape (and associated wine) production is the leading agricultural commodity in California in terms of net dollar value.

In Sonoma County, wine grape production increased from less than 50,000 acres in 1998 (Merenlender 2000) to a peak of 70,000 acres in 2002 and has leveled off at around 60,000 acres during the past decade (fig. 1). Concerns about the impacts of vineyard water use on salmon runs are focused here (Lohse et al. 2008) because the county includes a large part of the Russian River watershed.

Water use, groundwater recharge

Hydrologists have long been interested in the impacts on soil water conditions and groundwater recharge when converting native grasslands or woodland to agriculture in the world's semiarid and arid regions. Hydrologic analyses conducted decades ago at the UC Hopland Research and Extension Center in coastal Mendocino County considered land conversion in terms of watershed water yields (see page 145); Burgy and Adams (1977) characterized the focus at that time:

> Quantitative studies of the hydrologic responses of watersheds where dense vegetative cover has been replaced with range and forage grasses have consistently shown increases up to 50% or more (equivalent to 3- to 5 acre-inches per acre) in annual runoff over long periods of measurement. These runoff studies cover the variety of conditions found

Online: http://californiaagriculture.ucanr.edu/landingpage.cfm?article=ca.v066n04p144&fulltext=yes

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in Northern and Central California. About half of the yield increase occurs in the latter portion of the season, giving usable flow in dry periods. The balance of the increase is produced as increased outflow during the post-storm periods.

After oak woodlands were converted to annual grassland, the researchers found increased storm runoff volumes and the establishment of perennial summer stream flows. Base flows had increased and overall groundwater demand dropped when oaks were removed. Currently, watershed management encompasses a broader perspective, considering the land conversion impacts on ecological diversity, soils and water quality.

Similar observations have been made of increased groundwater recharge following the conversion of native land use (rangeland) to agriculture in the U.S. Southwest, Central Plains and High Plains (Gurdak et al. 2007; McMahon et al. 2006; Scanlon et al. 2005), and the Murray-Darling basin of Australia following conversion of native woodland (mallees) to dryland farming and pasture (Thorburn et al. 1991).

Scanlon et al. (2005) noted that groundwater recharge under rangeland use is typically nonexistent in arid regions and quite small in some semiarid regions (~ 1 millimeter per year); it increases to roughly tens of millimeters annually in dryland agriculture and hundreds of millimeters in irrigated agriculture. The annual recharge rate in semiarid regions is likely rainfall dependent; for example, in a drip-irrigated coastal orchard, Grismer et al. (2000) measured rainfall-driven groundwater recharge rates of about 180 millimeters per year in both irrigated and fallow areas from 1996 to 1998.

Clearly, when regional water supply allocations are based on water balances that include groundwater resources, rates of groundwater recharge and lag times to the depths associated with different land uses are critical (Grismer 2012; Sophocleous 2005). Scanlon et al. (2005) underscored that developing "sustainable land-uses requires quantitative knowledge of the linkages between ecosystem change, recharge and groundwater quality." An effort to understand water use in

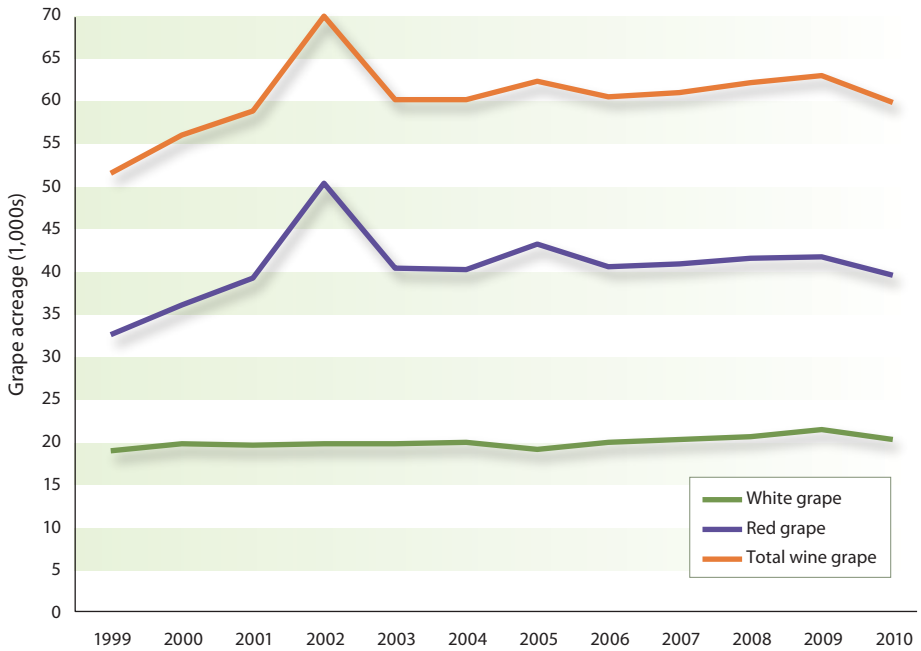


Fig. 1. Annual wine grape production in Sonoma County, CA. Source: County annual agricultural crop reports.

Glossary

Crop coefficient (K_c): Ratio of actual crop water use to reference ET_o; used to determine irrigation water demand in vineyards and other crops.

Effective rainfall: Fraction of total rain that infiltrates the soil after losses to leaf interception, surface runoff, depression storage and evaporation.

Evapotranspiration, plant: Sum of soil water and canopy (leaf) evaporation, plus plant transpiration, a process in which water moves through a plant or tree and is subsequently lost through stomata in the leaves.

Evapotranspiration, consumptive use (ET_c): Root extraction of available soil water used in plant transpiration.

Evapotranspiration, reference (ET_o): Evapotranspiration possible from a tall fescue grass crop when there is no limitation on available soil water.

Groundwater: Soil water stored in the root zone, or the combination of this and deep groundwater below the root zone, stored in water tables or aquifers.

Groundwater recharge: In the model, infiltration water that exceeds the capacity of the root zone compartment and percolates to deep groundwater below; such recharge typically occurs later in the rainy (winter) season.

Runoff: That part of the precipitation that appears in surface streams; may come either from the surface, or from shallow groundwater (the latter is usually referred to as interflow).

Soil water balance: Relatively simple model that accounts for daily changes in water storage in the root zone, associated with such processes as root water extraction (ET_c), infiltration by rain or irrigation, and seepage losses to groundwater.

Water inputs to the root zone: Include effective rainfall (the fraction of total rain that infiltrates the soil after losses to leaf interception, surface runoff, depression storage, and evaporation) and irrigation (in vineyards only in this study).

Water yield: Runoff from the drainage basin, including groundwater outflow that appears in the stream plus groundwater outflow that leaves the basin underground. Roughly, at the basin scale, water yield is the net precipitation minus the total evapotranspiration.

oak woodlands or savannas in terms of these linkages has been under way during the past several years.

Water use in oak woodland, grassland

While an understanding of vineyard water use has developed during the past few decades, only in the past several years has there been research directed at measuring rates of water use in native oak woodland and grassland systems, and their possible impacts on groundwater resources (see box; fig. 2).

Teuling et al. (2006) summarized the relationships between soil moisture and plant evapotranspiration (ET_c) for a broad range of grasslands, native brush, tree and savanna landscapes across the world, in an effort to establish the parameters for regional and global atmospheric modeling. Generally, they found that evapotranspiration rates declined exponentially with decreasing soil moisture, which was later confirmed by Chen, Baldocchi et al. (2008) and Chen, Rubin et al. (2008) for California oak savannas.

Baldocchi et al. (2004) quantified the rates of canopy evaporation to soil moisture in California oak woodland and grasslands and found that ET_c rates for the grasslands declined when volumetric water content dropped below 15%, corresponding to a soil water potential of –1.5 mega-Pascals (MPa). (Soil water potential is the measure of the relative strength of water attachment to soil; the more negative the "potential," the more tightly bound the soil water.) They found that at soil water potentials below –2.0 MPa, transpiration in grasslands effectively ceased and the grass senesced. On the other hand, the oak trees continued to transpire, albeit at low rates, under very dry soil conditions (soil water potentials less than –4.0 MPa), probably due to deep root access to groundwater. Overall, annual woodland ET_c was about 380 millimeters at about 40% canopy coverage, while ET_c for grasslands was about 300 millimeters.

Miller et al. (2010) recorded groundwater uptake by California oak trees at rates ranging from 4 to 25 millimeters per month during June, July and August, representing about 80% of total ET_c. They suggested that "blue oaks should be considered obligate phreatophytes," that is, water-loving plants similar to, for example, riverbank willows. They noted that available groundwater, including deep soil storage, provides a buffer to changes in the native oak tree hydroclimate.

Following up on earlier studies of oak trees, David et al. (2004) and Baldocchi et al. (2010) noted that the adaptation potential of savanna vegetation differed to accommodate low soil moisture conditions during the summer and fall in Mediterranean climates. In sparse evergreen oak woodlands of southern Portugal, David et al. (2004) monitored sap flows (water use) in eight points of a

A closer look: The hydrologic cycle

While Earth's total water content is virtually constant, water itself continually changes state between liquid, solid and gas (fig. 2). It also moves and resides in different places, or compartments, shifting at different rates between them.

Hydrologists view soil water balances partly in terms of water residence times. Water resides for different lengths of time in the atmosphere, on the soil surface, and within the soil root zone, a stream or groundwater. It may take a few minutes for a drop of water to evaporate from a leaf, or it may exist frozen in a glacier for 10,000 years.

When large amounts of water shift suddenly due to human use or natural causes, the species and ecosystem services supported in each compartment shift. If municipalities or growers withdraw a large amount of well or stream water in a drought, it could affect species dependent upon the stream, and groundwater levels may not recover for months, or even years.

Scientists develop models to better understand soil water balances based on conditions in a specific water basin. This study marshals data from a 12-year period in Sonoma County, a major part of the Russian River basin, and estimates water movements.

— *Janet White*

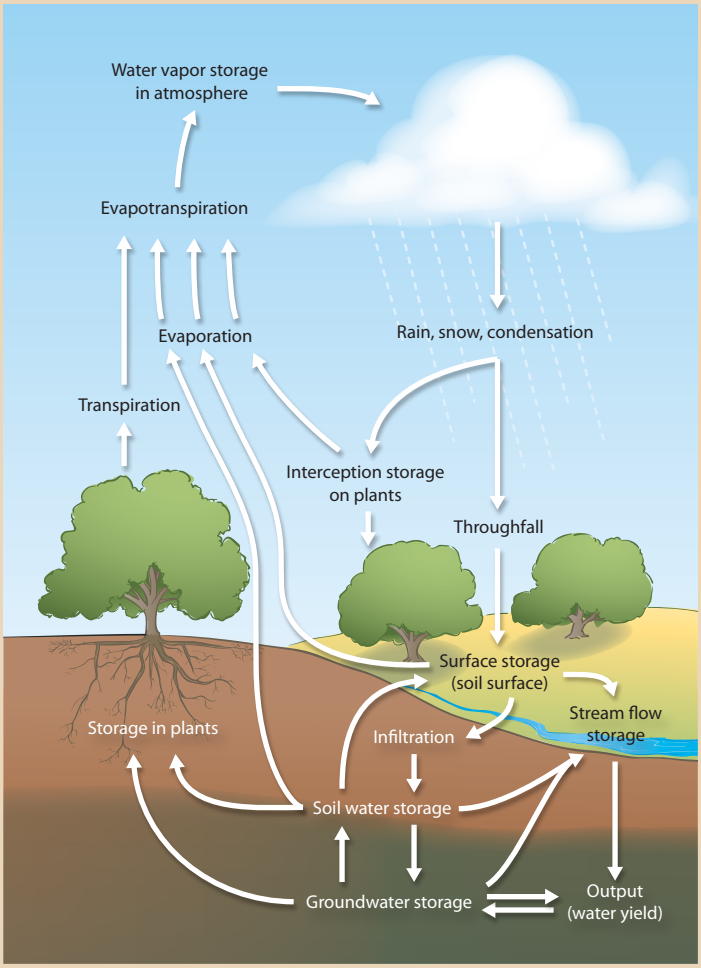


Fig. 2. The hydrologic cycle. Adapted from *Encyclopedia of the Earth* (Hubbart JA, et al. 2010, www.eoearth.org/article/Hydrologic_cycle).

Holm oak (*Quercus rotundifolia*) stem over 2 years (May 1996 to August 1998). Leaf water potentials, canopy conductance, whole-plant hydraulic conductance and meteorological processes were also measured, and all evidence indicated that the trees did not suffer water stress and remained adequately watered throughout the 2 years. The greatest evapotranspiration rates occurred during the summer when little, if any, rain or available soil moisture was accessible, suggesting that the root system's direct access to a 42-foot-deep water table met the tree's water demand.

Likewise, Paço et al. (2009) noted in Portugal that grass transpiration stopped during the summer as surface soils dried, but trees continued transpiring because of deep root access to groundwater. Tree transpiration represented more than half of the ecosystem's transpiration, in spite of the low tree density (crown cover of 21%). Transpiration accounted for 76% and tree-canopy leaf rainfall interception loss for only 24% of overall tree evaporation.

Baldocchi et al. (2010) examined multiple years of data from five comparable evergreen oak woodlands in France, Italy, Portugal and California. Confirming a previous study of California oaks (Baldocchi and Xu 2007), they found that Mediterranean oaks survived in the seasonally hot/dry, wet/cool conditions by ensuring that their ET_c was less than the available water supply.

Lastly, Fisher et al. (2007) found that water use (sap flow) in Sierra Nevada oak woodland continued through the night during summer and fall, underscoring that groundwater satisfied this continuous water demand.

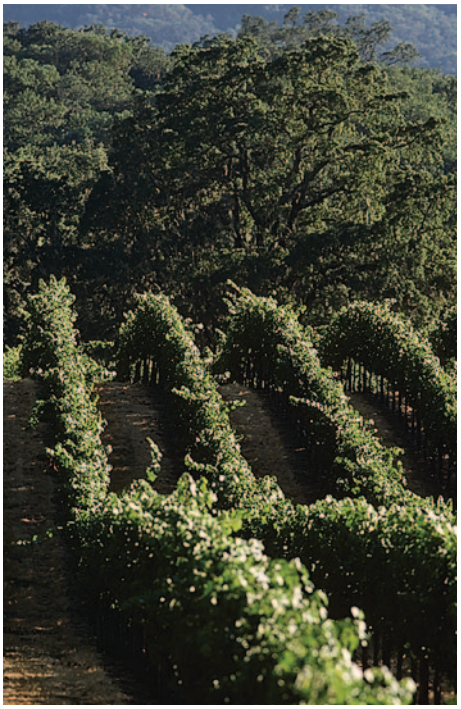
Vineyard water use

Vineyard water use once vines are established has been extensively studied to develop appropriate irrigation management and scheduling and to achieve particular grape quality and yields. Allen et al. (1998) summarized some of the original evapotranspiration (ET_c) crop coefficients (referred to as K_c, the ratio of actual crop water use to reference ET_o) used to determine irrigation water demand in vineyards. Pritchard (2010) refined them for California wine grape production, as did Caprile (2007) for the North Coast, including Sonoma County.

Grapevines are fairly drought tolerant and can be managed with deficit irrigation to obtain the levels of sugars, tannins and acids desired by the winemaker. For premium wine grape production, the plants are often water stressed in late summer or fall to reach desirable grape sugar and tannin levels, with less consideration of yield. Following grape harvest, the vines are largely dormant, and winter rains effectively leach soils and replenish water available in the root zone for bud break in the late spring.

Study objectives

We hypothesized that following vineyard establishment, annual groundwater recharge exceeds that from oak savannas.



Jack Kelly Clark

Grapevines are largely dormant after harvest, allowing winter rains to leach soils and replenish moisture in the root zone. *Above*, an Alexander Valley vineyard.

Based on our observations of tree densities, our corollary hypothesis was that a certain percentage of oak tree canopy coverage (i.e., areal tree density) alternatively results in annual water use or groundwater recharge equivalent to that from a vineyard in the same landscape.

Our objectives were to determine daily and annual soil water use and deep percolation (recharge) rates from a vineyard and oak savanna or woodland under average climate conditions of the past decade in Sonoma County, and to determine the amount of tree canopy coverage that would result in net groundwater use or net recharge equivalent to that of a vineyard.

Soil water balance methodology

We based our soil water process modeling on daily water balances in the root zones of a hypothetical vineyard, grassland and oak tree. Soil water balance is a relatively simple model that accounts for daily changes in soil water storage of the root zone associated with such processes as root water extraction (ET_c), infiltration by rain or irrigation and deep percolation losses to groundwater. We then combined the grassland and oak tree balances to create one balance for an oak woodland savanna of variable tree density.

UC Regents/ANR Repository

Water use by vineyards has been extensively studied to inform irrigation management and ensure grape quality and yields. *Above*, wine grapes in Sonoma County's Valley of the Moon region.

Water inputs to the root zone include effective rainfall (the fraction of total rain that infiltrates the soil after losses to leaf interception, surface runoff and depression storage, and evaporation) and irrigation (vineyard only). Plant consumptive water use (ET_c), that is, water taken up by the grass or trees, removes available soil moisture from the root zone.

In the model (fig. 3), oak trees were allowed to extract groundwater to meet ET_c demand when available soil moisture was zero. No additional water source was available to the grasslands beyond root zone soil moisture, and in the vineyard ET_c demand in excess of available soil moisture was met through irrigation (groundwater pumping). Irrigation events were triggered when water was depleted in the root zone to a specified fraction (maximum allowable depletion, MAD) of its available water capacity.

Effective rain (plus irrigation for grapevines) minus plant consumptive use that was in excess of available water storage capacity in soil in the root zone became deep percolation or groundwater recharge. Grismer et al. (2000) observed that rain-driven groundwater recharge reached depths of nearly 18 feet within 4 to 6 months in drip-irrigated coastal orchards; therefore, we assumed that lag times for groundwater recharge (Grismer 2012) were likely less than 1 year. In other words, the previous year's recharge was available for irrigation pumping in the next year. In comparing oak savannas with vineyards, we focused on annual groundwater use for each system.

To run the model, we used reference evapotranspiration (ET_o) and rainfall depths averaged daily from four meteorological stations across Sonoma County (Bennett Valley, East Petaluma, Santa Rosa and Windsor) to develop a continuous, approximately 13-year record as input data. We used seasonally dependent K_c values for plant consumptive use from Allen et al. (1998) for grasses and Caprile (2007) for North Coast wine grape vineyards (table 1). The original K_c values for oak trees were derived from those for olives (Allen et al. 1998) and modified based on studies by Baldocchi et al. (2004), which indicated that oak tree ET_c was 40% to 50% of annual ET_o in the Sierra foothills.

In this model, plant consumptive use (as annual fractions of ET_o) was consistent with published studies: 23% for the vineyards and 52% for oak trees (the results were slightly higher in our study's cooler and wetter environment than in that of Baldocchi et al. [2004]). Estimated values for maximum available water capacity (AWC_m), effective rain fraction, irrigation

M. Wisniewski

In this study, groundwater use by oak woodlands was equivalent to that of vineyards when tree canopy cover was about 50%. Groundwater demand by trees was greatest in the late summer and early fall, and averaged 270 milliliters annually.

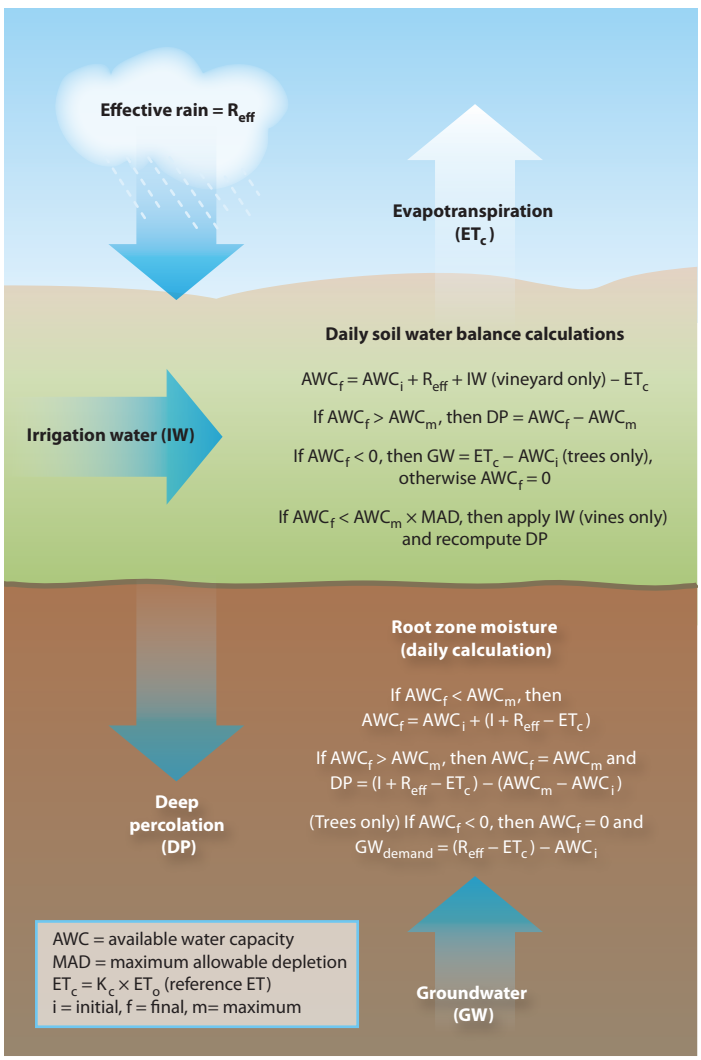


Fig. 3. Water balance model for soil in the root zone.

TABLE 1. Crop coefficients used in daily modeling of soil water processes in vineyards, oak trees and grasslands

Vineyards		Oak trees		Grasslands	
Period	K_c	Period	K_c	Period	K_c
3/1–4/15	0.10	3/1–3/31	0.5	3/1–3/15	0.90
4/16–4/30	0.20	4/1–10/1	0.6	3/16–4/30	0.95
5/1–5/15	0.25	10/2–11/25	0.5	5/1–5/15	0.25
5/16–5/31	0.30	11/26–2/28	0.4	5/16–6/15*	0.10
6/1–6/15	0.35			6/16*–10/13	0.00
6/16–6/30	0.40			10/14–10/31	0.25
7/1–9/30	0.50			11/1–2/28	0.75
10/1–10/15	0.30				
10/16–10/31	0.20				
11/1–11/15	0.15				
11/16–11/30	0.05				
12/1–2/28	0.01				

Sources: Allen et al. 1998 (grasses and trees); Caprile 2007 (vineyards).
* Variable date depending on available soil moisture.

and maximum allowable depletion were used, assuming loam soils and a water-table aquifer at 20 to 25 feet below the ground surface.

After running the model with the initial assumed parameter values for available water capacity (AWC), maximum allowable depletion, effective rain fraction and groundwater depth, we evaluated the sensitivity of calculated groundwater use values to these estimated parameters. This sensitivity analysis provided guidance on optimal parameter selection as well as a sense of the robustness of model predictions (that is, how much error in groundwater use calculations might be expected if assumed parameter values were incorrect).

Estimating water needs

In presenting the results, we set each year beginning on March 1, when water conditions in soil are most likely to be at or near capacity (table 2). Though net possible annual water demand (ET_o minus rain) ranged widely from 140 millimeters in 2005 to 790 millimeters in 2008, the applied water needed for vineyard production remained roughly the same from year to year, at about 300 millimeters. In the model, applied water was typically given in three large irrigations, but the depth of irrigation required was independent of irrigation frequency so that equivalent results would have been obtained if, for example, six 50-millimeter irrigations had been applied.

The wide variability in net possible water demand by vineyards was reflected in the net groundwater use (applied water minus deep percolation) associated with vineyard production; groundwater use ranged from a net recharge of 153 millimeters in 2005 to a net use of 241 millimeters in 2008. During the 13 years, there was on average a very small groundwater demand of roughly 15 millimeters per year; this small demand was largely due to the deep percolation of winter rain.

In oaks and grasses, deep percolation occurred only when maximum AWC_m was exceeded (table 3). Grasses could only access soil moisture in the root zone, and plant water used (ET_c) ceased when AWC was zero; a condition noted in several studies outlined above. For oak trees, relatively dry conditions from 2007 to 2009 resulted in no deep percolation, because the maximum soil moisture–holding capacity was never exceeded. Not surprisingly, groundwater demand by the trees was greatest in late summer and fall. Extraction rates averaged about 270 millimeters per year, similar to those measured by Baldocchi et al. (2004).

Tree canopy cover

Daily soil water balance calculations for the combined oak trees and grasslands depended on the area of tree canopy cover, and deep percolation and groundwater use rates fell. In grassland, deep percolation was available to meet

TABLE 2. Major water balance factors for wine grape production in Sonoma County, 1999–2011

Year	ET_o*	Rain*	IWR†	Applied water	Irrigations	Deep percolation	Groundwater use‡
	mm				no.	mm	
1999	1,169	598	400	500	4	384	116
2000	1,145	581	300	375	3	268	85
2001	1,207	1,344	300	375	3	472	28
2002	1,157	848	200	250	2	436	–61
2003	1,109	890	200	250	2	471	–96
2004	1,169	676	200	250	2	331	44
2005	1,100	961	200	250	2	528	–153
2006	1,074	820	200	250	2	441	–66
2007	1,166	636	200	250	2	313	62
2008	1,185	396	300	375	3	259	241
2009	1,119	657	200	250	2	332	43
2010	1,062	804	200	250	2	444	–69
2011	1,011	445	200	250	2	181	69
Average	1,139	719	325	406	3.25	392	14.6
Standard deviation	45	158	45	57	0.45	85	108.8

* From accumulated daily CIMIS data, March 1 to Feb. 28 each year.
† IWR = irrigation water requirement, assuming 80% application efficiency.
‡ IWR minus deep percolation.

TABLE 3. Major water balance factors for oak trees and grasslands, 1999–2011

	Oak trees				Grasslands		
Year	DP*	GW demand	GW demand period	Net GW use	GW demand rate	AWC depletion date	DP
	mm			mm	mm/day		mm
1999	5.0	313.1	6/27–11/6	308.2	2.35	4/16	157.3
2000	32.9	257.5	7/4–10/24	224.6	2.28	4/20	105.3
2001	98.9	389.9	6/4–10/28	291.0	2.65	4/22	253.7
2002	149.3	295.7	7/2–11/5	146.3	2.33	4/16	283.0
2003	121.0	219.1	7/28–11/5	98.1	2.17	7/13	234.7
2004	50.1	308.9	6/23–10/15	258.7	2.69	4/21	194.3
2005	112.2	156.2	8/10–10/27	43.9	1.96	4/25	271.2
2006	175.8	235.8	7/14–11/1	60.0	2.12	6/1	222.5
2007	0.0	325.8	6/15–12/1	325.8	1.92	5/5	148.9
2008	0.0	350.2	6/16–10/29	350.2	2.57	3/28	52.6
2009	0.0	315.9	6/20–10/12	315.9	2.75	4/10	173.8
2010	49.5	176.5	7/31–10/21	127.0	2.13	5/13	187.2
2011	129.6	194.9	7/26–11/4	65.3	1.85	4/20	52.3
Average	71.1	272.3		201.2	2.29		179.8
Standard deviation	62.8	71.4		114.2	0.30		75.9

* DP = deep percolation; GW = groundwater; AWC = available water capacity.

groundwater demand by the trees. In all the years studied, deep percolation decreased and net groundwater use increased as tree cover increased. This linear relationship enabled us to determine the amount of cover that provided the same net annual groundwater use as that from the vineyard. On average, during the 13-year period, oak tree cover of about 50% resulted in groundwater use equivalent to that for average vineyard production (table 4). While vineyards received irrigations during hot, dry months, oaks extracted needed water from deep soil storage.

Completing a soil water balance using just the 13-year averaged daily ET_o and rain data provided a similar area of trees (~ 45%) and allowed us to illustrate average conditions and determine the sensitivity of the calculated groundwater use to variations in model parameters (fig. 4). With the smallest available water capacity in the root zone, soil moisture in grasslands is depleted early in the season and gradually replenishes after plant senescence. The demand for additional water in vineyards (provided by irrigations) begins after about 120 days, or early July, while deep groundwater demand in oaks begins approximately 2 weeks later.

In oak woodlands with 45% to 50% tree canopy coverage, groundwater use was initially less than available soil moisture, resulting in net recharge of about 10 millimeters per day for about 140 days. At that point, cumulative groundwater demand steadily increased to 92 millimeters and leveled off. Groundwater demand dropped as tree ET_c decreased and early winter rains replenished the soil moisture. Similarly, vineyard groundwater use showed the three-step increase associated with groundwater withdrawals for irrigations. As demand leveled off, winter rains replenished groundwater via deep percolation and groundwater use rapidly declined.

In both vineyards and oak woodlands (~ 45% canopy coverage), calculated groundwater use was small at 5.5 millimeters per year under these climate conditions, although it is important to note that vineyard irrigation results in more groundwater use than oaks in late summer.

TABLE 4. Density and canopy cover of oak woodlands with equivalent groundwater usage to vineyards, 1999–2010

Year	Cover	Density*
	%	*trees/ha*
1999	59	18.9
2000	58	18.4
2001	52	16.5
2002	52	16.4
2003	42	13.3
2004	53	16.8
2005	38	12.0
2006	55	17.6
2007	44	14.2
2008	73	23.2
2009	44	14.1
2010	38	12.0
Average	51	16.1
Standard deviation	10	3.3

* Approximate, and assumes trees are 13 yards tall with a canopy diameter of 20 yards and remaining area is grassland.

Model prediction sensitivity

This modeling is subject to interpretation because of the uncertainties associated with selecting various parameter values. While precise values can be elusive, their ranges are generally limited. Aside from K_c values for daily water use by plants, the primary parameters affecting groundwater use are effective rainfall, available water capacity and maximum allowable depletion.

Figure 5 shows the effects of different effective daily rainfall values on annual groundwater recharge for the equivalent vineyard and savanna shown in figures 4 and 5, in which the assumed value was 0.6. Increasing effective rainfall values implies that a greater proportion of daily rainfall infiltrates and thereby more rapidly replenishes soil moisture while increasing possible deep percolation. In reality, effective rainfall values vary with storm intensity and prior soil moisture conditions — high storm intensities and near-saturated soil result in small effective rainfall values because rainfall runs off rather than infiltrates.

Rainfall interception by oak tree canopies ranges from 20% to 30% of the total rain when the canopy is relatively dry, possibly further reducing effective rainfall. Similarly, increasingly steep ground slopes increase runoff fractions of rainfall, reducing effective rainfall. Assuming losses to surface depressions of about 10%, canopy interception and some soil moisture, 0.7 may be a practical average upper limit for the effective rainfall fraction, and, with the exception of very low-intensity storms, 0.5 is the lower limit. The effect of uncertainty in this parameter

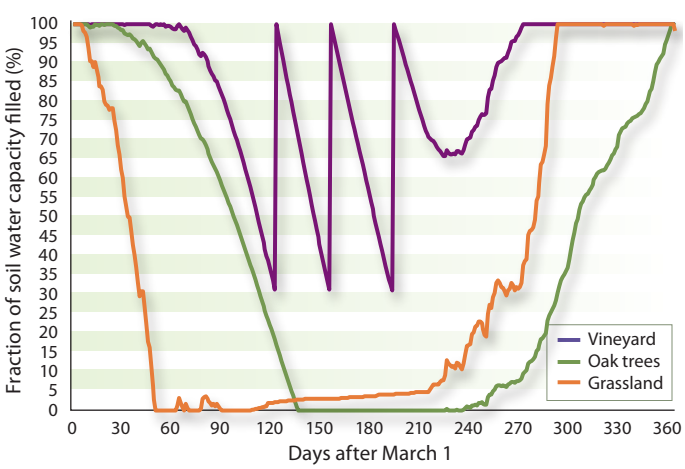


Fig. 4. Daily variation in root zone soil-water storage during an average year for vineyards, oak trees (only) and grasslands.

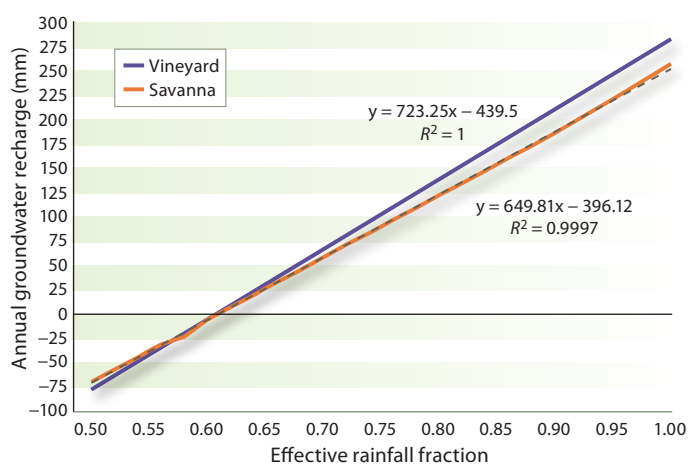


Fig. 5. Effect of effective rainfall fraction used in modeling on net annual groundwater recharge for vineyard and equivalent oak woodland.

is nearly identical for vineyards and oak woodlands, suggesting that whatever the exact effective rainfall value, there would be little or no change to estimated tree areas (as determined above).

Uncertainty in estimated available water capacity stems from variation in soil types, soil layer thickness and the depth to relatively impermeable layers or groundwater. Setting available water capacity (storage volume) is the same as setting a threshold, because changes in calculated groundwater use are not smooth but incremental (tables 5 and 6).

For typical established vineyards, available water capacities likely range from 100 to 150 millimeters, within which there is little effect on groundwater use (table 5). This suggests that the assumed AWC value of 122 millimeters should be sufficient for comparisons. Available soil water capacity for oak trees is largely unknown, though expected to be large. From the continuous water balance modeling, the assumed value of 250 millimeters was exceeded in 9 of the 12 years, and in 2009 maximum soil storage was only 238 millimeters. Because oak savannas and woodlands are not irrigated, decreased available water capacity can offset increased deep percolation and groundwater demand. Thus, changing the water available to trees from 200 to 250 millimeters results in relatively small values of net groundwater use or recharge (table 6). Overall, the range of likely available water capacity values for grapevines, trees and grasslands will have little effect on the equivalent tree area fraction as estimated from annual groundwater use.

TABLE 5. Sensitivity of annual vineyard irrigations and groundwater use on available water capacity (AWC)

AWC range	Irrigations*	Groundwater use
mm	*no.*	*mm/year*
142–213	2	[19.5]†
106–141	3	5.5
85–105	4	30.5
71–84	5	55.5

* Maximum allowable depletion (MAD) = 30%.
† Brackets indicate net recharge.

Finally, the allowed maximum allowable depletion for irrigated agriculture determines the managed soil water storage and frequency, and the possible depths of applied water. Wine grape vineyards are typically managed with deficit irrigation, allowing soil water to be substantially depleted to between 20% and 30% capacity. In this range, net groundwater recharge remained unchanged at 5.5 millimeters per year. Allowing the soil water to become entirely depleted to 0% of capacity (dry) resulted in a greater net groundwater recharge (19.5 millimeters per year). The MAD factor therefore had a minor effect on estimated tree areas based on annual groundwater use.

Overall, uncertainty in the model parameter values results in an equivalent variability in tree area that is similar in range to that associated with hydrologic variability (ET_o and rain) (tables 2, 3 and 4). For Sonoma County, conditions in oak woodland with a tree canopy of 40% to 60% are likely equivalent in terms of net annual groundwater use or recharge to that of an established irrigated wine grape vineyard. In both the vineyard and woodland, groundwater demand is greatest in late summer, though the rates from groundwater pumping for vineyard irrigation likely exceed those from extraction by oak tree roots (fig. 6).

Canopy coverage of 40% to 60% in oak woodlands results in average annual groundwater use equivalent to irrigated mature wine grape vineyards in Sonoma County.

Further study

Overall, canopy coverage of 40% to 60% in oak woodlands results in average annual groundwater use equivalent to mature, irrigated, wine grape vineyards in Sonoma County. However, though the

TABLE 6. Sensitivity of annual groundwater demand in oak woodland on soil available water capacity (AWC)

Oak AWC	Grass AWC	Groundwater use
·····mm·····		*mm/year*
300	95	19.3
290	90	16.5
280	85	13.8
270	80	11.0
260	75	8.3
250	70	5.5
240	65	2.8
230	60	0.02
220	55	[2.7]*
210	50	[5.5]
200	45	[8.2]

* Brackets indicate net recharge.

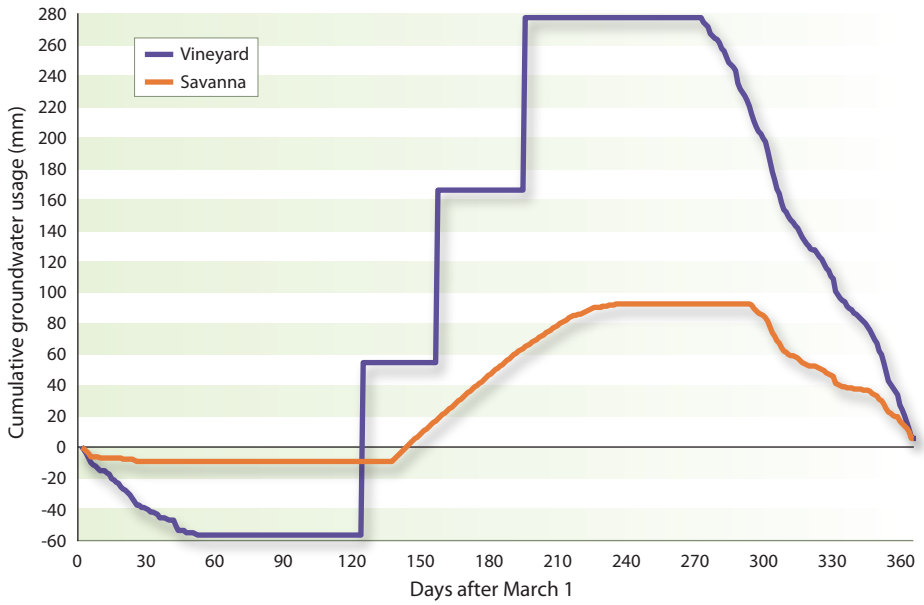


Fig. 6. Daily variation in cumulative groundwater use during an average year for vineyards and equivalent oak woodlands.

annual net use of groundwater was equivalent, the seasonal timing of this use is important to consider. Daily patterns indicate a relatively steady rate of groundwater extraction by oak tree roots beginning in late summer, when extraction increases and regional groundwater supplies are likely stressed. Water resource managers may need to consider this distinction between net use and timing.

Our analysis also provides some insight into the concept of integrated oak woodland and vineyard landscapes, in which the oak tree/savanna grasslands are replaced with vines, leaving a patchwork of trees. These landscapes would provide greater ecological diversity than occurs in vineyards alone. However, oak trees in combination with irrigated vineyards could potentially result in greater net groundwater use than either landscape individually.

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Landscapes that integrate oak woodlands and vineyards (shown, in Glen Ellen) provide more ecological diversity, but water resource managers must consider seasonal variations in water usage by both land uses, together and individually.

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Turnover rates are decreasing in California dairies

by Gregorio Billikopf *and* Gustavo González

Dairy employees in the San Joaquin Valley are staying longer in their jobs. Our study in 2009 showed that the average length of employment has increased 250% since 1953 and 40% since 1984. However, tenures among non-Hispanic employees were twice as long as among Hispanic employees, suggesting there are opportunities to further increase workforce stability. The reasons why workers leave dairies are mostly the same as they were 30 and 60 years ago. We also compared our 2009 California interview results with recent studies in the eastern United States, where trends were similar.

Gregorio Billikopf

Dairy production cannot be readily downsized in response to labor shortages, making employee turnover an ongoing management concern.

Dairy is California's top agricultural commodity, valued at $5.9 billion in 2010 (CDFA 2012). The dairy industry employs 443,574 full-time workers (California Milk Advisory Board 2011), of whom 17,000 (fewer than 4%) work in dairies (Ellerby 2010). Labor represents 10.3% of dairy production costs; since 2006 it has ranged from 9.5% to 12.1% (CDFA 2011). Merced, San Joaquin and Stanislaus counties are among the top 10 dairy counties in the United States; other top dairy counties in California include Fresno, Kings, Riverside, San Bernardino and Tulare.

Dairies are labor intensive because cows are milked two or three times per day year-round. Excessive employee turnover is expensive and upsets routines, which in turn can affect animal health and dairy productivity. By all accounts, 2009 was the worst year since the Great Depression (Willis 2009) for U.S. industries, including dairies (Barrett 2012). As a recession intensifies, the number of employees who voluntarily quit generally goes down while the number of terminations increases. Using Bureau of Labor Statistics data, Hill (2011) showed exactly that pattern between 2007 and 2010, with 2009 as the peak year for terminations and the lowest year for voluntary quits.

In agriculture, the willingness to terminate may have been offset during this time by employers' concerns about labor shortages; many employees are undocumented, and there is great uncertainty regarding immigration reform. According to the National Milk Producers Federation, 20.5% of dairy farmers faced a labor shortage in the months leading up to a 2009 survey and 18.7% feared a shortage (Jordan 2009).

Costs of turnover

In most industries, the costs associated with employee turnover are significant; they include losses in productivity (pre-turnover as well as post-turnover); recruitment, selection and hiring; safety issues; and the orientation and training of new employees (Bliss 2010, 2012; CEPR 2012; O'Connell and Kung 2007). Labor experts often speak of turnover costing about 150% of an employee's annual wages (Bliss 2012; O'Connell and Kung 2007) and as much as 250% (Bliss 2012) for employees with managerial responsibilities. Bureau of Labor Statistics data (O'Connell and Kung 2007; Smith 2006) shows turnover costs in manufacturing and construction (the industries closest to agriculture) are close to 75% of the highest turnover costs in any industry (found in information management) and double the lowest turnover costs of any industry (leisure and hospitality).

The high turnover costs in dairies are partly due to the nature of dairy management. Dairy production cannot be downsized temporarily in response to labor shortages as easily as in retail or manufacturing. When a worker quits, a substitute must be found to do the work until the worker is replaced. Labor-management challenges (e.g., poorly designed pay for performance systems, ineffective supervision, interpersonal conflicts among dairy employees) may cause unwanted turnover (Billikopf 2003a). Dealing with these underlying difficulties can help dairy managers reduce turnover and improve worker morale and productivity.

For some workers, job dissatisfaction has to be quite high before they will seek other employment, because changing jobs can also be traumatic

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(Jex and Gudanowski 1992). The period before a worker's separation may be accompanied by reduced productivity and increased absenteeism. This absenteeism is sometimes physical (the worker doesn't show up) and at other times mental (the worker is present, but his or her mind is somewhere else, which is sometimes described as "quit and stayed") (Billikopf 2003a).

Turnover classifications

There are a number of ways to classify worker turnover (Billikopf 1984, 2003a; Milkovich and Boudreau 1994). Some turnover may be beneficial. A dairy manager may look at the voluntary departure of an employee as an opportunity to hire a better-qualified individual without having to fire one. It may also be an opportunity to replace a long-term employee who is earning a high wage with a lower-paid, entry-level person (Billikopf 2003a).

Turnover can be classified by the degree of control the dairy manager has over the separation. For example, managers have more control over pay issues than over employees' personal problems, milk prices and other economic conditions that affect the dairy's well-being. Separations can also be classified as either producer initiated (firings and layoffs) or worker initiated (quits). Regardless of how turnover is classified, dairy managers can benefit from a better understanding of why workers leave dairies.

Measuring length of employment

There are three ways to measure the length of employment (LOE), or tenure, of employees.

Snapshot. This approach records the worker's exact length of employment in his or her current job at the time of a survey or interview (Stack et al. 2006). For example, an employee who has been on the job for 3 days at the time of a survey is reported as having a 3-day length of employment. This approach does not take into account whether that individual will work 1 more week or 3 more decades, but if a large number of subjects are surveyed, the length-of-employment measures should even out.

Completed tenure. This approach measures the worker's total time on a dairy job after he or she has left it (Billikopf 1984). The greatest concern with this method is that data for employees who are new to the industry, or who have held their present job throughout their careers, is not included.

Range. This approach measures the percentage of workers who fall into specific length-of-employment ranges; for example, 4% may have worked less than 2 years, 15% between 2 and 6 years, and so on (Maloney and Grusenmeyer 2005; Marchand et al. 2008). The ranges are seldom the same, however, so these studies are less useful for comparative research.

Survey of dairy workers

In our 2009 study, we compared the snapshot and completed-tenure approaches. We looked at length of employment and the reasons why dairy workers leave jobs. We compared the data with that from two previous dairy turnover studies — one by Fuller and Viles (1953) in Fresno County and the other by Billikopf (1984) in San Joaquin, Stanislaus and Merced counties. We also compared the data with studies conducted outside of California.

Over the years, compensation and benefits are the top reasons employees have given for leaving their jobs.

The second author conducted most of the interviews and drove to locations in San Joaquin, Stanislaus and Merced counties where there is a high density of dairy operations. He stopped at dairies and asked permission to interview employees. No attempt was made to collect data from workers who had left the industry permanently (e.g., for a job in another industry or because of disability, unemployment or retirement). Our survey followed the approach used by Billikopf (1984).

Demographics. In our sample, all respondents were male (n = 209). By job category, 50% (n = 103) were milkers, 19% (n = 40) were cow feeders, 17% (n = 35) were calf feeders, 12% (n = 25) were herdspeople, 1% (n = 2) were relief workers or helpers and 0.5% (n = 1) were maternity workers (responsible for taking care of pregnant cows). Forty-five percent (n = 95) of the subjects had never worked at another dairy.

Eighty-eight percent (n = 183) of the subjects were Hispanic and 12% (n = 26) were white (of the latter, 81% were Portuguese). The average worker was 36 years old; the range was from 19 to 69.

Gregorio Billikopf

In a recent survey of San Joaquin Valley dairy workers, the reasons most often cited for leaving employment were compensation and benefits, economic problems at the dairy, and personal and family matters.

Interviews. Because we were speaking to individuals during work time, we kept the interviews brief so as to minimize the disruption of work operations. We spoke to workers in Spanish and English. Our questions were open-ended. Each subject was asked (1) What is your job in this dairy? (2) How long have you worked in this dairy? (3) Have you ever worked at another dairy? (4) If yes, how long did you work there? and (5) Why did you leave? Questions 4 and 5 were repeated for each of the previous dairy positions the worker had held. The 209 individuals interviewed had worked in 432 distinct dairy jobs.

Responses were given quickly, and we did not probe. We are confident that the answers given were sincere. The process was anonymous; we did not ask for the names of the subjects.

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The average length of dairy employment was 6.6 years; the range was from 2 weeks to 40 years. The average number of jobs among people with previous dairy positions was three.

Length of employment

Using the snapshot approach, the average length of employment at the time of interview was 6.6 years, and the range was from 2 weeks to 40 years. By contrast, when we used the completed-tenure approach, the average length of employment was only 3.5 years. The subset of subjects without previous dairy employment (n = 92), who would not have been interviewed if we had used only the completed-tenure approach, had an average length of employment of 7.1 years, and the range was from 5 weeks to 40 years. The subset of subjects with previous dairy jobs (n = 114) had an average length of employment of 6.2 years. On average, these subjects had held three dairy positions, that is, the present job plus two more. As Billikopf noted in 1984, there is great variability in these numbers because some workers seldom change jobs while others do so regularly.

The 1984 data provides further indication that the completed-tenure approach underestimates the true length of employment. Individuals who had never worked in other dairies already had stayed 4 years on the job compared with the average 2.5 years for those who had completed and left dairy positions.

Reasons for leaving

Most workers had a single prominent reason for leaving their jobs. At times one or two additional reasons affected their decision for leaving. The subjects who had left previous dairies (n = 114) reported a total of 222 previous dairy positions. For each of these job changes, interviewees gave a main reason for departure. In addition, secondary reasons were given for 8% (n = 18) of the jobs and tertiary reasons were given for 1% (n = 2) (table 1).

The reasons given for leaving previous dairy jobs in the 2009 study, from the most to the least common, included:

Compensation and benefits. Workers typically felt they were either working too many hours for the pay received or that wages were simply too low, regardless of hours worked. Other traditional reasons for worker dissatisfaction in this area were unfulfilled promises often made at the time of employment.

Dairy economic problems. Most typically, the former dairy employer had to sell, or would soon be selling, the farm operation.

Personal and family reasons. This included employees' need to move in order to be closer to family members, and personal or family-related reasons such as divorce or poor health.

Working schedules and time off. This included employees' preferences for a different number of days on or off and the need to take time off to visit family, get married or other personal reasons.

Housing and transportation. This included employee dissatisfaction with their housing and difficulties getting to work.

TABLE 1. Reasons for leaving dairy employment in survey of dairy workers in Merced, San Joaquin and Stanislaus counties, 2009 (n = 222)

Reason	Primary	Secondary	Tertiary
		n (%)	
Compensation and benefits	65 (29)	1	0
Dairy economic problems	32 (14)	1	0
Personal, family reasons	24 (11)	0	0
Working schedules, time off	24 (11)	0	1
Housing, transportation	18 (8)	5	0
Relations with management	17 (8)	3	0
Job duties	16 (7)	3	0
Laid off, discharged	15 (7)	0	0
Relations with co-workers	6 (3)	0	0
Job injuries	4 (2)	0	0
Started own dairy	1 (0.5)	0	0

Relations with management. Employees reported not getting along with either their direct supervisor or the dairy owner (sometimes one and the same person).

Job duties. Employees reported preferences for certain kinds of work, such as outside work instead of milking, and dissatisfaction with the way their job was designed.

Other reasons cited by workers included being laid off or discharged, poor relations with co-workers, job injuries or leaving to start their own dairy.

Historical comparisons

It is not clear which measurement approach was used in the 1953 study; later studies used the completed-tenure approach for comparison purposes. Historical data comparisons showed an upward trend in length of employment (fig. 1). In 1953, average length of employment was about 1 year, in contrast to about 2.5 years in 1984 (a 150% increase) and 3.5 years in 2009 (an increase of 250% since 1953 and 40% since 1984).

Over the years, compensation and benefits are the top reasons employees have given for leaving their jobs. Yet, there seems to be a slight downward trend in the percentage of workers listing it as their reason for leaving: 35% in 1953, 33% in 1984 and 29% in 2009.

Two of the largest changes since 1953 were in layoffs and discharges, which were highly reduced in the more recent surveys (24% in 1953, 7% in 1983 and 2009), and dairy economic problems, which increased in the more recent studies (not listed in 1953, 11% in 1983, 14% in 2009). We once again note that 2009 was the worst year in the history of the dairy industry. In 1953, economic problems were not listed as a reason for leaving employment, but perhaps this reason was subsumed under layoffs and discharges.

Another key area of change has been in relations with management. In the more recent studies, dairy employees seemed to get along considerably better with their managers or supervisors, with fewer employees listing it as their reason for leaving (17% in 1953, 8% in 1983 and 2009). Perhaps this is due to better management practices than in the past as well as employment laws that protect workers from arbitrary treatment.

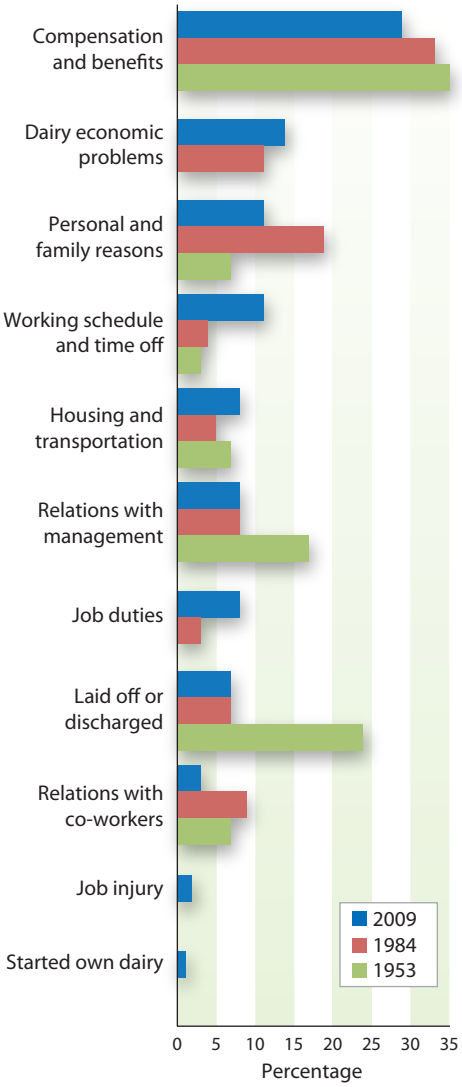

Fig. 1. Reasons for worker turnover in California dairies. In 2009 survey, *n* = 209.

Related studies

In a recent survey study conducted in three Eastern dairy states (New York, Pennsylvania and Vermont), snapshot data was collected for length of employment at the time of survey (Stack et al. 2006) (table 2). The authors found that Hispanic employees tended to be younger on average than their non-Hispanic counterparts (29 years old versus 36 years old) and have shorter lengths of employment (1.1 compared with 5.8 years). Although Hispanics in California are staying much longer in dairy jobs than their counterparts in the East (5.8 compared with 1.1 years), we found similar differences between Hispanic and non-Hispanic dairy employees in our 2009 data (34 years old versus 48 years old, and lengths of employment of 5.8 compared with 12.4 years). The hiring of Hispanic employees in the Eastern states is a much newer phenomenon than in California.

Also of interest are two studies that measured length of employment around the time of our study in the Canadian pork industry (Marchand et al. 2008) and the New York state dairy industry (Maloney and Grusenmeyer 2005). The New York study confirms the findings of higher turnover among Hispanic employees than non-Hispanic employees in the East; 40% had worked less than 1 year at the time of the study, and only 1% had worked 6 years. The Canadian study concerned swine operations rather than dairy, and there was no focus on Hispanic workers. It showed a normal data distribution, with the fewest number of employees having worked for the least amount of time (less than 1 year) or the longest (over 15 years). Unfortunately, for purposes of comparison, both of these studies measured length of employment using ranges rather than exact numbers.

Further questions

Length of employment among California dairy employees has increased in recent decades, indicating improved stability in the workforce. Despite these gains, however, it seems that much could be done to lengthen Hispanic employees'

TABLE 2. Length of employment in Eastern (2006)* and California dairies (2009)

	Eastern			California		
	Hispanic	Non-Hispanic	Probability† (*P*)	Hispanic	Non-Hispanic	Probability† (*P*)
Age	29.0 (*n* = 192)	35.9 (*n* = 770)	< 0.01	34.2 (*n* = 182)	48.1 (*n* = 24)	< 0.001
Tenure (years)	1.1 (*n* = 192)	5.8 (*n* = 770)	< 0.01	5.8 (*n* = 183)	12.4 (*n* = 26)	< 0.01

* Source: Stack et al. 2006.

† *P* is from two-way *t*-test.

employment in California, considering that non-Hispanic workers have tenures that are twice as long. We wonder how much of the shorter employment tenure for Hispanic employees — who have much in common with Portuguese employees, both being foreign-born and having cultural similarities — has to do with legal status.

Billikopf (2003b) hypothesized that the number of women working in dairies tended to decrease as the number of foreign-born Hispanic employees increased. For instance, he showed that in regions of the United States where there are greater numbers of women working in dairies, there are fewer Hispanics, and vice versa (Billikopf 2003b, 2006, 2009). California seems to be no exception; there is a strong Hispanic presence in the state's dairies and relatively few female employees. Perhaps employers who cannot secure Hispanic employees go out of their way to recruit female employees in order to meet their labor needs.

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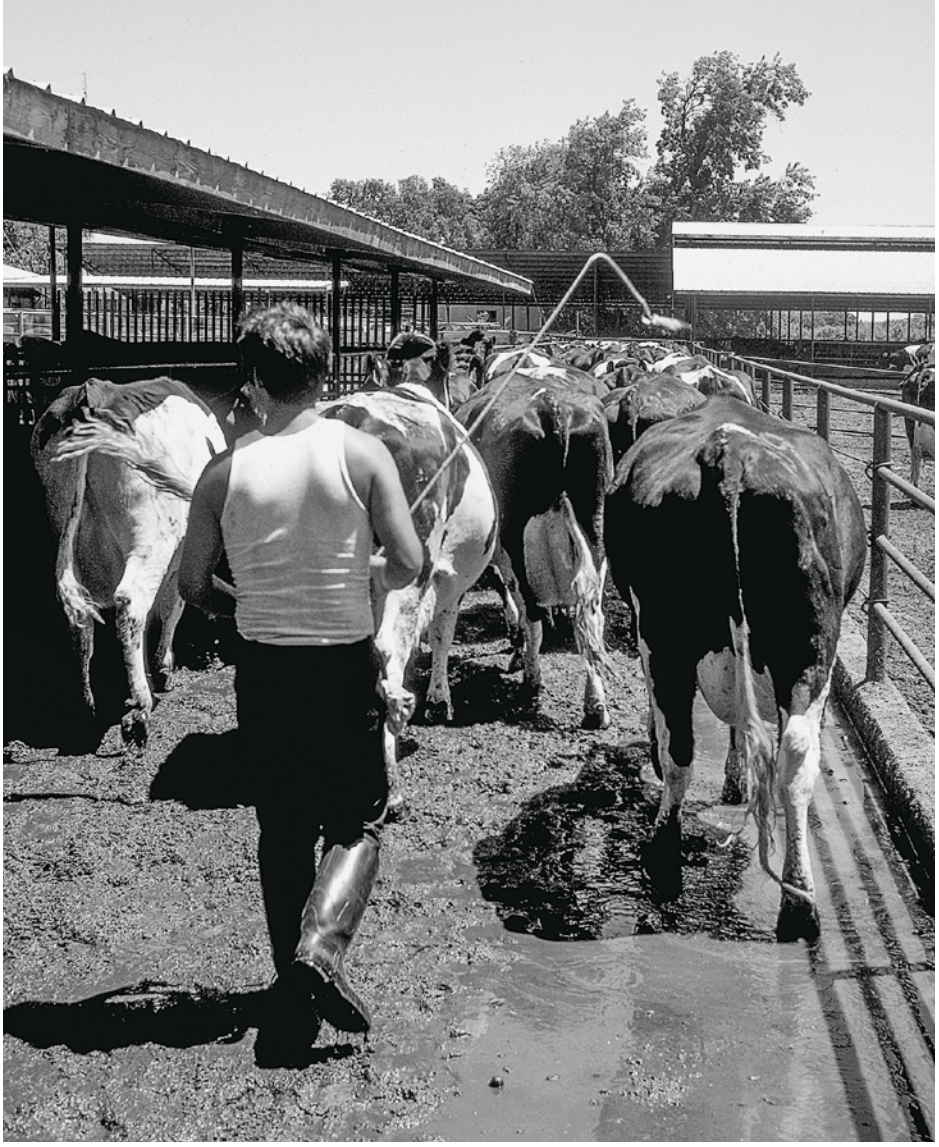

Gregorio Billikopf

The lead author's previous survey of why workers leave dairies was published in *California Agriculture* journal in 1984. Lengths of employment have increased 250% in the Central Valley since an earlier study in 1953, and 40% since 1984.

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4-H boosts youth scientific literacy with ANR water education curriculum

by Martin H. Smith, Katherine E. Heck *and* Steven M. Worker

Scientific literacy among K-12 youth in the United States needs to be improved, and UC Agriculture and Natural Resources has identified this as a key area for research and extension. In 2010, ANR developed a water education curriculum for implementation by 4-H, which has a record of successful, nonformal science education programming that complements classroom-based instruction. The development of the new curriculum,* There's No New Water!*, is described, and preliminary results from a pilot test with high school youth are provided. Preliminary outcomes showed gains in both science knowledge and life skills.

Steven Worker

The 4-H curriculum *There's No New Water!* was developed in response to ANR's Strategic Vision 2025, and it is guided by National 4-H Science literacy goals and strategies. During a workshop at UC Merced, 4-H members simulate the pathways raindrops may traverse through a watershed.

Twenty-first-century society is highly dependent on science and requires a scientifically literate population (NAS 2007). Individuals who lack fundamental science knowledge and skills risk being unqualified for many careers and unable to participate fully in society (Miller 2006). In particular, citizens need to understand scientific concepts and theories in order to address important issues such as public health, water quality, agriculture, transportation, communication and energy conservation (NAS 2007). The National Academy of Sciences maintains that a scientifically literate population is critical for a robust national economy driven by "well-trained people and the steady stream of scientific and technical innovations they produce" (NAS 2007).

Research has revealed, however, that scientific literacy in the United States is low. Miller (2006) found that only 28% of U.S. adults have a level of scientific understanding necessary to function as citizens in modern society, and scientific literacy among young people is also undesirably low. Nationally, assessments have shown stagnant or declining science scores among school-age youth. The 2005 and 2009 National Assessment of Educational Progress (NAEP) results for 4th, 8th and 12th graders showed poor science achievement at all three grade levels (Grigg et al. 2006; NCES 2011). These trends are not distributed equally across the population; science achievement tends to be higher among male than female students, white and Asian American than black and Latino youth, and those from high-income than from low-income households (Grigg et al. 2006; NCES 2011). State-level data show that California is not an exception to the poor national achievement in science.

Low scientific literacy has compromised the nation's ability to train new scientists, as demonstrated by the decline in the number of college science graduates. It is also evident in the drop in production of new scientific knowledge by U.S. scientists compared with that of scientists in many other developed nations over the past 20 years (NAS 2007). For these reasons, identifying effective strategies to address low scientific literacy among youth is imperative.

Learning in nonformal programs

Achieving higher scientific literacy among the school-age population will

Online: http://californiaagriculture.ucanr.edu/landingpage.cfm?article=ca.v066n04p158&fulltext=yes
DOI: 10.3733/ca.v066n04p158

require a variety of complementary strategies, including nonformal science programs that occur outside of school. On average, U.S. citizens spend less than 5% of their lives in classrooms, and a growing body of evidence demonstrates that most science is learned outside of school (Falk and Dierking 2010). Science learning out of school may actually be more effective than learning in classroom settings (Sullenger 2006). Nonformal learning environments generate excitement around science that encourages learners to explore and interact with the subjects and to think of themselves as able to use science in everyday life (Bell et al. 2009).

Adult staff members or volunteer educators usually lead nonformal education programs with youth (Carlson and Maxa 1997). These opportunities can occur in a variety of venues, including after-school and school enrichment programs, clubs, camps or museums. Nonformal education programs emphasize learner-centered strategies that engage participants to develop their knowledge and reflect on how science takes place in the real world (Carlson and Maxa 1997). Learner-centered strategies engage youth in an active manner through hands-on activities that involve problem solving, critical thinking and active reflection. This is in contrast to more traditional classroom-based approaches such as lectures and demonstrations. Although not considered to be alternatives to school, nonformal education programs can expand school curriculum offerings and complement classroom teaching (Kahler and Valentine 2011).

ANR's Strategic Vision 2025

UC Agriculture and Natural Resources (ANR) connects the research base of the university to local communities throughout the state. Its Strategic Vision 2025 charts a course of action for the role ANR will play in "improving California's future by providing leadership and innovation through research, education and service" over the next 15 to 20 years (ANR 2009). In descriptions of targeted strategic initiatives, the document outlines plans for science-based solutions to issues and challenges facing California's environmental, agricultural and human resources.

Scientific literacy is a key issue targeted for applied research, education and extension efforts. In integrated, multidisciplinary approaches outlined in the Healthy Families and Communities (HFC) Initiative (Campbell et al. 2010), the university has committed to improving scientific literacy among Californians. The Initiative's plan describes the need to develop and implement science programs that use active-learning strategies, involve schools and community-based education programs and increase civic engagement among target audiences, particularly youth. Delivering educational programs at the community level is a cornerstone of ANR's efforts to increase scientific literacy.

Water supply and quality for agricultural, urban and environmental systems are additional focal concerns outlined in ANR's Strategic Vision 2025 (ANR 2009). Specifically, the Initiative to Improve Water Quality, Quantity, and Security suggests that the following issues need attention: water availability due to competition among different sectors of the population, short- and long-term climate changes that will affect water supplies, the degradation of water quality, and legal and regulatory decisions that will affect water availability, use and quality. Strategies outlined by the Strategic Vision 2025 for UC ANR personnel to address these problems include research, education and partnerships with agricultural and environmental groups and regulatory agencies.

4-H Youth Development

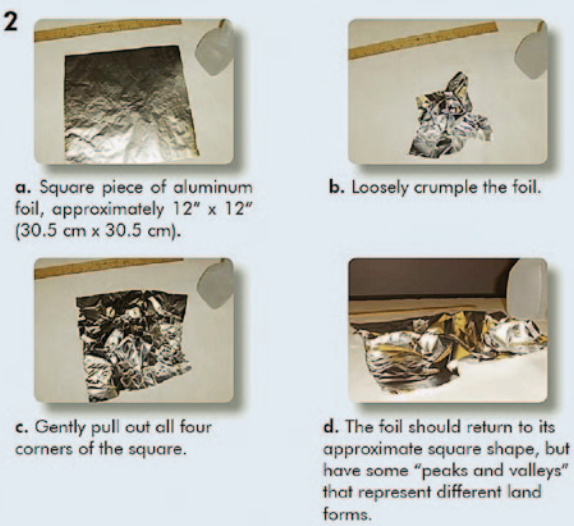
The National 4-H Youth Development Program has provided nonformal educational opportunities to youth ages 5 through 19 since its establishment by Congress in 1914, and it is one of the largest community-based youth organizations in the world. Using strategies that engage youth in hands-on, learner-centered projects and programs, 4-H staff and adult volunteers serve as nonformal educators and deliver 4-H projects and activities that address the interests of young people and help meet the needs of their communities (Enfield 2001). California 4-H is the youth education program of UC ANR.

The 4-H program offers a wide variety of educational opportunities that reflect its diverse membership (Enfield 2001). Nationally, more than 50% of all 4-H members participate in science projects and activities, ranging from geology and minerals to soil conservation, from forestry to wildlife and fisheries, from computer science to animal and veterinary science (USDA 2003). In California, over 130,000 4-H youth were enrolled in science, engineering or technology programming during the 2009-2010 school year (UC ANR 2012).

Outcome data from evaluations shows that 4-H plays a vital role in helping U.S. youth contribute to their communities (Lerner et al. 2012). 4-H youth are almost twice as likely as other youth to make community contributions; additionally, they have higher measures of civic duty, civic voice and participation in volunteer activities (Lerner et al. 2009). Likewise, youth who participate in 4-H are more likely than other young people to have a positive attitude toward science (Lerner et al. 2009).

Youth who have more exposure to 4-H science, engineering and technology programs are more likely to agree that science is their favorite subject, and they are more likely to want to pursue a job in science (Mielke et al. 2010). In addition,

Figure 2



Photos by Eryanne Edgerly

In the "Going With the Flow" activity, youth simulate a landscape using aluminum foil and predict how water drains through the watershed.

youth engaged in 4-H science programs take higher-level science coursework in high school compared with young people outside of 4-H (Heck et al. 2012). Furthermore, youth in the California 4-H program are more likely than other young people to report that programs they participate in after school and in the summer increase their interest in taking more science courses as they get older, as well as their interest in pursuing science as a career (Heck 2009).

California 4-H SET Initiative

In 2007, National 4-H Headquarters developed the 4-H Science Mission Mandate (Schmiesing 2008). Grounded in research that indicates the importance of community-based programs in improving youth scientific literacy (Bell et al. 2009), this mandate established programmatic priorities to help guide state 4-H programs' efforts to develop and implement new, research-based curricula, as well as develop staff and volunteers, partnerships, evaluation and funding sources (Schmiesing 2008).

In 2008, California 4-H launched its 4-H Science, Engineering and Technology (SET) Initiative as a direct response to the National 4-H Science Mission Mandate. The SET Initiative has youth scientific literacy as its overarching goal and aims to improve existing 4-H SET programming and develop new programming that aligns with the initiatives outlined in ANR's Strategic Vision 2025 (ANR 2009). One major focus of the California 4-H SET Initiative plan of action is the development and implementation of effective SET-based curriculum materials that align with UC ANR priorities and support county-based 4-H SET programming.

Educational programs based on high-quality curriculum materials are most relevant for young people when they reflect societal needs and concerns.

There's No New Water!

In response to the Strategic Vision 2025, ANR academic staff developed the youth science curriculum *There's No New Water!* (Smith et al. 2010). This peer-reviewed curriculum, published by National 4-H Council, focuses on increasing scientific literacy by engaging middle and high school youth in hands-on, inquiry-based science activities that include opportunities for real-world applications of knowledge and skills through service learning. The sequenced activities build learners' knowledge and skills by emphasizing interrelated concepts, support state and national science standards, and are applicable for use in schools and community-based education programs.

There's No New Water! was developed using the backward design method (Wiggins and McTighe 1998), which involves identifying learning objectives and indicators before designing activities. Once the objectives and indicators were outlined, the curriculum design team, consisting of ANR academic staff and university undergraduates, formed subgroups focused on specific content areas. Each subgroup then engaged in an iterative process that involved reviewing relevant literature, drafting and pilot testing activities, and collecting formative data (qualitative information on content and processes used) for revisions. The curriculum includes elements outlined by Siemer (2001) for effective water stewardship education: sequential learning experiences that occur over time, opportunities to develop relevant ecological knowledge, and skill building such as decision making, communication and evaluation.

Educational programs based on high-quality curriculum materials are most relevant for young people when they reflect societal needs and concerns (Ediger 2002). The major themes of *There's No New*

There's No New Water! Table of Contents

Eryanne Edgerly

Water! are priority issues in California and nationally: water distribution and water availability, conservation and quality. Topics include the natural water cycle, watersheds, human interventions in the water cycle, the urban/rural interface and topographic mapping of watersheds in different geographic locations (see box).

Curriculum activities support the National Science Education Standards (NRC 1996), and they include explorations of science processes, scientific inquiry, natural resources and environmental quality, and natural and human-induced hazards. Furthermore, the curriculum addresses specific science content standards for California public schools for grades 9 to 12 — California geology and water (9c and 9d) and skills in investigation and experimentation (1a, 1d, 1h, 1l and 1m) (CDE 2003).

A unique feature of *There's No New Water!* is the opportunity for youth to engage in their community through service learning. In module five, guidelines help youth identify water-related issues in their community and develop a project to address them. This application of learning is particularly germane to improving scientific literacy and also workforce preparedness; engaging youth in inquiry relevant to their community has been shown to increase their interest in science (Eick et al. 2008). Module six includes age-appropriate activities on water resources designed for implementation by teens with elementary school youth. Research-based strategies that help teens to have a successful experience teaching younger youth are provided (Lee and Murdock 2001). Teens have been shown to be extremely effective teaching science to younger youth; they relate well to younger audiences, are optimistic in their roles as cross-age teachers and engage in science content and processes with children in an active manner (Ponzio et al. 2000).

Steven Worker

Participants at the "water treatment" station learn that wastewater must be treated for harmful pathogens, toxins and organic matter that can have damaging effects on human health and the watershed. *There's No New Water!* includes a module to help youth identify local water concerns and develop a program to address them, activities shown to increase interest in science.

Testing the curriculum

A school enrichment program was used to pilot test *There's No New Water!* and collect preliminary outcome data. School enrichment programs are often used to implement 4-H youth science programs (Kahler and Valentine 2011), which have been shown to provide experiential education opportunities in school settings, increase participating youths' knowledge and skills and help reach diverse audiences (Diem 2001).

Modules one through four of the curriculum were implemented once per week for 1 hour over an 8-week period with students in two ninth-grade earth science classes in a north-central California urban high school. The curriculum was offered in lieu of the students' regular class instruction. Modules five and six were not offered due to time constraints.

A retrospective pretest survey was used to examine changes in content knowledge (Pratt et al. 2000). Participants self-reported how much knowledge they believed they had gained in content areas related to water resources. A retrospective pretest design can provide a more accurate assessment of change due to a program intervention than other types of survey methodologies (Pratt et al. 2000). Specifically, this type of survey design reduces the problem of response-shift bias, which is the overestimation of knowledge and skills on a pretest that can occur when using a pretest versus posttest comparison (Pratt et al. 2000). Furthermore,

a retrospective pretest design helps reduce the time needed to administer the survey and mitigates the challenge of obtaining complete data sets (Raidl et al. 2004).

A second survey was used to investigate youths' perceived gains in various life skills from participating in the activities (Hendricks 1996). Using a posttest design, this survey replicated questions from previously published evaluation research on life skills outcomes from participation in Cooperative Extension programming (Bailey and Deen 2002).

Six UC Davis undergraduate students were recruited as volunteer educators to implement *There's No New Water!* with participating youth in the pilot program. They were trained over a 10-week period in effective science-teaching strategies and all of the curriculum activities. The high school where the pilot evaluation occurred is located in a mid-sized city and serves approximately 1,900 students from 9th to 12th grade. Approximately 22% of the school's students receive free or reduced-price meals, and about 10% are classified as English learners or reclassified as English proficient.

A total of 59 youth, aged 14 to 17, participated in the pilot evaluation; most were 14 or 15, and 58% were male. Approximately 29% of the participants reported that they were Latino, 10% were black, 14% were Asian or Pacific Islander, 37% were white, and 10% were other or did not report their race/ethnicity.


Steven Worker

Youth work with topographical maps to learn how the impact of pollutants varies depending on the natural landscape and types of human activities.

Preliminary results

Participants were asked eight retrospective pretest questions on content knowledge (e.g., on global water distribution, point and nonpoint source pollutants, watersheds and urban/rural interface) to ascertain their perceived level of knowledge gain. On a scale of 1 (poor) to 4 (excellent), responses to all eight questions revealed a statistically significant ($P < 0.01$) increase in self-perceived knowledge gain using a paired *t*-test comparison of the means (table 1).

The 20 questions on the second survey related to life skills, including wise use of resources, social skills, communication and responsible citizenship, as specified in the Targeting Life Skills Model (Hendricks 1996). Participants rated their levels of knowledge gain using a scale from 1 (not at all) to 4 (a lot). The means

TABLE 1. Mean change in level of knowledge around *There's No New Water!* content topics

Topic	Level of knowledge before	Level of knowledge after	*P* value for difference
Global water distribution	1.85*	2.54	< 0.01
Water conservation	1.83	2.53	< 0.01
Nonpoint source pollutants	1.65	2.33	< 0.01
Watershed	1.43	1.97	< 0.01
Topographic maps	2.00	2.75	< 0.01
Urban/rural interface	1.66	2.32	< 0.01
Point source pollutants	1.92	2.49	< 0.01
Water quality in my community	1.78	2.34	< 0.01

* Mean value; level of knowledge self-reported as poor (1), fair (2), good (3) or excellent (4).

TABLE 2. Mean gain in selected life skills for *There's No New Water!* curriculum

Life skills	Mean value*
Water and environment	
I improved my ability to think about and understand concepts related to water.	2.66
I learned the importance of protecting the natural environment.	3.10
I learned ways I can help improve the environment.	2.97
Citizenship, leadership and responsibility	
I learned how my actions affect my community and the world.	2.80
I improved my ability to accept responsibility that comes with being a good citizen.	2.58
I improved my ability to involve others in sharing leadership responsibilities.	2.27
Social skills, cooperation and communication	
I improved my ability to help out as best I can when working with a group.	2.63
I improved my ability to cooperate with others toward a goal.	2.64
I improved my ability to relate to others socially.	2.56
I improved my ability to listen carefully to what others say.	2.55
I improved my ability to clearly state my thoughts and ideas to others.	2.27

* Amount of gain self-reported as not at all (1), a little (2), some (3) or a lot (4).

for their responses ranged from 2.3 (a little) to 3.1 (some), with the greatest perceived gains reported around citizenship and helping the environment (table 2).

Success and future of program

The preliminary learner outcomes from the pilot test support previous researchers' assertions on the importance of nonformal science education programming (Bell et al. 2009) and how such programs can expand school curriculum offerings and complement classroom teaching (Kahler and Valentine 2011). The outcomes are also congruent with the goals of the California 4-H SET Initiative, the National 4-H Science Mission Mandate and ANR's Strategic Vision 2025 to strengthen curriculum materials and programming for youth in science (ANR 2009; Kahler and Valentine 2011). They also address the ANR Strategic Vision 2025 directives on improving citizens' understanding of water issues, why and how to care for the environment and ways to conserve natural resources.

The preliminary results presented build a case for an in-depth evaluation of *There's No New Water!* in multiple nonformal contexts, including 4-H clubs, after-school programs and camps, using multiple measures to improve the validity and reliability of the findings. The curriculum is currently being implemented through county-based 4-H programs in California, as well as in 4-H programs in numerous other states. It is available for purchase through the National 4-H Program's Curriculum Resource Library (www.4-h.org/resource-library/curriculum).

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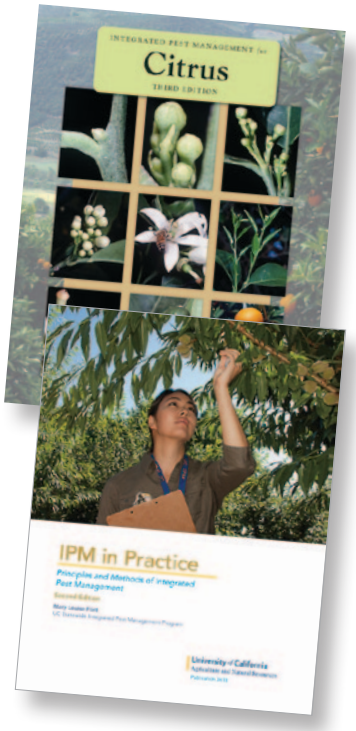

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COMING UP *in California Agriculture*

Improving youth, family and community health across California

Scientists from UC Agriculture and Natural Resources (ANR) have launched a 5-year program to promote healthy lifestyles, science literacy and positive youth development. By combining research, education and community partnerships, UC's Healthy Families and Communities strategic initiative (http://ucanr.org/sites/HFC) aims to improve health and scientific understanding across the state.

Rachel Scherr

***Above*, a fourth-grade student pedals the "smoothie bike" to blend a spinach banana smoothie at an ANR-sponsored health fair in Sacramento County.**

In the next issue of *California Agriculture* journal, these scientists review ongoing research and present new findings in youth development, childhood obesity, nutrition, garden-based education, farm-to-school linkages, teen financial literacy and 4-H volunteer training. The initiative is pursuing measurable changes that increase fitness levels, improve dietary outcomes and decrease obesity rates; improve science test scores and graduation rates, college enrollment and young adult employment; encourage more healthful school and community environments; promote greater equity for racial and ethnic groups; secure funding for effective programs; and empower citizens to use research to improve conditions in their own communities.