APRIL–JUNE 2011 • VOLUME 65 NUMBER 2

# California Agriculture


## Down on the farm: Agritourism on the rise

*Also: Free trade, constructed wetlands, rice nitrogen, smart sprayers, almond irrigation*

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

# Transformative high-tech solutions leverage ANR response

As we go to press with this issue, the scope of the catastrophe in Japan grows as events continue to unfold. The human suffering, economic damage and environmental consequences will command global attention, effort and resources of historic proportions. In this context, any editorial comment on the issues facing California's agriculture and natural resources seems inappropriate. On the other hand, global events are sobering reminders of the importance of our commitment to healthy food systems, environments, communities and Californians.

In the last issue's editorial, Vice President Dan Dooley described systemic and environmental challenges to the global food system, as well as the risk of regional natural disasters and resulting environmental, economic and human impacts. There can be no argument that both short and long term, the response to the events in Japan, New Zealand, Haiti and elsewhere must and will be global, affecting us all directly and indirectly.

For *California Agriculture*, we recognize that while our role is small in the short term, the long-term importance of the issues-focused research that we publish is not. We are also aware that expanding access to and speeding the publication of policy-relevant science from the University of California is both imperative and possible.

Last year at this time, I wrote about successful efforts, coordinated by Executive Editor Janet White, to digitize, index and post online the entire library of *California Agriculture*'s 64-year history. The immediate impact of that effort resulted in millions of page views and has continued to grow. Since then, the evolution of electronic publishing has accelerated rapidly while the current economic situation has constrained our ability to immediately print all of the research that has passed rigorous, anonymous peer review.

**Expanding access to and speeding the publishing of policy-relevant science from the University of California is both imperative and possible.**

In response, we will soon accelerate our electronic publishing efforts at *California Agriculture* to provide authors the option of fast-track, electronic-only publication of peer-reviewed research. Providing the rapid turnaround of time-sensitive findings increases the journal's value to academic and lay audiences alike and builds the division's electronic reach through *California Agriculture*'s presence in multiple indexes, databases and repositories.

In addition to benefitting to the academic and scientific community, our ongoing expansion of electronic publishing is helping us to define and implement a much broader vision of providing UC research and outreach information and programs. In the near future, we envision integrated web-based and mobile electronic tools, resources and applications that will provide ready access to existing UC digital repositories and research data, along with an array of location-aware applications (apps) enabled by geographic information systems. These tools will support UC researchers and educators, gather critical data and deliver site-specific information almost anywhere or anytime.

**Robert S. Sams**
Director, UC ANR
Communication Services and Information Technology

UC academics are already delivering tools that illustrate what is possible. For example, Maggie Kelly, UC Berkeley cooperative extension specialist, has led the development of a free smart-phone app that allows users to report oak trees displaying the symptoms of sudden oak death, a disease causing significant damage to California's oak species. While Kelly's app and related website, OakMapper.org, help scientists study the disease, they also enable involved citizens to contribute important data in real time directly to research databases.

In another example, Anthony O'Geen, UC Davis cooperative extension specialist, has created a smart-phone app that exploits the device's GPS (global positioning system) capabilities to provide location-specific information on soil type, composition and other characteristics.

Likewise, Matthew Fiedelibus, associate cooperative extension specialist at the UC Kearney Agricultural Center near Fresno, is exploiting the capabilities of an array of social media to speed communication within growing communities of raisin, table and wine grape producers and distributors, pest control advisers, and agency scientists in this important industry.

These and other efforts demonstrate the potential of web and mobile technology to deliver powerful, integrated tools that deliver UC resources and support a range of UC academics and programs, from today's issue of *California Agriculture* alongside 65 years of indexed articles to the latest report of a new invasive pest.

We all face the challenges of responding to natural disasters, daunting economic realities and seemingly intractable problems, both public and private. For us, publishing and providing greater access to good science and leveraging the power of transformative technology are privileges and passions and, we hope, things that makes a difference.


COVER: Agritourism can provide growers with access to new customers as well as bolster income. The first statewide survey of agritourism operators (page 57) found that nearly 80% engage in direct sales. At its annual Pleasure of the Peach Day, Good Humus Farm in the Capay Valley offered a range of farmstead products. During recent agritourism workshops (page 56), participants discussed the growing role of social media for marketing farms and their products. *Photo: Nancy Warner*

APRIL–JUNE 2011 • VOLUME 65 NUMBER 2

# Down on the farm: Agritourism on the rise

## Research and review articles









## News departments

### Research news




### Outreach news



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# About California Agriculture

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*California Agriculture* is a quarterly, peer-reviewed journal reporting research, reviews and news, published by the Division of Agriculture and Natural Resources (ANR) of the University of California. The first issue appeared in December 1946, making it one of the oldest, continuously published, land-grant university research journals in the country. The print circulation is currently about 15,000 domestic and 1,800 international, with a strong online presence.

**Mission and audience.** *California Agriculture*'s mission is to publish scientifically sound research in a form that is accessible to a well-educated audience. In the last readership survey, 33% worked in agriculture, 31% were faculty members at universities or research scientists, and 19% worked in government agencies or were elected office holders.

**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) databases; EBSCO (Academic Search Complete); Gale, including Lexis-Nexis; Google Scholar; Proquest; and others, including open-access databases. It has high visibility on Google and Google Scholar searches. All peer-reviewed articles are posted to the California Digital Library's eScholarship Repository.

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

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

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

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

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

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

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## California Agriculture

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1301 S. 46th St., Bldg. 478, Richmond, CA 94804-4600
Phone: (510) 665-2163; Fax: (510) 665-3427; calag@ucdavis.edu
**http://californiaagriculture.ucanr.org**





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# Unique engagement tools shape nitrogen assessment

Nitrogen is one of the most important inputs for California agriculture. As fertilizer, it fuels an agricultural system that makes the state a world leader in production. Yet the excess nitrogen that leaks from agricultural systems can cause water and air quality problems that negatively affect ecosystems and human health.

Before leaders can take action to address these unintended consequences, they need a sound scientific foundation on which to make decisions — one that integrates an understanding of the importance of nitrogen to agricultural production. The California Nitrogen Assessment (CNA), an interdisciplinary project of the Agricultural Sustainability Institute (ASI) at UC Davis, is creating this knowledge base with the input of numerous California stakeholder groups.

"The California Nitrogen Assessment will be policy relevant but not prescriptive, which means it will offer a range of possible options and outcomes that stakeholders and policymakers will be able to use to inform their decision-making," says ASI director Tom Tomich.

To establish a firm scientific baseline, the project comprehensively examines the existing knowledge on nitrogen science, policy and practice in California, using methodology modeled on integrated assessments like the Intergovernmental Panel on Climate Change and the Millennium Ecosystem Assessment. Ultimately, the California Nitrogen Assessment is designed to find leverage points where policy and technology can have a positive effect on California's air and water, and the health of its citizens, while at the same time maintaining the success of its thriving agriculture. Funded in part by a grant from the David and Lucile Packard Foundation, the assessment began in 2009 and will continue through 2011.


**Stakeholders confer at a recent nitrogen workshop in UC Davis's Putah Creek Lodge. *Left to right:* Albert Medvitz, McCormack Sheep and Grain; Antoine Champetier de Ribes, CNA; and Edward Hard, CDFA Fertilizer Research and Education Program.**

## Stakeholder input

Asking stakeholders to set the research agenda for the assessment is a uniquely important aspect of the project and one that sets it apart from other types of academic research. ASI has met with producers and farm groups, nonprofit leaders, government representatives and others around California, who all helped shape the assessment's focus. Some stakeholders came to the table skeptical about the project, but they quickly became interested in participating.

"The question that you have coming in is, how fair will it be to my point of view?" said Tim Johnson, president of the California Rice Commission. Johnson said that not only has the assessment engaged a wide range of stakeholders, but he has also been impressed "with the quality and the honesty of the dialogue."

Johnson and other stakeholders participate by serving on the assessment's stakeholder advisory committee, which works in an outreach capacity, sharing assessment information and findings with the groups they represent. Committee members provide specialized feedback to the assessment team in both face-to-face and virtual forums.

"Providing stakeholders with preliminary results and responding to their questions on work-in-progress is unusual for many scientific projects but will help foster results that are more useful to those who use and are affected by nitrogen," Tomich says.

## The future of nitrogen management

Advisory committee members are also participating in a scenario-building process, where they come together in workshops to create plausible stories about how nitrogen will be managed 20 years from now. These stories help participants, many of whom come from diverse perspectives, to address key uncertainties about the present-day landscape.

"It was really interesting to hear a lot of different agricultural perspectives and priorities about the issue," said Laurel Firestone, co-director of the Community Water Center, a nonprofit addressing the health impacts of nitrates in drinking water.

Paul Martin, director of environmental services for Western United Dairymen, said he is pleased to participate but is concerned about how policymakers will use the results. "The important thing is to avoid the rapid leap to conclusions."

As the assessment progresses, there will be more opportunities for stakeholder engagement. Drafts of the assessment document will be available for comment in 2011, and the assessment team welcomes the input of any groups or individuals who have a particular interest in the topic of nitrogen in California agriculture.

*For more info, go to: http://nitrogen.ucdavis.edu.*

*— Stephanie Ogburn*

# *Scientists discover redwoods' resiliency in Fritz's Wonder Plot*

Rapt with awe under the cool canopy of Northern California's majestic, 1,000-year-old redwoods, visitors may wonder what could possibly have motivated early Americans to chop down these giants without restraint.

Did the expanse of forests seem infinite? Were the settlers desperate for work and security? Were they unaware of how long it takes an undisturbed forest to grow into cathedral-like grandeur?

In fact, they couldn't have known much about the regeneration of a logged, old-growth redwood forest. In the recorded history of the world, the process had never been observed. Today, however, scientists are well on their way to understanding California's redwood forest regrowth because of the foresight and efforts of Emanuel Fritz, the late UC Berkeley professor of forestry.

**Emanuel Fritz, founder of the Wonder Plot, rode a lumber load on the Meadow Valley Grays Flat lumber tramway, circa 1926.** *Photo: Fritz-Metcalf Photographs Collection, Marian Koshland Bioscience and Natural Resources Library, UC Berkeley (www.lib.berkeley.edu/BIOS).*

In 1923, Fritz and a colleague, Woodbridge Metcalf, happened upon a thicket of young redwoods in a forest that had been harvested in the 1860s, about 100 miles northwest of San Francisco.

"We could hardly believe what we saw," Fritz later wrote.

The stand was dense; the volume high. Fritz and Metcalf secured the 1-acre grove to study second-growth tree and forest development. Fritz believed it to be "the best and oldest second-growth forest in the entire redwood region." He called it the Wonder Plot.

## Decades of data

Each decade, Fritz counted trees, mapped their locations, measured the tree trunk diameter at breast height, and estimated the average height and total volume of the stand in board-feet. He found that, while the number of trees in the plot decreased, the average tree diameter, estimated average tree height and estimated stand volume increased.

In the 1920s, many timber companies did not see value in their cut-over lands. However, Fritz was an advocate of sustainable second-growth of redwood trees for wood production. He understood that old-growth was a finite resource, and he set up his research plots knowing that in 30 to 50 years, foresters would be asking questions about second-growth management. His study helped demonstrate the remarkable regeneration potential of the species.

"I have been on the plot nearly every year since 1923 and hope to make what will likely be my last measurement in 1963," Fritz wrote in 1960. He actually took measurements in the plot until 1983, when he was 97 years old. After Fritz died in 1988, his legacy was carried on by researchers who have recorded the data every decade since. The collective study has provided one of the most complete descriptions of how an older second-growth forest matures.

## Foresters preserve research plot

Ownership of the Wonder Plot has changed many times. When Fritz first took measurements, Casper Lumber held the deed. The plot was later transferred to Union Lumber and then Georgia-Pacific. Each time the Wonder Plot changed hands, Fritz maintained a rapport with the foresters and had access to the plot. In deference to the dedicated researcher, foresters never took trees.

In 1975, Georgia-Pacific permanently protected the Wonder Plot for the purposes of research on redwood growth and yield. In 2003, ownership transferred to the Conservation Fund, and then the California state park system as part of Mendocino Headlands State Park.

Georgia-Pacific foresters, many of them graduates of UC Berkeley's forestry program, collected data on the plot every 10 years until forestry professors John Stuart and Jerry Allen of Humboldt State University took over the task in 1995. In 2005, Greg Giusti became the research leader.

"I didn't want the chain to be broken," said Giusti, UC Cooperative Extension forest advisor in Mendocino and Lake counties. "I recruited volunteers from Save the Redwoods League, the Mendocino Land Trust and California State Parks to maintain the research continuum."

## Along the Big River

The Wonder Plot is in the Big River watershed, in the central section of California's Coastal Redwood forest belt. There are reports that the Big River's name came not from the size of the waterway, but from the size of the trees originally lining its banks.

"It is no surprise that river logging came to the watershed soon after the California Gold Rush," Giusti said. "These guys would float down the river as far as they could go — drag logs to the river and float them down to the coast."

The remarkable old-growth of the Big River's lower terraces and hillsides was quickly cleared and transported by water to the new town of Mendocino, where it was milled to produce the lumber needed in boom-era San Francisco.

Giusti said it is unlikely that deeds to the land had been established at that time. "It was just the Wild West."

There is one asterisk on the assertion that humans maintained a hands-off policy in the Wonder Plot.

"In the 1990s, a number of trees blew down during a storm," Giusti said. "Foresters went in and took those logs. As an ecologist, I think that's too bad. But no one has ever gone in and cut out trees, and no one has removed fallen trees since then."

### Dense vegetation affects methodology

The nature of the Wonder Plot has provided an invaluable opportunity to study the development of a stand from a known point of harvest to the modern era. But the modern era hasn't offered many improvements for scientists in data collection. In an age of satellite imagery and GPS mapping, Giusti conducted the 2005 survey using a reproduction of the 1923 plot map hand-drawn by Fritz.

"The forest canopy is so dense that you can't use electronic devices," Giusti said. "The trees block the satellite signal."

Even a high-technology tool commonly used to measure tree height, a hypsometer, was foiled by the Wonder Plot's dense vegetation.

"We relied on old-fashioned measuring tapes and clinometers. All the new electronic devices intended to provide data points with a click of a button were impossible to use because of the density of the trees."

Giusti's 2005 survey revealed some changes since the last review of this patch of forest. He found that 70 of the original trees counted in 1923 were still standing, and he recorded 17 new saplings. "This represents a significant drop from the 112 trees on the plot in 1995, many of which were lost in a storm event in 1998," Giusti said.

The 1998 windstorm created openings in the plot's dense canopy that allowed the establishment of a new generation of redwoods for the first time in more than a century.

Average tree height in 2005 was 198.5 feet, and average diameter at breast height was 39.9 inches. Stand volume remains roughly equivalent to the 1963 measure. The Wonder Plot would produce four times the amount of board-feet expected from an average stand, a volume Fritz called "astronomic, even for California redwood."

### Understanding forest habitat

In addition to understanding wood production in the Wonder Plot, Giusti is interested in studying the unique habitat elements associated with old-growth forests. For example, in nearly 150 years, none of the second-growth trees has developed trunk hollows common in older redwood stands in Mendocino County, he said.

A still more enigmatic old-growth forest habitat — reiterative branches with epiphytic plants — is also absent in the grove. Reiterative branches are limbs that over generations of exposure are broken, twisted or overgrown into a sort of platform. Over time, dust and duff accumulate on the branches, creating a soil bed high in the canopy on which moss mats, ferns and other foliage grow. Populations of clouded salamander living high off the ground have been found in such old-growth habitats.

"We know very little about the development of these treetop habitats. It's a whole new world," Giusti said. "But that's something else we hope the Wonder Plot will reveal in the coming decades."

The data will be invaluable to California redwood conservationists, such as Save the Redwoods League, the Conservation Fund and the Redwood Forest Foundation. In Mendocino County alone, there are more than 90,000 acres of cut-over land owned by nonprofit organizations.

"They want to reestablish the primordial forest," Giusti said. "The Wonder Plot gives us some insight on how a cut-down redwood forest will recover. We have a baseline for recruiting old-forest characteristics and the grandeur that was lost by rapid cutting in the 20th century. The Wonder Plot serves as an example of what we will have over time."

And that example is promising. Giusti uses a highly technical term to describe the Wonder Plot.

"It is *über* cool," he said. "The trees are huge, but they are just babies at 100, 120 or 150 years old. They have the potential to live for a millennium. You already sense that cathedral-like quality when you walk in. The air changes. The way noise moves through the forest is different. It's starting to feel like an older forest."

— *Jeannette Warnert*

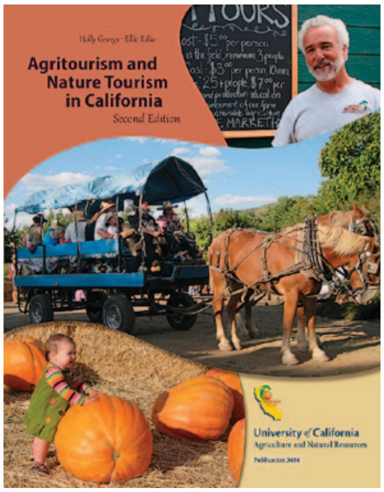
Dan Porter

**The Fritz plot research team took a lunch break from measuring trees in August 2005; UCCE forest advisor Greg Giusti leaned against a redwood.**

# Agritourism operators embrace social media for marketing

When it comes to marketing, the hottest topic among California's agritourism operators is clearly social media. Many operators are embracing this tool to market their farm-related businesses.

"We're seeing the older generation eager to learn from the 30-year-olds how to jump into this new way of communicating with their customers," said Penny Leff, agritourism coordinator for the UC Small Farm Program. "But they are also worried about having enough time to learn something new while keeping their businesses running."




**The second edition of *Agritourism and Nature Tourism in California* will be published later this year.**

Attendees at four recent regional agritourism workshops — funded by USDA Western SARE (Sustainable Agriculture Research and Education) — expressed considerable interest in learning how to use Facebook, Twitter, blogs, YouTube and other new tools.

"[Social media is] the most affordable, efficient, time-conscious way to interact with people, keep tabs on changing market trends, brand your business and tell your story," said marketer Chris Kerston of Chaffin Family Orchards in Oroville. "Expect it to take a fair amount of time. It might make sense to hire someone."

In response to the key findings from the first statewide agritourism survey (see page 57), the UC Small Farm Program organized the workshops in January and February 2011 to address challenges related to permits, regulations, planning, marketing and risk management. The first four workshops — held in Merced (Merced County), Rio Vista (Solano County), Ukiah (Mendocino County) and Red Bluff (Tehama County) — brought together more than 300 agritourism operators; farmers and ranchers considering agritourism; agricultural and tourism professionals; and regulators, elected officials and community leaders.

"Regulatory issues and tools for marketing agritourism operations were identified as primary concerns," said Ellie Rilla, the study's lead investigator and community development advisor with UC Cooperative Extension in Marin County.

### Regulatory approaches

At the workshops, local planning professionals shared ways that many counties have been incorporating agritourism into their general plan revisions. For example, Calaveras County's latest general plan notes: "The sustainability of the many segments of agriculture in the county is directly related to the success of agritourism and the economic benefits it provides."

Likewise, Butte County's plan states: "By promoting certain aspects of farming as a tourist attraction, agriculturalists educate the public about agricultural land and farming practices, while marketing a variety of retail products."

Butte County is implementing a Unique Agricultural Overlay designation in its general plan in order to protect and promote small-scale agriculture. This designation allows agricultural-support and specialty-agriculture uses either by right or under discretionary permit, regardless of whether they are allowed in the underlying zoning. Allowed uses include wineries, roadside stands, farm-based tourism, bed and breakfasts, and ancillary restaurants and stores.

"The designation will be used by small-scale producers in the East Oroville Foothills, the historic center of the Butte County citrus industry from 1900 to 1940," said Butte County principal planner Dan Breedon. "This area includes small-scale citrus, vineyards, orchards, organic gardens, wineries and olive oil tasting, which all can benefit from the county's innovative approach to zoning."

— *Shermain Hardesty and Editors*

## *Hilgardia* digitization project under way

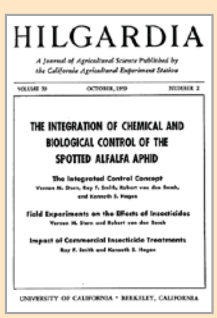
UC faculty and staff are spearheading an effort to scan and digitize *Hilgardia*, the primary technical publication of UC Agriculture and Natural Resources for 70 years.

Although production ceased in 1995, *Hilgardia* includes classic editions that formed the cornerstones of agricultural, environmental and nutritional research. The journal is still widely cited in scientific literature.

Despite its distinguished past, *Hilgardia* has virtually no web presence, and one-half of published issues (including the first 24 volumes and 58 other editions) are now out of print. The remaining paperbound journals are subject to physical degradation.

The committee's goal is to raise $30,000 for scanning and digitization. The *Hilgardia* monographs will then be posted online, freely available to scholarly and lay readers worldwide.

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



# California agritourism operations and their economic potential are growing

*by* Ellen Rilla, Shermain D. Hardesty, Christy Getz *and* Holly George

***More than 2.4 million visitors participated in agritourism at California farms and ranches in 2008. They stayed at guest ranches in the foothills, picked peaches in the Sacramento Valley, played in corn mazes up and down the state, shopped at on-farm produce stands along the coast, held weddings in fields and vineyards from coast to mountains, and experienced myriad other agriculture-related tourism activities. The UC Small Farm Program conducted the first statewide economic survey of California agritourism operators to better understand their goals, needs and economic outlook. University researchers from several other states provided input and sample data from state surveys conducted between 2000 and 2007. This information will help to target outreach and address current and emerging challenges.***

Gary Romano

**Many California growers offer the public "agritourism" opportunities as a way of improving their farm's visibility and profitability. *Above*, visitors enjoy a gourmet "Dinner in the Barn" at the Romano Family's Sierra Valley Farm in Plumas County.**

The pressures of urbanization and shrinking profits have led California farmers to seek alternative approaches for maintaining profitable agricultural enterprises. "Agritourism" includes any income-generating activity conducted on a working farm or ranch for the enjoyment and education of visitors. It includes the interpretation of the natural, cultural, historical and environmental assets of the land and people working on it (George and Rilla 2008).

Agritourism is growing nationwide as farm operators in many states offer activities as a way to diversify and increase their profits (Brown and Reeder 2007). In 2002, the U.S. Department of Agriculture (USDA) Census of Agriculture began collecting agritourism statistics. In 2007, 685 California farms reported a total of $35 million in revenue related to agritourism (USDA 2009). However, the USDA definition of agritourism is extremely limited; it includes some recreational or educational experiences occurring on farms, such as hay rides and pumpkin patches, but does not explicitly include other major on-farm activities such as festivals, accommodations or direct sales of products.

The USDA Economic Research Service's Agricultural Resource Management Survey (ARMS) (USDA 2004) was used as a data set for the agency's 2007 report on farm-based recreation (Brown and Reeder 2007). The authors used the terms "farm-based recreation" and "agritourism" interchangeably but acknowledged that because ARMS data on farm-based recreation does not describe hospitality services and direct sales of on-farm products, their estimates are conservative. (Both the Census of Agriculture and ARMS data would be more useful if the USDA developed and applied a standardized definition of agritourism activities.)

Other national data sources also support the economic development potential of agritourism. Nearly two-thirds of all U.S. adults (87 million) have taken a trip to a rural destination within the last 3 years (Miller 2005). USDA estimates that more than 82 million people, including approximately 20 million youth and children under age 16, visited farms during a 1-year period between 2000 and 2001. U.S. Fish and Wildlife Service reports indicate that in 2006 more than 6.2 million wildlife and nature tourists spent more than $7.8 billion in California (Leonard 2008).

### Building a survey

Nationally, few systematic statewide studies have evaluated the agritourism sector (Ryan et al. 2006; Bruch and Holland 2004; Kuehn 2002), and none have been conducted in California (with the exception of the California wine industry, which attributes $2 billion to tourism-related sales [The Wine Institute 2006]).

To help fill this void, chairs of the UC Cooperative Extension (UCCE) Agricultural Tourism Workgroup convened a survey team, which included the director of the UC Small Farm Program, academics and graduate students. The team members identified key areas that would enhance a general understanding of California's agritourism sector and improve the quality of UCCE outreach and extension. The


Swanton Berry Farm

Value-added products such as jams attract consumers to roadside stands and farmers markets. In the first statewide agritourism survey, 17% of growers with agritourism operations reported offering farmstead items for sale.

survey contained fill-in-the-blank and multiple-choice questions about location, products and services, motivation, advertising, management, profitability, visitation and future plans. It also included open-ended questions, giving agritourism operators the opportunity to share issues, concerns, challenges and successes. The survey asked respondents to answer financial and management questions based on their experiences in 2008.

Historically, one barrier to conducting a systematic analysis of the agritourism sector in California has been the lack of a comprehensive database of farms engaged in agritourism. The survey team built a database from addresses contributed by UCCE academics, lists of agritourism operators and workshop participants, addresses from local marketing campaigns, and other relevant agency lists and databases. The new database also included small, family-owned wineries (which produce fewer than 10,000 cases annually) that were engaged in non-wine-related agritourism activities such as on-farm sales of jams, herbs, olive oil, grassfed beef and other value-added products.

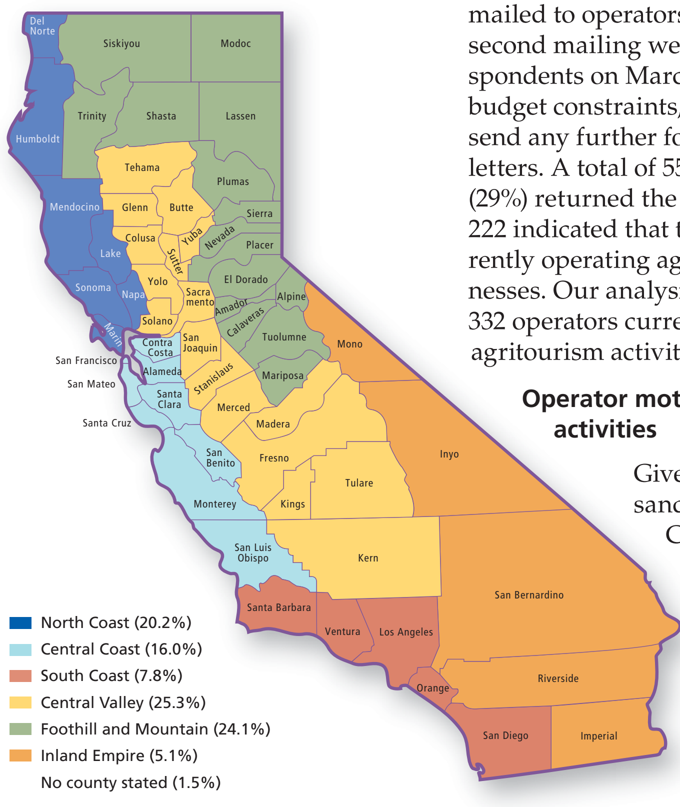



**Fig. 1. Responses to agritourism survey by California region.**

Despite our attempts to be comprehensive, the resulting database of 1,940 farm businesses most likely does not include all agritourism operators in the state. As such, our resulting sample is not completely random, and therefore we are not able to generalize our findings to the entire agritourism sector. The total number of visitors is likely orders of magnitude larger, especially when compared with other visitor figures reported in less populated states. Nonetheless, our findings provide valuable insights into the political, social and economic context, and characteristics of agritourism in California.

After developing and piloting the survey, the team worked closely with the UC Small Farm Program to implement it. On Jan. 10, 2009, the survey was mailed to operators in the database. A second mailing went out to all nonrespondents on March 10, 2009. Due to budget constraints, the team did not send any further follow-up reminder letters. A total of 554 farm businesses (29%) returned the survey, of which 222 indicated that they were not currently operating agritourism businesses. Our analysis is based on the 332 operators currently participating in agritourism activities.

## Operator motivation and activities

Given the tens of thousands of small farms in California and the competitive pressure on small farmers due to agricultural restructuring, we hypothesized that the financial need to diversify would be a key factor in motivating farm and ranch operators to open up to visitors. Indeed, 75% of our respondents cited the need to increase profitability as a reason for entering into agritourism. Other economic reasons included "to market farm products" (62%) and "to provide an employment opportunity for family members" (22%).

Profit and employment opportunities were not the only reasons cited. Three-quarters of those who entered the agritourism sector for financial or employment reasons also did so because they "wanted to educate visitors," "enjoyed working with people" or wanted to provide "outreach to the community." Only 15% started an agritourism venture solely for outreach or educational purposes, with no financial motivation. These findings support other research suggesting that a complex set of economic and social factors motivate farmers to pursue agritourism (Mace 2005).

**Operator characteristics.** Almost half (43%) of the agritourism operators surveyed had been in the sector less than 10 years. Respondents were grouped into six regions in California, with the Central Valley region having the most operations (25%) and the Foothill and Mountain region close behind (24%) (fig. 1).

**Agritourism activities.** Agritourism operators in California were engaged in a wide range of activities, offering direct sales (78%), tours or lectures (81%), demonstrations, lessons or participant experiences (69%) and special event facilities (51%) (table 1). In general, agritourism operators made more money from direct sales of agricultural products (45% on average of all agritourism gross income) than from other activities. The most common direct-sales activity was selling produce, nuts or flowers at a farm stand (38%).

The most common agritourism activity (51%) was hosting school field trips, with only 17% charging a fee. With the exception of weddings, overnight stays, horse or wagon rides, and fishing or hunting, less than half of agritourism operators participating in each service activity charged a fee, underscoring the public-service, educational and marketing/outreach nature of these activities.

While the low percentage of operators charging fees for school field trips is not surprising given the public-service nature of the activity, the fact that many other services are provided for free is puzzling. Although service activities such as tours already have a strong marketing angle related to direct sales, other activities such as cultural festivals or farm demonstrations could potentially serve as a source of income. One operator commented, "We have not developed agritourism into a moneymaking operation. Most visitors are nonpaying customers. We are moving in the direction of having paid activities and stays."

## Promotional strategies

There is no single formula for marketing success in agritourism (Chesnutt 2007). Operators estimated that on average 88% of their visitors in 2008 were from California, with 50% coming from the same county. This finding is consistent with the state tourism and travel commission figure that 85% of visitors were from in-state in 2008 (CTTC 2008). On average, only about 3% of visitors were from Canada or other countries.

More than half (51%) of the businesses responding to the survey had fewer than 500 visitors in 2008, while 12% hosted more than 20,000 visitors. October was the highest volume month, with activities such as pumpkin patches, apple picking, winery tastings and tours, corn mazes, harvest festivals and end-of-summer fruit and vegetable purchases.

**Types of promotion.** Word of mouth was the leading form of promotion used by respondents (97%) to reach customers (fig. 2). Signs outside of businesses (81%), business cards/brochures (76%) and websites (78%), along with listings in regional guides (74%), were the next most popular forms of marketing. The next tier of marketing included

**TABLE 1. Agritourism activities reported in survey of California farmers ($n$ = 332)**

| | Offered | Offered for a fee |
|---|---|---|
| | % | |
| **Direct sales** | **78.3** | |
| Farm stand with fresh fruit, vegetables, herbs or flowers | 37.6 | |
| Farm stand with farmstead items (pies, cider, soaps, etc.) | 17.0 | |
| U-pick fruit, vegetable, herb or flower operation | 22.7 | |
| Christmas tree sales (U-cut or retail) | 9.7 | |
| Pumpkin patches | 17.6 | |
| Corn mazes | 7.0 | |
| Animal meat or cheese sales | 9.1 | |
| Vineyard, winery | 21.5 | |
| Other sales | 10.9 | |
| **Tours or lectures** | **81.0** | |
| School field trips | 51.1 | 17.2 |
| Traditional farm or ranch operation and buildings | 40.8 | 9.4 |
| Seasonal activities (calving, shearing, planting, harvesting, etc.) | 32.3 | 5.4 |
| Scenic attractions: Unique features of property | 30.5 | 7.6 |
| Small-animal demonstrations | 13.0 | 2.7 |
| Historic buildings or farm equipment | 18.7 | 3.6 |
| Seasonal sites (spring blooms, fall foliage, winter snow, etc.) | 18.7 | 2.4 |
| Forest ecology or native plants | 14.8 | 2.4 |
| **Demonstrations, lessons, participant experiences** | **69.3** | |
| Classes, workshops (cheese making, felting, cider production, etc.) | 35.8 | 13.6 |
| Cattle drives, branding, roping, rodeo, etc. | 2.7 | 1.5 |
| Horseback riding, wagon or sleigh rides | 8.8 | 4.8 |
| Barn raising, pond or fence construction | 3.3 | 1.5 |
| Gardening: Plant selection, planting, harvesting, etc. | 23.0 | 3.6 |
| Cooking, food tasting or wine/beer pairing | 27.5 | 12.1 |
| Land restoration or habitat improvements | 11.8 | 2.4 |
| Fishing or hunting | 10.9 | 6.6 |
| **Special event facilities** | **50.6** | |
| Weddings, family reunions, retreats, etc. | 32.9 | 22.4 |
| Farm stays (people stay in home or another farmhouse) | 15.1 | 8.8 |
| Camping or RV accommodations | 10.6 | 3.9 |
| Cabins or overnight facilities not in home or another farmhouse | 11.2 | 7.6 |
| Cultural festivals | 10.9 | 5.1 |
| Wildlife or migratory bird festivals | 3.0 | 0.6 |
| Horse activities and events: Cuttings, rodeos | 5.7 | 2.4 |
| Dog trials | 3.3 | 2.7 |
| Youth camps | 6.6 | 4.8 |

**Those with business plans for their entire farm were about twice as likely as those with no business plans to have agritourism incomes above $100,000.**

feature stories in a newspaper or magazine (63%), agricultural organizations (57%), paid advertising (55%), chamber of commerce (46%), visitor's bureau (39%), direct mail (37%) and business newsletters (32%).

**Effectiveness.** Respondents were asked to rate the effectiveness of their promotional strategies on a scale from 1 to 5. Seventy-three percent rated "word of mouth" as effective or highly effective (4 or 5), followed by websites (68%) and feature stories (69%).

More than 80% of respondents used some form of signage. A few people expressed frustration with county zoning restrictions and state and federal "scenic road" designations that prohibit the use of signs. Some suggested special considerations for small farmers.

**Websites/Internet.** The Internet is often the first source of information for vacation plans or purchasing items, making a website the first impression that a business makes on the consumer (Klotz 2002). Regardless of how much money businesses allotted for marketing and promotion, the vast majority (78%) ($n$ = 311) had a website. About two-thirds of operators spending less than $500 on all marketing efforts had a site (fig. 3). Comments from respondents indicated that they were very satisfied with results generated from their websites. One respondent commented, "The Internet is proving to be the biggest PR tool we have. Lots of Bay Area families came after a lady posted a rave review of us."

A University of Delaware study (German et al. 2008) found that there may be opportunities for producers to improve their profitability by adding e-commerce to their websites in order to attract new and returning visitors. More than 65% of the 98.3 million travelers to California made their arrangements online in 2004 (CTTC 2007).

## Challenges to agritourism growth

Agricultural tourism supports local farms and ranches as well as their surrounding communities by generating revenue, but diversification also presents challenges. Zoning, permitting, environmental health regulations, liability and insurance issues were the


Jack Kelly Clark

**The survey found that agritourism operators considered word of mouth the most effective form of promotion (97%), followed by signs (81%) and websites (76%). In the Apple Hill region of El Dorado County, a farm advertises food, wine, U-pick, crafts and other amenities.**

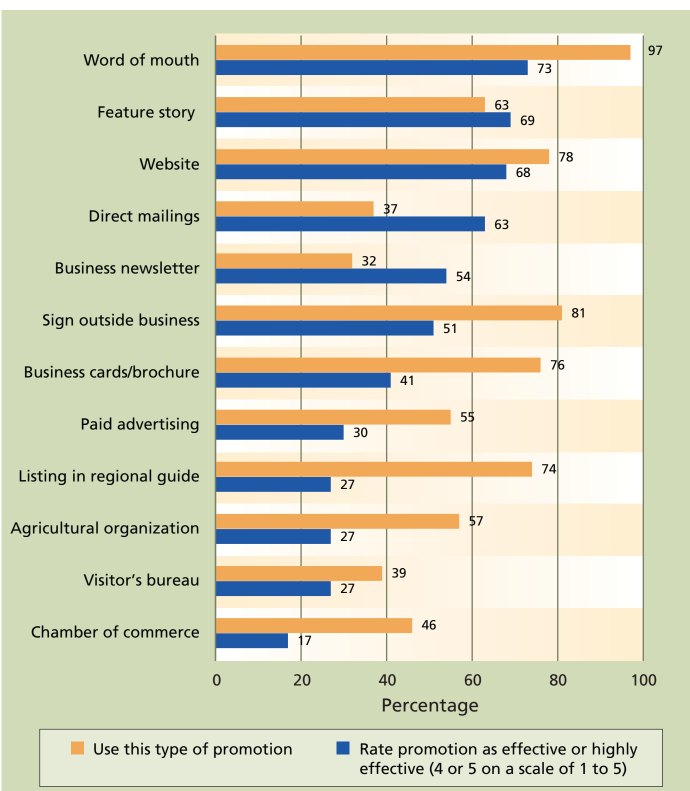



**Fig. 2. Respondent ratings for use and effectiveness of agritourism promotions.**

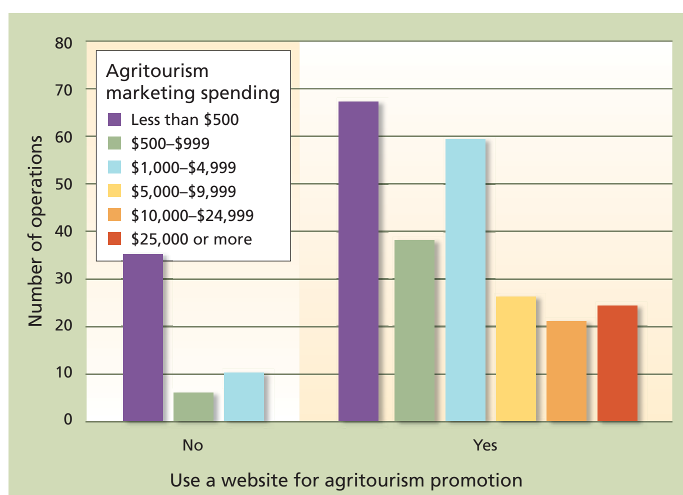



**Fig. 3. Website use in relation to annual marketing expenditures.**

leading impediments to farmers and ranchers who wanted to expand their operations to include agritourism (fig. 4). Comments from respondents, regardless of region, indicated that they were frustrated and overwhelmed with their county's policies and procedures, and the expenses related to initiating or expanding an agritourism enterprise on their farm or ranch.

Twenty-nine percent (*n* = 97) indicated that they had acquired a use permit from their county for an agritourism operation. Among these respondents, 69% responded negatively (expensive, difficult, slow) to questions about the permitting process, while 31% responded with positive or neutral comments (workable, not complicated, officials very cooperative). These comments echo the frustration expressed by operators who participated in a 2002 survey regarding the permitting process for agritourism in 10 California counties (Keith et al. 2003).

Only 24% of the respondents had a business plan for their entire farm or ranch, but of those who did, 91% included their agritourism operation. Those with business plans for their entire farm were about twice as likely as those with no business plans to have agritourism incomes above $100,000.

**TABLE 2. Gross agritourism revenue by region**

| | Region | | | | | | |
|---|---|---|---|---|---|---|---|
| Gross revenue | North Coast | Central Coast | South Coast | Central Valley | Foothill and Mountain | Inland Empire | Total |
| | *number (% within region)* | | | | | | |
| Less than $1,000 | 16 (31.4) | 10 (22.2) | 2 (8.7) | 8 (12.7) | 21 (33.3) | 1 (6.7) | 58 (22.3) |
| $1,000–$4,999 | 8 (15.7) | 7 (15.6) | 2 (8.7) | 14 (22.2) | 13 (20.6) | 1 (6.7) | 45 (17.3) |
| $5,000–$9,999 | 7 (13.7) | 0 (0) | 2 (8.7) | 3 (4.8) | 7 (11.1) | 2 (13.3) | 21 (8.1) |
| $10,000–$24,999 | 4 (7.8) | 6 (13.3) | 4 (17.4) | 4 (6.3) | 6 (9.5) | 1 (6.7) | 25 (9.6) |
| $25,000–$49,999 | 4 (7.8) | 8 (17.8) | 6 (26.1) | 12 (19.0) | 5 (7.9) | 1 (6.7) | 36 (13.8) |
| $50,000–$99,999 | 4 (7.8) | 4 (8.9) | 2 (8.7) | 7 (11.1) | 2 (3.2) | 1 (6.7) | 20 (7.7) |
| $100,000 or more | 8 (15.7) | 10 (22.2) | 5 (21.7) | 15 (23.8) | 9 (14.3) | 8 (53.3) | 55 (21.2) |
| Total number | 51 | 45 | 23 | 63 | 63 | 15 | 260 |

When asked about liability insurance and other risk management practices, 87% reported having liability insurance, and 90% of the insured were covered for $1 million or more. Several people commented about the cost of liability insurance and expressed concerns about being sued. Although most of the respondents carried insurance, operators rated liability and insurance issues as major challenges, along with permitting, zoning and other regulations and legal constraints.

Farmers and ranchers share the problems voiced by California agritourism operators across the nation. However, other states are moving forward on programs to help operators overcome challenges, and they may be useful models for California. For example, Colorado and Tennessee are appropriating funds for the promotion and development of agritourism, and Georgia and Missouri give tax benefits to agritourism operators. At least 19 states have enacted statutes that address agritourism, ranging from tax credits to zoning requirements to liability issues (Mirus 2009).

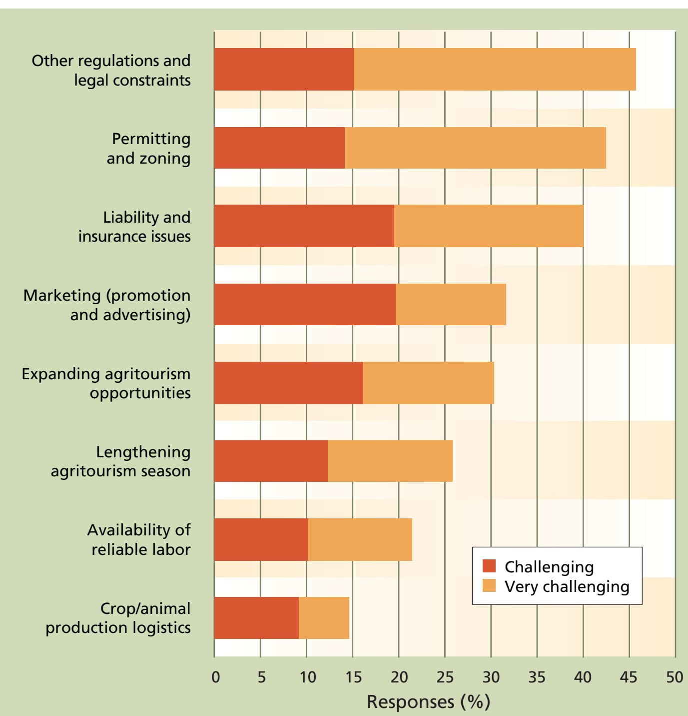



**Fig. 4. Major challenges rated 4 or 5 by California agritourism operators, on a scale of 1 (not a problem) to 5 (very challenging).**

## Profitability of agritourism

Although 14% of the survey respondents had annual revenues of $1,000,000 or more, 68% fit the USDA definition of a small farm, having annual gross revenues of $250,000 or less in 2008. Almost half (48%) of the operators reported less than $10,000 in gross revenues from their agritourism operations in 2008, while 21% had revenues of $100,000 or more (table 2).

While the number of Inland Empire respondents was relatively small, the region had a considerably higher proportion of operations with gross revenues of $50,000 or more (60%). Conversely, the North Coast (61%) and Foothill and Mountain (65%) regions had higher proportions of small agritourism operations with gross revenues under $10,000. Differences in the proportion of operations within gross revenue categories among regions were statistically significant at the 0.05 level.

A primary activity was defined as one generating more than 50% of an operation's total agritourism revenue. The primary activities for which operators were most likely to have gross agritourism revenues of $50,000 or more were corn maze/pumpkin patch (44%), nature activities (43%), retail sales of agricultural products (33%) and events (25%). Differences in the proportion of operations within gross revenue categories among regions were statistically significant at the 0.05 level (differences in observations across all categories were tested using the Pearson chi-squared test).

Agritourism operators were asked to rate the profitability of their operation on a 7-point scale, with "1" indicating "not at all profitable" and "7" meaning "highly profitable." One-fourth considered their agritourism operations to be at least "fairly profitable" (rated 5 or higher), while 16% rated their operations as "not at all profitable." The mean profitability rating was 3.3. However, generating profit was not a direct objective for some agritourism operations. One operator commented, "Even though this business only breaks even, we continue on because I consider it a marketing arm of our other business." Another operator noted, "Agritourism is primarily for education on herbs. Profits come from [sales of] herbal products produced on the farm."

Agritourism operators' assessments of their profitability increased with gross revenues, and the differences were statistically significant at the 0.01 level. More than half (53%) of the operators with agritourism revenues of $50,000 or more considered their operations at least "fairly profitable," compared to 15% with agritourism revenues under $50,000.

Respondent assessments of their operation's profitability varied by region, and the differences were statistically significant at the 0.05 level. Similar to gross revenues, a noticeably higher proportion of operators in the Inland Empire rated profitability as at least a 5 (fairly profitable) (40%). Conversely, North Coast operations were most likely to rate their profitability as 3 (somewhat profitable) or lower (67%), followed by the Foothill and Mountain region (62%). The types of agritourism activities most prevalent in these low-revenue/low-profitability regions should be investigated; these operations appear to have the greatest potential to benefit from consultation regarding business planning and marketing.

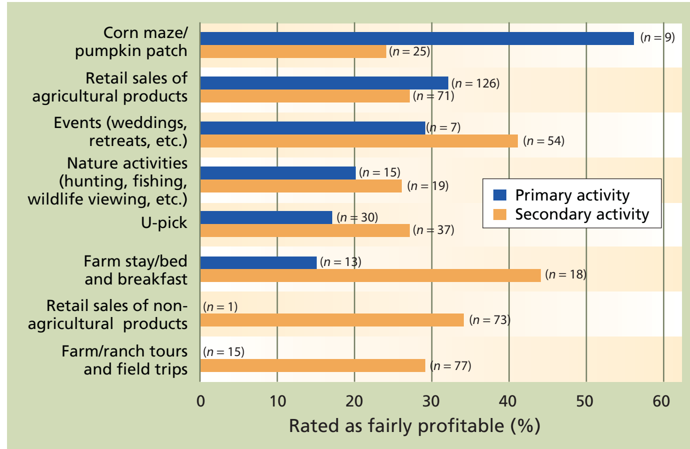



**Fig. 5. Percentage of operators rating primary and secondary activities as at least "fairly profitable" (4 or higher on 7-point scale); *n* = no. of operators.**

Profitability assessments varied widely by primary activity (fig. 5). Thirty-two percent of operators rated retail sales of agricultural products, the largest activity category, as at least "fairly profitable," compared to 27% of operators for whom retail sales were a secondary activity. Retail sales of agricultural products and corn maze/pumpkin patch were the only activities rated more profitable as primary than secondary activities. Those for whom tours and field trips were secondary activities rated their profitability considerably higher than those for whom they were primary activities.


**Most agritourism operators said that they like interacting with visitors to their farms. Those surveyed had an estimated total of 2.4 million visitors in 2008. At Full Belly Farm in Yolo County, visitors tour the farm during the Hoes Down Harvest Festival.**

## Creating jobs and growth

In general, tourism is considered to have both negative and positive economic impacts. Critics contend that tourism often generates low-paying, seasonal job opportunities; however, if tourism can attract high numbers of seasonal and permanent residents, then it is usually considered to have positive impacts on a community (Reeder and Brown 2005).

**Employee numbers and pay.** In our survey, agritourism operators reported their employee numbers (excluding themselves) based on categories of hours worked. One-third of the operations had employees who worked at least full time primarily or exclusively for the agritourism operation; a similar proportion had employees who worked between 21 and 39 hours a week. More than half (54%) of the operations had employees who worked half time or less, primarily or exclusively for the agritourism operation; some of these operations also had full-time employees. Overall, California operations surveyed averaged 6.3 employees (both full- and part-time) hired to work mainly or only for agritourism activities.


**Leah van der Mei, of San Francisco, picks raspberries at Good Humus farm in the Capay Valley, in northwest Yolo County. About 23% of the farms surveyed offered U-pick.**

In addition, more than half of the operations had employees working mainly for their farming/ranching operation who also pitched in on agritourism activities; on average, there were 2.3 such employees per agritourism operation. Operations with no employees were included in calculating the reported mean values; however, the mean calculation did not include the "missing cases" that occurred frequently because respondents checked a particular employment category but did not indicate the number of employees for that category.

Overall, 83% of the operations had paid employees, with an average of 11.6 per operation. This value is significantly higher than the sum of the average numbers of employees in the previously discussed categories (hired primarily or exclusively for agritourism activities, or for farming and ranching activities). This disparity is due to the fact that there were many missing cases that occurred when adding together the number of employees for the two categories. Not surprisingly, on average half of all agritourism operations hired one family member, meaning that there were 10.6 nonfamily employees per agritourism operation.

It is not uncommon for agritourism operations to have multiple employees. In our survey, 17% had no employees and only 5% had just one employee; but 13% had more than 10 employees and 8% had more than 20 employees. (Forty-five percent of respondents checked a specific employee category but did not report the number of employees.)

In the largest primary-activity category (retail sales of agricultural products) there were 8.4 jobs per operation on average, despite the fact that 32% of such operations reported no employees. One-fourth of the retail operations had more than 10 employees.

**Wages and salaries.** Slightly more than half of the operations (53%) had no employees or paid less than $5,000 in employee wages, almost one-fifth (19%) paid between $10,000 and $49,999 in salary expenses, and 13% paid more than $100,000 per year (fig. 6).

Since this wage data was categorical, total salary expenses were estimated using the midpoint of each category as the observed value, along with $1,000 for the lowest and $100,000 for the highest category. This procedure generated average wage expenses of $24,489 per agritourism operation, probably a considerable underestimate given the relatively large proportion of operations in the highest wage-expense category.

The economic effects of agritourism are apparent. Even though many of the agritourism operations hired employees at least part time (83%), agritourism is adding additional economic activity to rural communities. The average $24,489 in wages paid is likely spent within the community and sustains other local businesses.

**Growth trends.** When asked about their agritourism plans over the next 5 years, the majority of operators (64%) indicated that they expected to expand or diversify. Almost a quarter (23%) planned to maintain their current income level. Only 4% expected to go out of business.

Not surprisingly, growth plans appeared to be correlated with profitability. Seventy percent of the operators who rated their enterprises at least "fairly profitable" planned to expand or diversify, compared to 53% who rated theirs "not at all profitable" or "slightly profitable."

There were differences across regions regarding growth plans. The highest proportions of operations planning to expand or diversify were in the South Coast, Inland Empire and Central Valley regions (fig. 7A).

There were also differences regarding growth plans among primary activities ($P < 0.05$) (fig. 7B). Events, corn

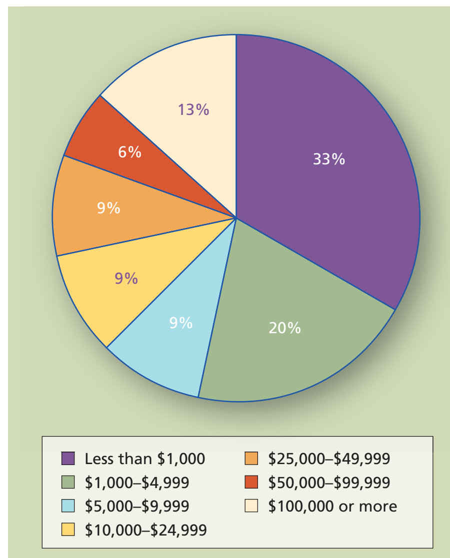



**Fig. 6. Range of wages and salary expenses paid by agritourism operations ($n$ = 277).**

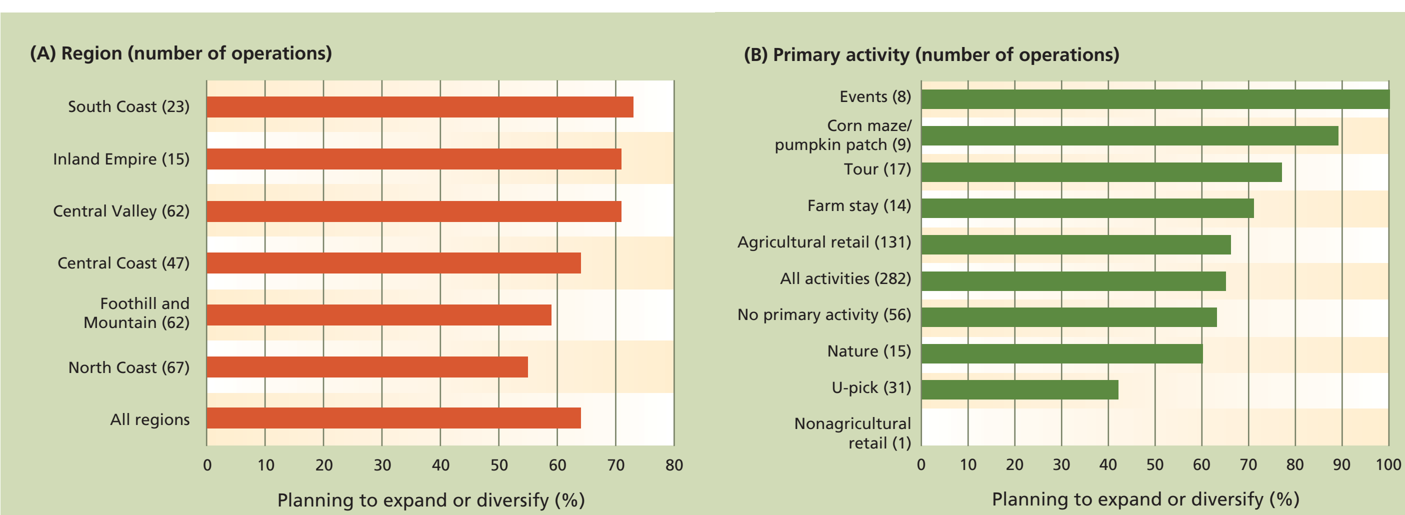



**Fig. 7. Survey respondent's growth plans by (A) region and (B) primary activity.**

mazes/pumpkin patches and tours were the primary activities with the highest proportions of operators planning to expand or diversify.

These differences in growth plans indicate a potential need for further information about agritourism management. Specifically, networking and business development consultation may be particularly beneficial for agritourism operators in the North Coast region and Foothill and Mountain region, and for operators of U-pick operations.

Tim Friesen

**While relatively few of California's 80,000 farm operators engage in agritourism, it is a vital strategy for a significant number of the state's farms. At Squaw Valley Herb Gardens in the Sierra Foothills, visiting seniors throw rose petals during a Flowers and Folklore workshop.**

### A vital strategy

Agritourism is clearly not an economic panacea for all of agriculture, considering the small proportion of California's 80,000 farm operators engaged in such activities. But the survey results revealed that agritourism is a vital strategy for diversifying and boosting profit for a small but significant number of California farms. The trend seems to be growing, as many operators planned to expand their agritourism operations. In 2008, more than 2.4 million Californians (the sum of visitors estimated by 257 survey respondents) learned about and experienced firsthand the unique attributes and contribution that agriculture provides to the state, and this figure is likely to grow as new data becomes available.

Tim Friesen

**More than 80% of the surveyed farms that offered tours to school groups did so for free. Rosemary Nightingale shares herb lore with young visitors to Squaw Valley Herb Gardens.**

We confirmed that for most operators, both social and economic factors are important, and different motivations are dominant for different types of farm landholders at different stages in farm, family and business cycles (Ollenburg and Buckley 2007). Most respondents stated that they liked educating and interacting with visitors, possibly suggesting that farmers engaged in agritourism possess particular skills and personality traits. While observable in case-study research, most data on operator characteristics is anecdotal (Rilla 1998; Hilchey 1993). We found that agritourism farms are entrepreneurial in terms of the services and value-added products provided to others, and they are actively involved in marketing their products, with the vast majority using the Internet to reach customers.

In 2008, more than 50% of agritourism operators making more than $50,000 described their venues as profitable. Pumpkin patches and on-farm sales of products were their most profitable activities. Almost equal numbers of operators had revenue less than $1,000 and more than $100,000, and 43% of small farms earned $25,000 or more in agritourism income, which could account for 10% of the farm's total income.

Operators indicated a desire for business planning to improve success. Marketing and management assistance to improve fee revenues for activities currently provided gratis, and assistance with effective promotion, could also increase the bottom line.

A clearer picture of the overall economic impact of agritourism in California will require more work to define the operator database and capture more accurate data from the USDA Census of Agriculture and ARMS relating to on-farm income derived from agritourism activities such as farm stays, U-picks and farm stands. Continuing research on growth trends and profitability will help local governments and farm operators to track success.

The survey identified permitting, environmental health regulations, liability and insurance issues as the most critical challenges facing current and future agritourism operators. As local governments update countywide plans and zoning and development codes, revisions to accommodate on-farm agritourism businesses will help to support and sustain these small farms (see sidebar). Farm advocacy groups may want to follow the examples of other states in advocating for legislation to reduce liability exposure.

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*E. Rilla is Community Development Advisor, UC Cooperative Extension (UCCE) Marin County; S.D. Hardesty is Specialist, Department of Agricultural and Resource Economics, UC Davis; C. Getz is Associate Cooperative Extension Specialist, Department of Environmental Science, Policy and Management, UC Berkeley; and H. George is Livestock and Range Advisor, UCCE Plumas and Sierra counties.* *The authors thank Kristin Reynolds for her contributions to survey development and design; Penny Leff, Agritourism Coordinator, UC Small Farm Program, for her work on survey analysis; and intern Roman Trach for managing the SPSS data input. The California Communities Program provided funding for the internship.*

# California counties adapt permitting and regulations for agritourism

*by* Penny Leff

California's 58 counties bear the primary responsibility for permitting and regulating agritourism operations on agricultural land within their boundaries. The counties often struggle with creating allowances and ease of permitting for agritourism businesses while ensuring that agritourism is a supplemental (rather than primary) activity on a commercial farm or ranch. Regulations also must ensure that agricultural production and local residents are not adversely affected by tourism. Some counties have recently changed their general plans, zoning ordinances and staffing assignments to encourage agritourism and have created guides to agritourism permitting.

The Lake County general plan includes Goal AR-3, "To provide opportunities for agritourism that are beneficial to the county and its agricultural industry and are compatible with the long-term viability of agriculture." The countywide general plan in Calaveras County (Foothill and Mountain region) specifically allows, by right, on-site sales and tasting, and directs that the definition of agricultural operations allowed should be broadly construed. Solano County (Central Valley region) has designated new zoning that encourages agritourism in Suisun Valley, one of 10 county regions defined in its general plan.

Mariposa, Placer and El Dorado counties (Foothill and Mountain region) have involved farmers and ranchers on advisory committees that created ordinances to streamline permitting for agritourism operations while limiting the extent of allowed activities in proportion to the size of the primary agricultural operation.

Potential agritourism operators often complain about the lack of coordinated information from different county regulatory departments. To address this problem, Marin County (North Coast region) contracts with UC Cooperative Extension (UCCE) for an "agricultural ombudsman" to assist applicants with agriculture-related permitting. Marin County UCCE and Placer County staff created plain-language guides for farm-stay operations. Yolo County has created an Agricultural Permit Manual that describes all the permits that may be needed for various types of agritourism operations. More coordination among county departments and between counties would ease the regulatory burden on agritourism operators.

**Regulators must strike a balance between promoting agritourism and ensuring that local residents are not adversely affected by traffic and other impacts. *Above,* a toddler visits Dave's Pumpkin Patch in West Sacramento.**

*P. Leff is Agritourism Coordinator, UC Small Farm Program.*

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# South Korea–U.S. free trade agreement will lower export barriers for California products

*by* Hyunok Lee *and* Daniel A. Sumner

***The United States and South Korea negotiated a bilateral trade agreement in 2007. After final legislative approval, likely later this year, high tariffs on exports of most California agricultural products to South Korea will be gradually eliminated. Already, with the tariffs in place, South Korea ranks among the top six destinations for many California agricultural exports. More-open access to the South Korean market will create significant opportunities for major commodities produced in California such as almonds and dairy products.***

Tricia Bergland

**The United States has negotiated a free-trade agreement with South Korea that will greatly reduce tariffs on many California crops. The U.S. Congress is expected to pass the implementing legislation this year. *Above*, a wholesale produce market in Anyang City, south of Seoul.**

The Republic of Korea (South Korea) and the United States signed a free trade agreement (KORUS FTA) on April 1, 2007. In 2010, they negotiated a few adjustments to the agreement designed to facilitate approval by each country's legislature. With strong support from the Obama administration, legislation implementing the agreement is likely to be passed in spring or summer 2011. (We refer to the Republic of Korea as South Korea; isolationist and communist North Korea is a separate country.)

When it is implemented, the agreement will lower the trade barriers between the two countries in all sectors of trade. However, although it will benefit other sectors of U.S business, agriculture was central to the negotiations, and potential gains for the United States center around agricultural exports. Unlike the United States, South Korea has maintained high trade barriers for agricultural goods. KORUS FTA would lower those barriers and provide important opportunities for U.S. agricultural exports to South Korea.

The United States is already South Korea's top supplier of agricultural products, worth $3.5 billion in 2007. The South Korean economy is growing and already sizable; with about 50 million consumers, it has a per-capita income ($20,045 in 2007) above that of many European countries. Prices for many commodities are high, and premiums are paid for high-quality produce.

The United States has many free trade agreements, most of them long-standing; South Korea has implemented fewer and they are relatively new. As of January 2011, the United States had free trade agreements in force with 17 countries including Canada, Mexico, Singapore, Central America-5 (Costa Rica, El Salvador, Guatemala, Honduras and Nicaragua), Israel, Australia, Chile, Jordan, Morocco, Dominican Republic, Oman, Peru and Bahrain (USTR 2011). South Korea has free trade agreements with Chile, Singapore, ASEAN-10 (Association of South East Asian Nations) and EFTA-4 (European Free Trade Association-4: Iceland, Liechtenstein, Norway and Switzerland). The earliest South Korean free trade agreement was implemented in 2004.

KORUS FTA is especially significant for California agriculture because South Korea ranks among its top six export destinations (Matthews and Sumner 2008), and trade barriers for many agricultural products to South Korea are currently high. In many cases, major exports of California agriculture face tariffs of more than 30%. For some products, including beef, citrus and tree nuts, significant exports are able to penetrate the South Korean market despite high tariffs. Because of the size of the South Korean economy and the height of pre-existing trade barriers, KORUS FTA is considered the most commercially significant free trade agreement that the United States has negotiated in nearly 20 years.

KORUS FTA has little potential to stimulate South Korean agricultural exports to the United States in competition with California products. U.S. agricultural tariffs are already low and production costs in South Korea are high, so few South Korean agricultural products can compete successfully in the U.S. market. Once KORUS FTA is implemented, our assessment is that it will stimulate more demand for U.S. products in South Korea, and the consequences for California agriculture will be slightly higher farm prices, increased agricultural output, additional employment and an expansion of the California agricultural economy past the farm gate.

This paper explores the importance of the South Korean export market for California agriculture and the nature of current trade barriers; shows the schedule for removing tariffs; and explains how the new tariffs arrangement will improve the competitive position of California agricultural exports relative to South Korean products and other countries' exports to South Korea.

## Korean agriculture and trade

South Korea has changed phenomenally during the past half century, from an extremely poor, agrarian economy using 19th-century technology at best, to a wealthy, modern society at the cutting edge of applied science and technology. However, agriculture has not been transformed to the same degree as the industrial and service economies. Protection from imports has kept much of agriculture insulated from competitive pressures. Farm size has remained small, far below average farm sizes in other industrial economies. Furthermore, with limited natural resources, South Korean agriculture has little potential to expand in a freer trade environment.

The United States is a major net agricultural exporter and South Korea is a major net importer, reflecting the relative competitiveness of agriculture in each country (table 1). Agricultural goods are especially important commodities in bilateral trade between the United States and South Korea. The South Korean market accounted for 5% (in 2000) and 4% (in 2007) of U.S. agricultural exports, consistently higher than the 4% (in 2000) and 3% (in 2007) of U.S. general merchandise exports that went to South Korea. The United States is the most important source of South Korean agricultural imports, enjoying a 26% share in 2007. Coarse grain represented 24% of the U.S. share, followed by fruits, nuts and vegetables (12%) and meat (11%). In the past decade, U.S. market share in South Korea has declined, mainly due to the growth of competitors including China, Australia and Chile.

**TABLE 1. Values of agricultural and bilateral trade between the United States and South Korea, 2000 and 2007**

| | 2000 | 2007 |
|---|---|---|
| | *$ billions* | |
| **World trade** | | |
| United States | | |
| Exports | 51.3 | 89.9 |
| Imports | 39.0 | 71.9 |
| South Korea | | |
| Exports | 1.3 | 2.4 |
| Imports | 6.8 | 13.3 |
| **Bilateral trade** | | |
| U.S. exports to South Korea (South Korean imports from United States) | 2.5 | 3.5 |
| Share of U.S. exports (%) | 5 | 4 |
| Share of South Korean imports (%) | 37 | 26 |

Sources: FAS 2009; KATI 2009.

## California exports

In 2007, the total value of all California agricultural exports to South Korea was almost $400 million (table 2). South Korea was the sixth largest destination for California exports, with about 4% going to South Korea. For some products, South Korea was a much more important destination. Among all export commodities sent to South Korea, fresh oranges top the list, followed by rice, and beef and beef products. In 2007, the bulk of beef and beef products were hides and

**TABLE 2. Value of California agricultural exports to South Korea by commodity, 2007**

| Commodity | Exports*: To South Korea (A) | Exports*: To all destinations (B) | Share of S. Korean market | A/B (rank among all destinations)† |
|---|---|---|---|---|
| | *$ millions* | | % | |
| Total | 386.4 | 10,912 | 4 | (6) |
| Oranges | 55.0 | 260 | 21 | (2) |
| Rice | 43.3 | 313 | 14 | (2) |
| Beef, beef products | 40.5 | 199 | 20 | (2) |
| Almonds | 35.6 | 1,879 | 2 | |
| Walnuts | 35.2 | 444 | 8 | (4) |
| Dairy products | 28.9 | 963 | 3 | |
| Hay | 18.1 | 134 | 14 | (3) |
| Wine | 15.8 | 816 | 2 | |
| Cotton | 13.5 | 505 | 3 | |
| Tomatoes, processed | 11.3 | 300 | 4 | |
| Table grapes | 10.0 | 553 | 2 | |
| Cherries | 8.5 | 97 | 9 | (3) |
| Lemons | 8.4 | 169 | 5 | (4) |
| Grape juice | 6.7 | 32 | 21 | (2) |
| Raisins | 5.9 | 213 | 3 | |
| Grapefruit | 5.8 | 79 | 7 | |
| Kiwifruit | 2.5 | 14 | 18 | (3) |
| Plums, dried | 2.3 | 175 | 1 | |
| Pistachios | 2.2 | 364 | 1 | |
| Lettuce | 1.8 | 274 | 1 | |

Source: Matthews and Sumner 2008.
* No formal trade data available at state level; estimates by UC Agricultural Issues Center.
† Provided only when South Korea ranked 5 or higher.

| TABLE 3. Value of South Korean imports and major competitors for selected commodities, 2007 | | | | |
|---|---|---|---|---|
| | South Korean imports | U.S. share of South Korean imports | Import share of domestic consumption* | Major competitors' share of South Korean imports |
| | *$ millions* | . . . . . . . . . . | % | . . . . . . . . . . |
| **Fruits (total)** | **852** | **27** | **n/a†** | **Philippines (30), China (9), Chile (7), New Zealand (7), Brazil (5)** |
| Bananas | 171 | 0 | 100 | Philippines (100) |
| Oranges, fresh | 108 | 93‡ | 9.9 | —§ |
| Oranges, juice | 71 | 24 | 100 | Brazil (60) |
| Kiwifruit, fresh | 70 | 8 | 100 | New Zealand (77), Chile (14) |
| Pineapples | 68 | 0 | 100 | Philippines (98) |
| Table grapes | 58 | 18 | 8.3 | Chile (82) |
| Cherries, all | 36 | 91 | 100 | — |
| Grape juice | 25 | 47 | 100 | Spain (26) |
| Lemons | 11 | 77 | 100 | Chile (5), Italy (10) |
| Apples, processed | 10 | 0 | 100 | China (50), Chile (2) |
| Strawberries, frozen and processed | 10 | 26 | 3.7 | China (57), Mexico (5) |
| Peaches, processed | 9 | 0 | 100 | China (44), South Africa (20), Greece (14) |
| Grapefruit (incl. juice) | 9 | 74 | 100 | Japan (12) |
| Raisins | 6 | 98 | 100 | — |
| Olives | 3 | 1 | 1 | Spain (75), Italy (18) |
| Prunes, dried | 2 | 98 | n/a | — |
| Peaches, juice | 1 | 83 | 100 | China (8) |
| Pears, processed | 0.3 | 1 | 100 | China (48), Spain (18), South Africa (12) |
| Pears, fresh | 0.1 | 83 | 0 | — |
| **Vegetables (total)¶** | **466** | **14** | **11** | **China (69), Japan (4), New Zealand (3)** |
| Red peppers | 85 | 0 | 15 | China (95) |
| Carrots | 37 | 0 | n/a | China (98) |
| Tomatoes | 36 | 32 | 100 | China (42), Chile (10), Italy (9) |
| Garlic | 32 | 0 | 12.8 | China (100) |
| Pumpkins | 15 | 0 | n/a | New Zealand (88) |
| Onions | 13 | 6 | 3 | China (94) |
| Broccoli | 11 | 0 | n/a | China (100) |
| Cucumbers | 9 | 47 | n/a | China (41) |
| Lettuce | 4 | 48 | n/a | China (52) |
| **Tree nuts (total)** | **76** | **94** | **93** | **—** |
| Walnuts | 38 | 91 | 100 | Vietnam (9) |
| Almonds | 35 | 100 | 100 | — |
| Pistachios | 3 | 59 | 100 | Iran (37) |
| **Dairy, beef and beef products (total)** | **1,856** | **28** | **n/a** | **Australia (45), New Zealand (15)** |
| Beef | 1,037 | 9 | 59 | Australia (73), New Zealand (16) |
| Dairy products, all | 438 | 19 | n/a | New Zealand (24), Australia (15) |
| Hides and skins | 381 | 89 | n/a | — |
| **Other** | | | | |
| Cotton | 305 | 40 | 100 | Australia (13) |
| Hay | 237 | 82 | n/a | — |
| Wine | 150 | 11 | n/a | France (45), Chile (15) |
| Rice | 137 | 31 | 5.4 | China (61), Thailand (8) |
| Flowers | 68 | 1 | n/a | China (31), Taiwan (30), Netherlands (18) |

Sources: KATI 2009; KMAFF 2008.

* Some shares are based on quantity when values are not available (official South Korean data at the commodity level often includes only quantity).

† No domestic production statistics available, or commodity aggregation is not meaningful (e.g., dairy products).

‡ Discrepancy between South Korean and U.S. sources; U.S. figure was $85.4 million.

§ No major competitors.

¶ Lettuce imports are fresh; carrot and pumpkin imports are mostly fresh; pepper, cucumber and tomato imports are dried, frozen or preserved; other vegetables are mixed (for more detail, see Lee and Sumner 2009).

skins. Before the collapse of exports in 2004 — caused by the discovery of a U.S. slaughter cow with bovine spongiform encephalopathy (BSE) or "mad cow" disease in December 2003 — beef was the most important export item shipped to South Korea from California. Other products that hold double-digit shares of the South Korean market are hay, grape juice and kiwifruit. While the value of almond and walnut exports is about equal, South Korea is a more important market for the California walnut industry than it is for almonds.

Processed tomatoes and lettuce are the only vegetables exported to South Korea, which is not a major vegetable-importing country (table 2). Vegetables accounted for less than 5% of South Korea's total crop-based agricultural imports in 2007 (KMAFF 2008). Moreover, except for a few vegetables — such as processed tomatoes, lettuce and cucumbers — China dominates the South Korean vegetable import market, with a 69% share; the United States is a distant second, with an 11% share (Lee and Sumner 2009).

KORUS FTA will give California suppliers a price advantage over suppliers from nations without a South Korean free trade agreement, and allow California suppliers to keep up with those from nations that have current or prospective agreements with South Korea. When South Korea's free trade agreement with Chile became effective on April 1, 2004, Chilean exports to South Korea grew substantially for kiwifruit, grape juice, lemons, processed tomatoes, wine and whey, which are all major California export products (Lee and Sumner 2009).

California's major international competitors for trade with South Korea are Chile for table grapes and wine (next to France); Spain for grape juice and olives; New Zealand for kiwifruit, beef and dairy; Australia for beef, dairy and cotton; Iran for pistachios; and China for strawberries, lettuce, garlic, red peppers, rice, flowers and processed tomatoes (table 3).

The potential for California producers to increase exports to South Korea when the market is opened also crucially depends on the competitiveness of South Korea's domestic producers.

Jack Kelly Clark


**KORUS FTA will provide unrestricted market access for certain agricultural crops, phase out many tariffs and impose safeguard measures to protect some domestic crops during the transition. *Above*, a cargo ship is loaded at the Port of Oakland.**

Imports to South Korea currently represent a small share of the domestic consumption of many major products, such as table grapes, fresh strawberries, fresh apples, lettuce and rice (table 3). Import tariffs for these products are high, about 45% in most cases. Fresh peaches and pears are an extreme example of the closed nature of the South Korean market for some products; South Korea has a sizable market for these fresh fruits, but almost no imports enter the country. Under the South Korea–Chile free trade agreement, preferential (lower) tariffs are applied for all trade between the two countries; however, pears are excluded, and no imports are allowed. The situation for processed fruits is different, with almost all coming from imports. Mostly, imports are low when domestic production is available. Only a few products — oranges, beef, some dairy and hay — are imported when there is also substantial domestic production, indicating that the overseas producers of these products are able to compete with domestic supplies despite sizable tariffs.

## Opening the South Korean market

KORUS FTA defines four mechanisms for establishing better access for agricultural products: (1) the immediate opening of certain markets without restrictions, (2) the phase-out of tariffs over a specified number of years, (3) the expansion of tariff rate quotas (TRQs), with the phase-out of over-quota tariffs and (4) the imposition of safeguard measures (USTR 2008) (table 4). (Tariff rate quotas apply a relatively low tariff for an initial quantity — the "quota" amount — and then a higher over-quota tariff for any additional quantity of imports.) Safeguards will be imposed for some politically sensitive commodities to protect the domestic industry during the transition. Typically, a safeguard trigger level (either a quantity or price) is set, and once it is reached additional duties are assessed to control access to the market.

The impact of greater access to the South Korean market will critically depend on the levels of pre-existing tariffs, which vary by product (table 5). Importantly, KORUS FTA allows no additional access for rice, which has a quota allowed under a 1994 World Trade Organization agreement.

**Citrus.** South Korea is a major market for fresh oranges and other citrus from California, despite a current duty of 50%. While the agreement lowers trade barriers considerably during the off-season, in-season imports (Sept. 1 to Feb. 29) will still be subject to tight tariff rate quotas. The limited access improvement for in-season oranges is designed to protect the domestic producers of mandarin oranges, which are almost identical to Satsumas and referred to as "Korean citrus" in the agreement. The initial duty-free tariff rate quota of 2,500 tons is equivalent to only 0.4% of Korean citrus produced in South Korea in 2007. Imported oranges are clear substitutes for Korean citrus during the in-season, which is why imports are limited by the 50% tariff. In addition to limiting imports of fresh oranges, South

**TABLE 4. Access improvement for important agricultural products by general market access category upon implementation of KORUS FTA***

| | |
|---|---|
| **Immediate unrestricted opening:** Asparagus, cabbage, celery, cucumbers, eggplants, shallots, spinach (fresh and frozen), tomato paste, cherries, olives, raisins, frozen orange concentrate, grape juice, wine, almonds, pistachios, coffee, cattle hides and skin, live livestock, feed whey | |
| **Tariff phase-out** (numbers indicate years to complete) | |
| 2 | Avocados, lemons, dried plums |
| 5 | Chinese cabbage, carrots (fresh and frozen), cauliflower, broccoli, peas, beans†, dried mushrooms†, tomato juice, grapefruit, strawberries (frozen), orange juice, various fruit juices |
| 4 | Off-season table grapes |
| 6 | Walnuts (shelled), off-season fresh oranges |
| 7 | Tomatoes, ice cream, apricots |
| 9 | Strawberries |
| 10 | Artichokes, Brussels sprouts, preserved cucumbers, lettuce, fresh mushrooms†, peaches, pears (excluding Asian pears), dates, persimmons, tangerine juice |
| 12 | Chicken meat, frozen onions, watermelon, various berries |
| 15 | Korean citrus, kiwifruit, walnuts (in shell), chestnuts, pine nuts, oak mushrooms (fresh and dried), beef offal |
| 17 | In-season table grapes |
| 20 | Asian pears |
| **Duty-free tariff rate quota expansion with or without over-quota tariff phase-out:** In-season fresh oranges, many dairy products | |
| **Safeguard quantity and duty:** Garlic, onions, peppers, beans†, sweet potatoes, ginger, apples, beef, pork | |

Source: USTR 2008.
* Rice excluded from agreement.
† Some varieties excluded.

Korea has a 144% tariff on Korean citrus and mandarins from other countries.

While not currently large, South Korean demand for fresh grapefruit, lemons and limes is growing. South Korea is becoming a major export market for California grapefruit and lemons because it does not produce these citrus fruits. Lower domestic prices — resulting from lower tariffs — will further increase demand.

**Other fruits.** For most fruits, access is improved under a simple tariff phase-out, but schedules to open the markets for apples, Asian pears and table grapes are more restrictive. These are the noncitrus fruits consumed widely in South Korea. The initial safeguard quantity for apples is 9,921 tons (9,000 metric tons), less than 2.5% of domestic production. Further, Fuji apples, the variety favored by South Koreans, have a long period of market opening with the safeguard duty lasting 23 years (neither apples nor pears currently have access due to phytosanitary issues).

The South Korean market for grape products is substantial. In 2007, South Korea imported table grapes worth close to $60 million. Table grapes do not face overall quantity restrictions, but seasonal import restrictions apply. Along with the immediate tariff reduction from 45% to 24%, the tariff for off-season imports (Oct. 16 to April 30) phases out in 4 years, and the tariff for in-season imports phases out over 17 years. Chile and the United States (mostly California) dominate the South Korean grape import market. Chile currently holds 85%, in part because its exports are counter-seasonal to South Korean production. About 70% of U.S. table grape exports to South Korea are shipped during their off-season.

iStockphoto

**Cherries are the second largest fresh-fruit export from the United States to South Korea, with about 30% supplied by California. The elimination of a 24% tariff is expected to further expand this market.**

The import market for grape juice is also large, exceeding $25 million in 2007, with the United States holding a 47% share. South Korean wine imports reached more than $150 million in 2007, and U.S. wine, almost all from California, accounted for $17 million. Under KORUS FTA, the 30% tariff on U.S. wine will be eliminated immediately. South Korean raisin imports have reached close to $6 million per year, and over 95% are shipped from California. The immediate elimination of the 45% tariff for grape juice and 21% tariff for raisins will allow a substantial reduction in domestic prices in South Korea.

U.S. fresh cherry exports to South Korea rank second highest among all U.S. fresh fruit exports. South Korean fresh cherry exports reached close to $31 million in 2007, with 27% supplied by California. South Korea produces almost no cherries, and the elimination of the 24% tariff is expected to expand the fresh cherry market even further. Among other fruits, strawberries and kiwifruit are promising for market expansion. Strawberries are probably the largest greenhouse crop, by value, in South Korea (no official information is available for greenhouse crops). Currently, no fresh strawberries enter the country, and over 70% of strawberry imports are frozen. China is the number-one supplier of frozen strawberry imports to South Korea, with about an 80% market share, and the rest of frozen strawberry imports are supplied by the United States and Mexico. Kiwifruit is relatively new to South

**TABLE 5. Current base tariffs on exports to South Korea for selected products**

| Base tariff (%) | Product |
|---|---|
| 1 | Cattle hides and skin |
| 8 | Almonds (shelled and in shell) |
| | Tomatoes (paste) |
| 18–20 | Plums (dried), olive, casein |
| 21–24 | Raisins, cherries (fresh) |
| 27–30 | Artichokes, Chinese cabbage, broccoli, cauliflower, Brussels sprouts, garlic (frozen and pickled), peppers (frozen), onions (frozen), cucumbers (pickled), carrots (fresh, frozen, preserved and dried) |
| | Beef offal |
| | Lemons and limes, grapefruit (fresh and juice), wine, avocados, dates, pistachios, walnuts (shelled) |
| 36–40 | Cheese |
| | Beef (muscle cuts) |
| 45–50 | Apricots, cherries (canned), peaches, strawberries, other berries, oranges, peaches (preserved), juices (grape, apple, lemon, lime, peach, strawberry), walnuts (in shell) |
| | Lettuce, tomatoes |
| | Lactose, whey |
| 54 | Orange juice (frozen concentrate) |
| 89 | Butter |
| 135* | Onions (fresh and dried) |
| 144 | Korean citrus and mandarins |
| 176 | Skim and whole milk power |
| 270 | Peppers (fresh and dried) |
| 360* | Garlic (fresh and dried) |

Source: USTR 2008.
* Over-quota tariffs; base tariffs are 50%, but quotas are so tiny that higher tariffs are listed.

Korean consumers, but imports have grown rapidly and totaled $70 million in 2007. Kiwifruit imports are dominated by New Zealand, which has a 77% share, followed by Chile (14%) and the United States (8%); California supplies about half of the U.S. exports.

**Tree nuts.** California tree nuts have a strong presence in the South Korean market. Almond and walnut exports are already substantial (about $35 million each). In South Korea, there is no domestic tree nut industry to offer competition. The United States is the only supplier for almonds and has more than a 90% share in the walnut market. All U.S. walnut and almond exports to South Korea are supplied exclusively by California. The current 8% almond tariff will be eliminated, and in-shell and shelled walnut tariffs, as high as 45%, will be phased out over 6 and 15 years, respectively. Pistachios are relatively new in South Korea and not widely consumed. U.S. exports of pistachios (all from California) are currently small, but with immediate elimination of the 30% tariff, the potential will be large for California growers.

**Vegetables.** South Korean tariffs on vegetables will be eliminated either immediately or phased out over time, except for a few sensitive products for which safeguard restrictions apply. We only discuss the vegetables that have significant import value or potential as exports from California. Vegetable trading in South Korea is dominated by China, except for a few products such as fresh pumpkins (New Zealand supplies about 88%), pickled cucumbers (supplied almost solely by the United States) and fresh lettuce (the United States holds about a 50% market share, and California supplies about 41% of U.S. exports).

With a 45% tariff, U.S. exports of lettuce were $4.4 million in 2007. Imports constitute a small share of the domestic South Korean market, which is valued at $200 million. California lettuce competes mostly with off-season, high-cost greenhouse lettuce in South Korea and has substantial export growth potential under the 10-year tariff phase-out. Other fresh, leafy vegetables such as spinach are favored by Korean consumers and also have potential for substantial export growth.

For a few sensitive products the agreement allows gradual access through 18-year phase-outs, with safeguard restrictions. Garlic, onions and red peppers are important ingredients in the South Korean diet and among the major crops in Korean agriculture. The

Tricia Bergland

Under the free trade agreement, tariffs will be eliminated or phased out for many fruits exported by California growers to South Korea, including watermelon, table grapes and oranges. Safeguard duties and seasonal import restrictions will also apply to some fruits.

Jack Kelly Clark

California growers provide all walnuts shipped from the United States to South Korea, which has no tree nut industry. In-shell walnut tariffs of up to 45% will be phased out over 6 to 15 years.

initial safeguard quantities for these products are tiny. They double only after 15 years, and the safeguard duties will remain prohibitive.

Base tariffs for these sensitive products differ significantly depending on the way the product is prepared. While fresh and dried garlic have a base tariff of 360%, frozen garlic has a tariff of only 27%. Predictably, two-thirds of garlic imports are frozen and over 70% of red chili pepper imports, which have a relatively low tariff of 27%, are also frozen.

**Beef and related products.** KORUS FTA imposes safeguard restrictions on U.S. beef imports. Beef products are the number-one agricultural import into South Korea by value, exceeding $1 billion in 2007. South Korea became an important market for U.S. beef after its beef market was opened in 2001. The United States had the largest share of imports in December 2003, when South Korea banned U.S. beef following detection of the BSE case in the United States (South Korea accounted for 34% of California beef exports in 2003). Since then, Australia and New Zealand have replaced the United States, together supplying more than 90% of Korean imports.

The United States resumed supplying beef to South Korea in 2007. However, recapturing the market now depends on U.S. competition with Australia and New Zealand as well as domestic producers. Australia

**KORUS FTA is considered the most commercially significant free trade agreement that the United States has negotiated in nearly 20 years.**

Howard Rosenberg

South Korea's 45% lettuce tariff will be phased out over 10 years, providing substantial opportunities for growers of the California crop, *above.*

traditionally produces grass-fed beef, but producers expanded the production of grain-fed beef for export to South Korea. Under KORUS FTA, the initial safeguard quantity is sizable, amounting to about 60% of domestic consumption. But the within-quota tariff is scheduled to fall by 2.7% each year, providing a price advantage to U.S. producers over their competitors. South Korea also imported a substantial amount of bovine offal ($9 million) and cattle hides and skins ($381 million) in 2007. California's small share of the very large U.S. export total from beef and cattle products is nonetheless substantial for the state's industry.

**Dairy products.** South Korea has relatively high trade barriers for dairy products (Lee et al. 2006), but KORUS FTA gradually reduces them. Tariff rate quotas increase gradually with the phase-out of over-quota tariffs. Among dairy products imported to South Korea, the United States has a strong presence in cheese, lactose and whey. In 2007, South Korea imported $179 million of cheese and $144 million of whey, which contrasts to a relatively small milk powder import market ($21 million in 2007). The United States shipped $32 million each of both cheese and whey (trailing New Zealand's $47 million for each). In the same year, California exported $29 million worth of dairy products to South Korea. For cheese, the first-year duty-free tariff rate quota, 7,716 tons (7,000 metric tons) is close to the total of U.S. cheese exports to South Korea in 2007. For feed whey, KORUS FTA allows immediate duty-free access, and the tariff applied to whey exceeding the quota of 3,307 tons (3,000 metric tons) will be reduced immediately from 49.5% to 20% and phased out over 10 years. U.S. exports of lactose to South Korea are also sizable, worth $30 million in 2007, about half of Korean lactose imports. The current tariff of 49.5% is scheduled to be phased out in 5 years under the agreement. Because existing barriers are relatively high for dairy products, KORUS FTA is expected to expand the U.S. share of the Korean dairy market considerably.

ANR Communication Services

South Korea imported $1 billion of beef in 2007. U.S. beef producers currently compete with those from Australia and New Zealand for market share, but gradual tariff reductions will provide a price advantage for the United States.

## Opportunities ahead

Although South Korea already has an almost open border for many field crops — with the important exception of rice — it has high trade barriers for many vegetables, fruits and animal products that are important in California agriculture. Under KORUS FTA, California has substantial potential to expand its exports of agricultural commodities to South Korea. Lower trade barriers will allow California agriculture to compete in a large, growing and lucrative market. Commodity prices are high in South Korea, and consumers are willing to pay premiums for the high-quality products produced in California. When KORUS FTA is implemented, California agriculture should be in an excellent position to compete on both price and quality.

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*H. Lee is Research Economist, and D.A. Sumner is Frank H. Buck, Jr. Professor, and Director, Agricultural Issues Center, UC Davis.* *The authors thank William Matthews, John Thomas Rosen-Molina and Sanggon Jeon for assistance. The California Farm Bureau provided funds for the early stages of this research.*

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# Plants in constructed wetlands help to treat agricultural processing wastewater

*by* Mark E. Grismer *and* Heather L. Shepherd

***Over the past three decades, wineries in the western United States and sugarcane processing for ethanol in Central and South America have experienced problems related to the treatment and disposal of process wastewater. Both winery and sugarcane (molasses) wastewaters are characterized by large organic loadings that change seasonally and are detrimental to aquatic life. We examined the role of plants for treating these wastewaters in constructed wetlands. In the greenhouse, subsurface-flow flumes with volcanic rock substrates and plants steadily removed approximately 80% of organic-loading oxygen demand from sugarcane process wastewater after about 3 weeks of plant growth; unplanted flumes removed about 30% less. In field studies at two operational wineries, we evaluated the performance of similar-sized, paired, subsurface constructed wetlands with and without plants; while both removed most of the oxygen demand, removal rates in the planted system were slightly greater and significantly different from those of the unplanted system under field conditions.***

**Agricultural processing wastewaters may have high concentrations of organic matter that contaminate surface waters when discharged downstream. At Imagery Estate Winery in Glen Ellen, constructed wetlands with plants were tested for their ability to remove pollutants.**

The processing of sugarcane to create molasses for ethanol fuel and feedstock is rapidly expanding across Central and South America, while the number of vineyards and wineries continues to increase across the western United States. Both industries generate process wastewater (PWW) of variable quality, which can have deleterious impacts on receiving surface waters when discharged downstream.

Shepherd et al. (2001) described the negative impacts of winery wastewater downstream, which led to requirements for its control and on-site treatment. Similarly, downstream degradation from sugarcane process waters has been documented in the Ipojuca River of northeast Brazil (Gunkel et al. 2006) and in coastal lagoons of northwest Mexico (González-Farias et al. 2006). Wastewater from molasses processing follows a seasonal variation similar to that of wineries, with high flows and loadings from November through May, followed by harvesting and grape crush in late summer and early fall.

Both winery and molasses process wastewaters are responsive to natural treatment strategies prior to discharge. Remnant wetland systems, relatively common in the drainage channels of Central and South America, may be employed. Likewise, constructed wetlands have been designed and installed to treat winery process wastewater in California. Surprisingly, the role of plants and their associated biofilms in such systems is poorly understood and not well documented relative to treatment performance.

### Sugarcane and winery wastewater

Sugarcane, food-processing, winery and other distilleries generate wastewaters from processing and equipment wash-down. These differ greatly from domestic wastewater because of their high organic-matter concentrations, variable flow rates, relatively low levels of nutrients, low pH and lack of pathogens. Gunkel et al. (2006) monitored sugarcane fertigation and wash-down waters (used to clean equipment) in Brazil and noted their very low pH (3.8) and high sodium (1,320 milligrams per liter), salinity and organic loads. Kumar et al. (2007) obtained similar results in India and also noted high sulfates.

To determine the characteristics of sugarcane process wastewater in Mexico, in March 2007 we compared wastewater from a typical processor, Ingenio La Gloria, located on the coast south of Veracruz (Olguín et al. 2008), to sugarcane process wastewater in India and Brazil, and process wastewater from a California winery (table 1). In Mexico, sugarcane process wastewater is typically diluted 10 to 100 times with canal water prior to reuse for irrigation or release into drainage channels, making it similar in quality to that reported for Brazil. The biological oxygen demand ($BOD_5$, 5-day holding time) and chemical oxygen demand (COD) concentrations (both measures of organic loading), and $BOD_5$-to-COD ratio, for Brazilian sugarcane wastewater — as diluted for fertigation — were nearly the same as that for the California winery process wastewater. While at much higher concentrations, the $BOD_5$-to-COD ratio for the Indian sugarcane process wastewater was similar.

Shepherd et al. (2001) proposed that constructed wetlands are an attractive treatment system for moderate-sized wineries, with their ability to assimilate variable and large organic loadings as well as their low maintenance and operational costs. Likewise, process wastewaters can be treated naturally in drainage channels constructed at the outflow of sugarcane processing factories. Such constructed wetlands make use of wetland plants and associated microorganisms on the roots (called biofilms) to degrade organic pollutants such as carbohydrates, proteins and other carbon-based suspended matter that comprise the wastewater's $BOD_5$ and COD load.

Free-water surface ponds are one type of constructed wetland. In this system, vegetation is planted in base soils below water as deep as 4 feet. These systems are easy to maintain and are acceptable for relatively modest organic loadings, but generally they are not appropriate for winery or sugarcane processing unless the wastewater is pretreated (such as in aerated ponds, for odor and mosquito control).

Another type of constructed wetland, called subsurface-flow or vegetated submerged beds (fig. 1), involves planting wetland vegetation directly into a gravel substrate 3 to 4 feet deep. The wastewater passes through the gravel but does not cover its surface. This system has greater treatment capability but also higher initial installation costs.

Rates of flow into such constructed wetlands are managed so that there is sufficient hydraulic residence time (HRT) for adequate treatment. COD or $BOD_5$ removal rates are typically modeled as first-order degradation (decay) processes (Shepherd et al. 2001).

**TABLE 1. Comparison of process wastewaters (PWW) from sugarcane in Mexico (Ingenio La Gloria, Veracruz), Brazil and India; and a California winery**

| | Winery | Sugarcane (molasses) | | | | |
|---|---|---|---|---|---|---|
| Parameter* | Calif. PWW* | Brazil fertigation† | Brazil wash-down† | India PWW‡ | Mexico PWW | (± SD) |
| | *mg/L* | | | | | |
| Chemical oxygen demand (COD) | 22,290 | 23,727 | 1,050 | 105,000 | 118,270 | 305 |
| Biological oxygen demand ($BOD_5$) | 14,490 | 10,800 | 388 | 52,500 | 52,200 | 200 |
| Total Kjendahl nitrogen (TKN) | | | | | 1,598 | 106 |
| Nitrogen as ammonia ($N\text{-}NH_3$) | | | | | 772 | 16 |
| Nitrogen as nitrate ($N\text{-}NO_3$) | 163 | | | | 312 | 10 |
| Phosphorus as phosphate ($P\text{-}PO_4$) | | 67.7 (total) | 2.2 (total) | | 1,100 | 45 |
| Sulfur as sulfate ($S\text{-}SO_4$) | 61 | | | 6,250 | 8,220 | 197 |
| Potassium (K) | | | | | 19,250 | 250 |
| Total solids (TS) | 1,120 (TSS) | | | 85,000 | 106,465 | 1,534 |

* Source: Shepherd, Grismer et al. 2001.
† Source: Gunkel et al. 2006.
‡ Source: Kumar et al. 2007.

While plants are understood to be important to treating process wastewater in constructed wetlands, little quantitative information is available. Biofilms are defined as spatially and metabolically structured microbial communities (Nikolaev and Plakunov 2007) that interact with plant roots and the soil-water environment, while constantly adapting to changes in both. As such, plant roots provide the structure needed for biofilm bacteria to process wastewater. Biofilm microorganisms consume organic material and ultimately release carbon dioxide and water, or methane and water, depending on the amount of oxygen present. Since the surface area of plant roots is far greater than that of the sand/gravel/rock substrate alone, and because roots have the ability to partially oxygenate their surfaces, they can support thicker and perhaps more robust biofilms. In addition, plants consume some of the process wastewater nutrients, while roots physically filter them. In some cases the aesthetic appearance of the constructed wetland is not a concern, but the processing plant operators may not see the benefit of maintaining vegetation in planted wetlands. Our investigation was directed at determining the relative value of planted versus unplanted systems.

## Constructed-wetland performance

The success of constructed wetlands in treating process wastewaters containing high-strength organic matter depends on several factors related primarily to organic loading, HRTs, the tolerance of selected plants to possibly toxic components in the process wastewater, and plant biofilm activity. Comprehensive research reviews of brewery, winery and related distillery treatment methods for process wastewater have underscored the need for additional research, particularly of full-scale systems and individual processes (Grismer and Shepherd 1998; Grismer et al. 1999, 2000, 2002, 2003). Shepherd, Grismer et al. (2001) evaluated the performance of a subsurface-flow wetland (20 feet long, 8 feet wide and 4 feet deep) in treating winery process wastewater flows ranging from 80 to 170 cubic meters per day at organic loads of 600 to 45,000 milligrams COD per liter (mg COD/l), and measured average removal rates of 98% for COD and 97% for total suspended solids (TSS) when combining the constructed wetland with an upflow sand prefilter. The system also effectively neutralized the pH of the acidic winery wastewater and removed the limited nitrogen (78.2%), sulfide (98.5%), orthophosphate (63.3%), volatile fatty acids (99.9%), tannins and lignins (77.9%) and all settleable solids.

Olguín et al. (2008) achieved similar results from greenhouse-based, fiberglass, subsurface "flumes" (long, narrow boxes 10 feet long, 1 foot wide and 1.6 feet deep), used to treat diluted molasses process wastewater with 2.5- or 5-day HRTs and an average inlet concentration of 1,184 mg COD/l (534 mg $BOD_5$/l). After 30 to 40 days of plant (*Pistia sagittata*) establishment, the planted flumes achieved average removal rates of 80.2% for COD, 87.3% for $BOD_5$, 76.1% for total Kjeldahl nitrogen (TKN, the sum of organic nitrogen, ammonia and ammonium) and 68.6% for sulfate during the next month. In the same period, the corresponding control nonplanted flume achieved removal rates significantly lower than that of the planted flume — 40.1% for COD, 60.9% for $BOD_5$, 55.5% for TKN and 57.0% for sulfate.

Evaluating constructed wetlands in the field requires not only analysis of constituent degradation, or transformation, but also a hydraulic assessment of its bed-flow properties under the variable operating conditions of actual use (Grismer 2005). In the only published field-scale evaluation, Grismer et al. (2003) — using tracer methods developed by Grismer et al. (2001) — measured constructed-wetland degradation constants, HRTs and treatment performance at two operating wineries. System performance was evaluated through daily sampling of total dissolved solids (TDS), pH, total suspended solids, COD, tannins, nitrate, ammonium, TKN, phosphate, sulfate and sulfide.

The larger winery system showed similar COD and tannin removal rates to those of bench-scale columns (constructed of PVC pipes 6 inches in diameter by 24 inches tall), ranging from 49% to 79% (columns) and 46% to 78% (constructed wetlands). Greater removal occurred during the spring, noncrush period. During the crush season, with HRTs of about an hour compared to about 5 days during the noncrush season, the constructed wetland reduced inlet COD by half and other constituents 20% to 30%. Though it had smaller loading rates and greater HRTs, the small winery's constructed-wetland system achieved nearly complete COD removal (from about 8,000 to 5 mg/l) through the use of a recirculation system. These results suggested that the wetland system was quite capable of fully treating winery process wastewater when properly loaded and operated. Understanding the HRTs through tracer study analyses was crucial to the interpretation of water-quality measurements from the wetland.

While there is some literature on bench and pilot-scale testing for loadings and HRTs, scant information is available related to plant and biofilm factors, especially at the field scale. Constructed-wetland systems had not been compared side-by-side, with and without plants, for the high-strength process wastewaters typical of wineries and sugarcane processing. Moreover, the selection of suitable plants for treating process wastewaters depends in part on plants found locally, but little detailed information has been available to help guide that selection.

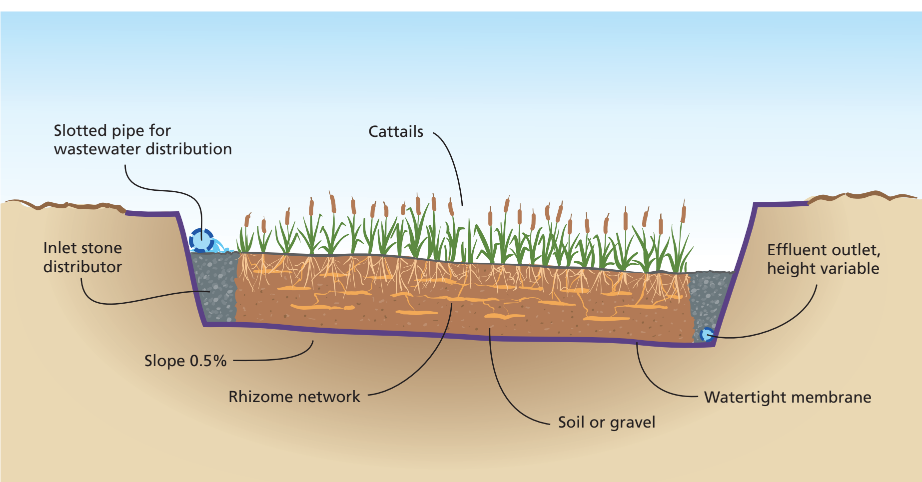

**Fig. 1. Cross-section of subsurface-flow constructed wetland.**

We conducted complementary green house (Mexico) and field (California) studies for treating molasses and winery process wastewater in constructed wetlands, with and without plants. In the greenhouse studies, we also considered the rate of plant growth and its effect on process wastewater (Olguín et al. 2008). In California, where plants are normally allowed to establish for about a year prior to the introduction of process wastewater, we monitored two planted and unplanted pairs of constructed wetlands at wineries on the Central Coast. In both cases, the wineries anticipated future expansion and chose to build two subsurface systems, one for current operations and another for the expansion. Since the second constructed wetland would not be in use for several years, it was installed without plants, allowing us to monitor and evaluate treatment performance under operating conditions.

## Greenhouse and field studies

**Mexico greenhouse studies.** At the Instituto de Ecología near Xalapa, Mexico, we employed the greenhouse facilities, constructed-wetland flumes and methods, all as described by Olguín et al. (2008). Duplicate flumes were used for each of the three different treatment systems and HRTs. These systems included a surface treatment with aquatic plants, a subsurface-flow treatment with plants, and a subsurface-flow treatment without plants (control). Two HRTs (2.5 and 5 days) were used for the planted systems, while only the 2.5-day time was used in the control. There were 10 flumes in total.

Different HRTs were used to develop preliminary estimates of the degradation constants necessary for field designs of constructed wetlands. Substrate in the subsurface flumes consisted of volcanic rock approximately 1.5 inches (40 millimeters) across, with a net porosity of about 50%, resulting in a flume volume of approximately 45 gallons (170 liters). In the surface treatment, we used

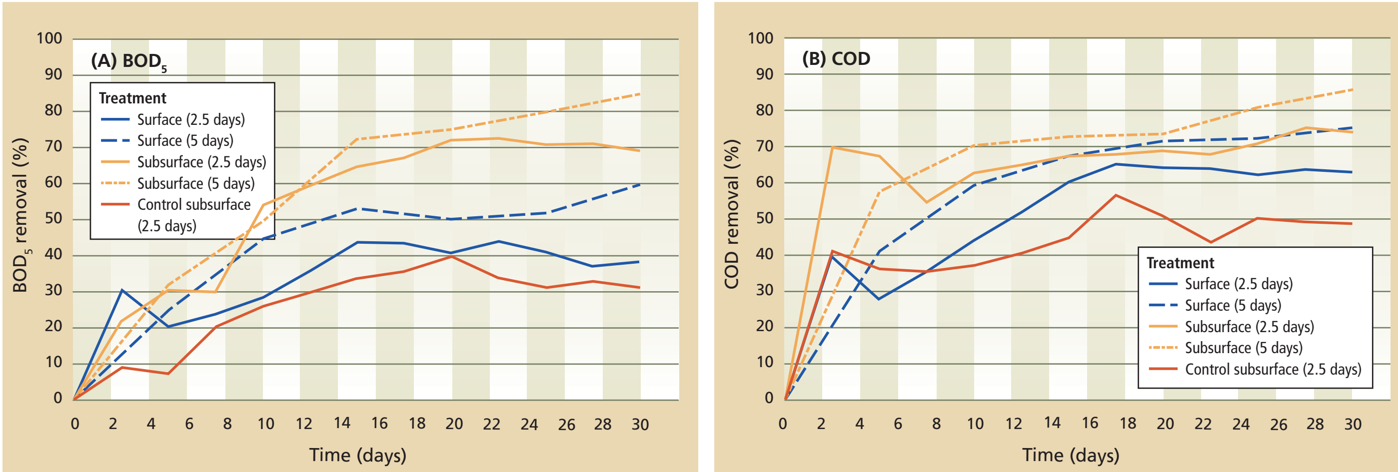


**Fig. 2. Daily variation of removal efficiencies for (A) biological oxygen demand, 5 days ($BOD_5$) and (B) chemical oxygen demand (COD) in constructed-wetland greenhouse flume experiments.**

the aquatic plant water lettuce (*Pistia stratiotes*), while the subsurface treatment was planted with pickerelweed (*Pontederia cordata*). Plants were allowed 3 weeks to establish and acclimate in local canal water before the experiments were initiated with 100-to-1 diluted sugarcane process wastewater.

Flow rates were carefully maintained, with steady flow provided by Masterflex peristaltic pumps for 30 days of monitoring at the inlet and outlet of each flume. In this study we focused on $BOD_5$/COD removal, based on sampling at 2.5- and 5-day intervals corresponding to flume HRTs. Relatively constant ambient conditions were maintained during May 2006. The overall mean temperature was 79.7°F (26.5°C), while the average evapotranspiration rate was 0.26 inches (6.7 millimeters) per day.

**California field studies.** Field studies were conducted on the California Central Coast at two wineries (A and B) to evaluate treatment effects on similarly sized, paired (planted/unplanted), subsurface constructed wetlands. At winery A, the systems were sized to handle process wastewater from the production of 14,000 cases of wine, with each wetland designed to treat half this process wastewater (that from about 7,000 cases of production). Each paired wetland was 52 feet by 12 feet by 3 feet deep, with washed pea gravel roughly 0.3 inches (< 8 millimeters) in diameter.

Subsurface wetlands at winery B were also sized to treat process wastewater from 14,000 cases of wine, but the expansion phases were different. One of the wetlands was designed to treat the process wastewater from 8,000 cases and the other from 6,000 cases; they were 55 feet by 14 feet, and 44 feet by 12 feet, respectively, both with approximately 3-foot-deep washed pea gravel.

At both sites, one of the wetlands had been planted with cattails (*Typha dominigensis*), bulrushes (*Scirpus acutus*) and some arrowheads (*Sagittaria latifolia*) the June previous to monitoring. These wetland plants were established though not fully grown by October. In both wineries, the process wastewater was pretreated in septic tanks designed to have a 2-day retention time. Also, both treatments were designed to have 10-day HRTs, though as noted above, in previous field studies the actual field times differed. Winery process wastewater flows were evenly split into the planted and unplanted treatments at the two wineries.

For 2 weeks during the October 2006 harvest, daily water samples were taken from the inlets and outlets of each constructed wetland (planted and unplanted at each winery) with care taken to sample at roughly the same time each day, when wastewater was flowing. Samples for COD, $BOD_5$ and total suspended solids were refrigerated and analyzed daily in the lab, while pH and total dissolved solids were measured directly in the field. As in Mexico, samples were generally analyzed immediately after collection following standard methods using Hach tests accepted by the U.S. Environmental Protection Agency. COD was measured using the closed-reflux colorimetric method adapted from Standard Methods 5220 D. The lower detection limit of the COD analysis was 1 mg COD/l. Total suspended solids were measured using the Hach 2010 Spectrophotometer turbidimetric method. In the field, pH was measured immediately after sampling using the Hach EC10 portable pH meter calibrated against pH 4 and pH 7 standards. Total dissolved solids were measured using the Hach Conductivity/TDS meter. Measured daily plug-flow rates were used to determine the actual HRTs of process wastewater in each constructed wetland following methods described by Grismer et al. (2001, 2003).

**Statistical analysis.** Because these studies only involved comparisons of mean outlet concentrations from the different treatments, we used simple single-tailed confidence level tests to determine the relative significance of differences in concentrations after they stabilized, or after 15 days in the greenhouse flumes.

## Greenhouse flume measurements

**System performance.** $BOD_5$ (fig. 2A) and COD (fig. 2B) removal rates steadily improved during the first 15 days of the greenhouse tests, after which they stabilized, presumably in response to additional plant growth and acclimation to the process wastewater (table 2). Average $BOD_5$-removal rates after 15 days were 34% for the unplanted control, 41% and 53% for the surface system, followed by 70% and 78% for the subsurface system, with HRTs of 2.5 and 5 days in both treatments, respectively. All mean outlet $BOD_5$ concentrations differed at greater than 99.9% confidence levels ($P < 0.00005$).

Similarly, mean COD-removal rates after 15 days of sampling were 49% for the control, 63% and 71% for the surface system, followed by 70% and 78% for the subsurface system, again at HRTs of 2.5 and 5 days, respectively. With the exception of the means comparison between outlet COD concentrations from the subsurface (2.5 days) and the surface (5 days) treatments having a significant difference at the approximately 96% confidence level, all remaining mean outlet COD concentrations differed at greater than 99.9% confidence levels ($P < 0.00005$).

The greenhouse studies showed that (1) the subsurface treatment outperformed the surface treatment in terms of $BOD_5$ and COD removal at both HRTs; (2) not surprisingly, greater HRTs resulted in greater removal rates of $BOD_5$ and COD for both systems; and (3) the planted subsurface system significantly outperformed the unplanted control in terms of $BOD_5$ and COD removal.

**$BOD_5$ and COD degradation.** The use of two different HRTs in the greenhouse studies enabled preliminary assessment of the simple first-order degradation constants (K) for each system, and how they varied with time during the 30-day test period. Such information is useful for the field designs of constructed-wetland systems. In addition, because COD is a measure of all possible oxygen-consuming material in the process wastewater, changes in $BOD_5$-to-COD ratio during the experimental period provide an indication of the relative ability of each system to degrade progressively more-recalcitrant organic compounds in the process wastewater (fig. 3). The K values for COD increased and appeared to stabilize after about 2 weeks. In this study, we found stable degradation constants of 0.2 and 0.4 per day for the surface and subsurface systems, respectively; this is much lower than the constant of about 1.5 per day found by Shepherd, Tchobanoglous et al. (2001) in pilot-scale, subsurface treatment of winery process wastewater in Davis used as the basis for our field experiment design. Our smaller K values may be due to the larger volcanic rock substrate used in the flumes as compared to the pea gravel used by Shepherd, Tchobanoglous et al. (2001).

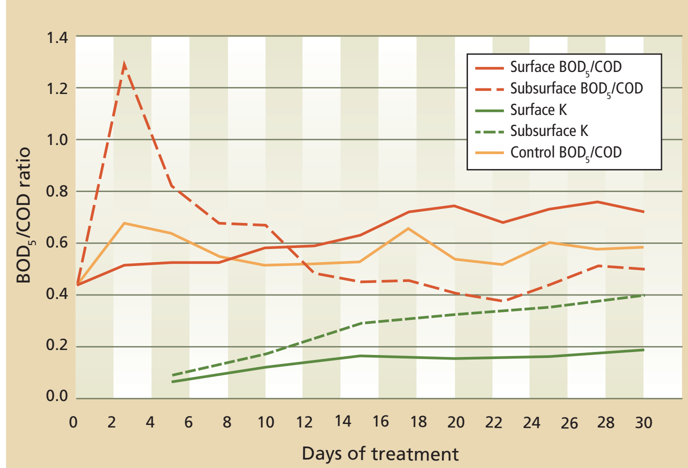


**Fig. 3. Variation of constructed-wetland treated wastewater $BOD_5$-to-COD ratio and first-order degradation constants (K(1/d) during experimental period.**

Perhaps more interesting is the change in average $BOD_5$-to-COD ratios from those of the initial wastewater stream ($BOD_5$-to-COD = 0.44). In the subsurface treatment, the ratio dramatically increased to greater than 1.0, leveling off to about 0.5 after 2 weeks. Meanwhile, this ratio remained approximately unchanged in the control at 0.55 to 0.60, and steadily increased to roughly 0.75 in the surface treatment. The latter ratio reflects the greater treatment capability of the combined plant/gravel biofilm system after acclimation in the subsurface system compared to that of the surface system.

In the subsurface system, 3 to 4 weeks were sufficient for plant establishment to achieve the steady removal rates reported by Olguín et al. (2008). Overall, COD removal rates indicate that the use of constructed-wetland systems in the drainage canals leaving sugarcane processing facilities should be advantageous for improving downstream water quality.

## Winery subsurface-flow systems

**Winery A.** Under actual field operations, the performance of constructed-wetland systems in California was variable depending on the winery process wastewater flows and loading rates. Due to greater wine production than anticipated at winery A**,** inlet loading (flow and COD concentrations) was much greater and more variable than anticipated, resulting in daily HRTs of roughly half the design value of 10 days, although constant. After 5 days of sampling at winery A, inlet COD loading peaked from roughly 60,000 mg/l to more than 130,000 mg/l for about 2 days due to uncollected juice flowing into the treatment system. This situation was corrected, and inlet COD concentrations steadily decreased to about 60,000 mg/l by day 11 of sampling. Outlet COD concentrations ranged from approximately 600 to 5,200 mg/l from the planted treatment to 600 to 8,800 mg/l from the unplanted treatment at winery A. Inlet total-suspended-solids

**TABLE 2. Mean outlet chemical (COD) and biological ($BOD_5$) oxygen demand concentrations from greenhouse flumes after 15 days of flow through constructed wetlands**

| | $BOD_5$ | | | COD | | |
|---|---|---|---|---|---|---|
| Treatment (HRT*) | Inlet | Outlet | Outlet SD† | Inlet | Outlet | Outlet SD |
| | mg/L (n) | | | mg/L (n) | | |
| Control (subsurface) | 522 (14) | 344 | 16.7 | 1,183 (28) | 605 | 49.5 |
| Surface (2.5 hours) | 522 (14) | 307 | 14.1 | 1,183 (28) | 437 | 21.0 |
| Surface (5 hours) | 522 (8) | 242 | 23.0 | 1,183 (16) | 338 | 34.5 |
| Subsurface (2.5 hours) | 522 (14) | 159 | 16.2 | 1,183 (28) | 359 | 42.9 |
| Subsurface (5 hours) | 522 (8) | 116 | 27.3 | 1,183 (16) | 260 | 60.4 |

* Hydraulic residence time.
† Standard deviation.

**Piping disperses process wastewater across the width of a constructed wetland at a Paso Robles winery. Samples were taken at the outflow (not shown) and the far end of the wetland, which was designed to handle wastewater generated by producing 14,000 cases of wine.**

concentrations ranged from 160 to 450 mg/l, and corresponding outlet concentrations ranged from 20 to 160 mg/l and 50 to 260 mg/l from the planted and unplanted wetlands, respectively.

**Winery B.** Conversely, at winery B full wine production was not achieved, and daily flow rates and loadings were much smaller and less variable. As a result, there were different flow rates to each constructed wetland and much greater HRTs, about double the design value of 10 days. Flow and loading conditions at winery B were more typical; inlet COD values were as high as 7,000 mg/l and outlet values ranged from 14 to 48 mg/l and 68 to 138 mg/l for the planted and unplanted treatments, respectively. Average total-suspended-solids concentrations at the winery B inlet were similar to those at winery A, ranging from 240 to 420 mg/l, but corresponding concentrations at the outlet were far less, ranging from 18 to 34 mg/l and 26 to 64 mg/l for the planted and unplanted wetlands, respectively. The average removal rates for total suspended solids of 76% (53% for unplanted) as compared to 91% (85% for unplanted) reflect the much shorter HRTs encountered at winery A compared to winery B.

**Plants and treatment performance.** Because COD and total-suspended-solids concentrations at the inlet of winery A were roughly 10 times greater than those at winery B — and as a result, HRTs were only one-third that for winery B — concentrations at the outlet were also considerably greater at winery A (table 3). This fortuitous change enabled us to better evaluate the effects of plants on treatment performance across a greater range of loading conditions than originally planned.

The mean outlet concentrations of COD, total suspended solids, total dissolved solids and pH between the planted and unplanted wetlands at winery A all differed significantly at greater than 99% confidence levels. Similarly, at winery B, despite significantly greater HRTs in the unplanted treatment, mean outlet concentrations between the planted and unplanted treatments were also significantly different at greater than 99% confidence levels. Outlet concentrations differed at the 95% confidence level.

At both wineries, salinity and total-dissolved-solids concentrations increased as a result of evapoconcentration within the constructed wetland. The subsurface treatments at both wineries were successful in substantially reducing COD and total suspended solids at the outlet by more than 96% and 76%, respectively, with the planted system significantly outperforming the unplanted system. Finally, acidic pH of the process wastewater at both winery inlets was more successfully neutralized by the planted than the unplanted wetlands.

Overall, the field evaluation demonstrated that plants can play a significant role in treating process wastewater from wineries. While the planted

**TABLE 3. Field inlet/outlet monitoring (14 days) of subsurface-flow constructed wetlands for process wastewater treatment at two California wineries**

| | HRT* | | COD | | | TSS | | | TDS | | | pH | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Parameter | Planted outlet | Unplanted outlet | Inlet | Planted outlet | Unplanted outlet | Inlet | Planted outlet | Unplanted outlet | Inlet | Planted outlet | Unplanted outlet | Inlet | Planted outlet | Unplanted outlet |
| | days | | mg/L | | | | | | | | | | | |
| **Winery A** | | | | | | | | | | | | | | |
| Mean | 6.0 | 6.0 | 72,965 | 2,321 | 4,770 | 297.9 | 71.3 | 140.5 | 639 | 1,447 | 1,910 | 4.50 | 6.41 | 5.81 |
| Standard deviation | 1.6 | 1.6 | 29,066 | 1,512 | 2,649 | 95.0 | 44.6 | 59.2 | 33 | 366 | 321 | 0.28 | 0.33 | 0.33 |
| *P* value/CL† | | | | 0.0013 | > 99% | | 0.0002 | > 99% | | 0.0002 | > 99% | | < 0.0001 | > 99% |
| Average removal (%) | | | | 96.8 | 93.5 | | 76.1 | 52.8 | | | | | | |
| **Winery B** | | | | | | | | | | | | | | |
| Mean | 17.5 | 24.1 | 5,080 | 30.8 | 106.0 | 324 | 27.5 | 44.50 | 615 | 1,178 | 1,401 | 5.35 | 6.96 | 6.52 |
| Standard deviation | 4.6 | 6.3 | 1,211 | 9.2 | 23.3 | 54.6 | 6.10 | 10.02 | 28.7 | 168 | 244 | 0.56 | 0.17 | 0.17 |
| *P* value/CL | 0.0008 | > 99% | | 0.0465 | > 95% | | < 0.0001 | > 99% | | < 0.0024 | > 99% | | < 0.0001 | > 99% |
| Average removal (%) | | | | 99.3 | 97.9 | | 91.1 | 85.5 | | | | | | |

* HRT = hydraulic residence time; COD = chemical oxygen demand; TSS = total suspended solids; TDS = total dissolved solids.
† CL = confidence level.

constructed wetlands were less than 1 year old and not fully developed, they showed consistently better removal of COD and total suspended solids, as well as better pH neutralization.

### Understanding natural treatments

Natural wastewater treatment systems have been effective in treating process wastewaters from fruit, wine and sugarcane processing, but many of the associated mechanisms are poorly understood, particularly at the operational scale.

In our greenhouse studies, planted subsurface flumes with volcanic rock substrates removed approximately 80% of the inlet $BOD_5$ and COD loading from molasses process wastewater, approximately 1,200 mg COD/l after about 3 weeks of plant growth. This ultimate removal rate was similar to the steady rate achieved in these same flumes later. The planted flumes outperformed the unplanted flumes by roughly 30% in terms of COD removal. The steady increase in $BOD_5$-to-COD ratio in the effluent of planted versus unplanted flumes suggests that the plant-biofilm system was better able to degrade more-recalcitrant compounds in process wastewater.

In the winery studies, operational conditions resulted in overloading and underloading of the constructed wetlands even though HRTs were designed to be the same. Average organic loadings spanned roughly 5,000 to 75,000 mg COD/l at HRTs of roughly 20 to 6 days, respectively. While total-suspended-solids concentrations at the inlets were similar at both wineries, much greater HRTs at one winery resulted in greater COD removal rates. At both wineries, the planted wetlands outperformed unplanted wetlands, with COD removal of 98% versus 95%, respectively; total-suspended-solids removal of 84% versus 69%, respectively; and better pH stabilization and less total-dissolved-solids in the planted wetlands.

**Plants can play a significant role in treating process wastewater from wineries.**

The slightly greater COD removal rates at the wineries may be associated with the finer substrate material used (pea gravel versus volcanic rock), plus the pea gravel possibly had greater cation exchange, or adsorption capacities, or simply a greater surface area for biofilm development. Our laboratory is investigating this issue. Nonetheless, we expect the performance of the field constructed wetlands to improve as the plant-biofilm system is further developed. Overall, as in the greenhouse studies, the field studies underscored the importance of plants to the treatment performance of constructed wetlands for the variable, high-strength process wastewaters typical of fruit, wine, distillery and sugarcane processing.

**Natural treatment systems are effective in reducing organic-matter levels in wastewater, and even more so when they incorporate plants. At Lemon Winery in Sebastopol, constructed wetlands include a planted bed (center) and an unplanted pond (middle right).**

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*M.E. Grismer is Professor, Departments of Biological and Agricultural Engineering, and Hydrology, UC Davis; and H.L. Shepherd is Independent Wastewater Consultant and Wetlands Specialist, Sebastapol, Calif.* *We thank the Instituto de Ecología, Xalapa, Mexico; the Wallace Group, San Luis Obispo; and the participating wineries and their staffs for supporting this work.*

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RESEARCH ARTICLE

# Rice field drainage affects nitrogen dynamics and management

*by* Bruce A. Linquist, Kaden Koffler, Jim E. Hill *and* Chris van Kessel

***Many California rice growers are now using foliar-active herbicides that require fields to be drained before application. Current regulations limit aerial herbicides and they must be applied by ground, requiring a soil surface dry enough to support application equipment. Our research showed that draining rice fields for a prolonged period early in the season led to a buildup of nitrate in the soil. About 60% of this nitrogen was lost when the field was reflooded, reducing nitrogen-use efficiency and uptake, and lowering grain yields. Nitrate-nitrogen accumulated at a rate of about 1.8 pounds per acre daily, and accumulation began about 4 days after the field was drained. During a typical drain of 10 to 14 days, about 20 pounds of nitrate-nitrogen per acre can be lost. Field experiments showed that incorporating fertilizer nitrogen into the subsurface soil increases nitrogen-use efficiency. Based on this research, we recommend that growers incorporate as much of their preplant nitrogen as possible below the soil surface and limit the drain period as much as possible.***

**Rice growers now drain fields early in the season to apply herbicides by ground, rather than by air. The impacts of this change on nitrogen management in rice are not well understood. *Above*, metal rings were used to evaluate nitrogen dynamics in flooded and nonflooded fields.**

A critical challenge facing California rice growers is managing herbicide-resistant weeds, which can inflict major yield losses and lead to exorbitant herbicide costs. The evolution of herbicide resistance, combined with increased restrictions on how and which herbicides are applied, has limited the effectiveness of traditional weed-control strategies. Consequently, many growers are using foliar-active herbicides, which require that rice fields be drained to expose the weeds before application (foliar-active herbicides must have adequate leaf surface area in order to be absorbed by the plant). Furthermore, regulations limit aerial applications of these foliar-active herbicides to prevent spray drift to sensitive crops.

In the past, herbicides were flown on and into flooded rice fields. Growers now apply a substantial portion of herbicides by ground, which requires that the soil surface be dry enough to support application equipment, increasing the length of time that the field is drained. The drainage period usually begins within 2 weeks of rice planting and can last up to 3 weeks, depending on how the grower plans to apply the herbicide, the soil type and climatic conditions such as wind and temperature.

This change in early-season water management has direct implications for nitrogen fertility management, but current recommendations were developed for continuously flooded rice. The impacts of an early-season drain on nitrogen fertilizer dynamics, particularly the effect on potential nitrogen losses, are not well understood. Of all nutrients applied as fertilizer, nitrogen is required by rice in higher quantities and is most susceptible to losses (Schnier 1995).

Fertilizer nitrogen is applied to rice fields in the form of ammonium ($NH_4$) or urea (which rapidly converts to ammonium). When a rice field is flooded, the fertilizer largely remains as ammonium (Linquist et al. 2006) and is taken up as ammonium by the rice plant.

When the field is drained and the soil becomes aerobic, ammonium is oxidized through microbial processes (known as nitrification) into nitrate ($NO_3$). Nitrate is susceptible to losses in rice systems, and it disappears from the rice rooting zone within a week or two of a soil being flooded (Linquist et al. 2006). The fate of nitrate in flooded soils is difficult to determine. Plants, including rice, can take up nitrate before it is lost by other means. The most likely cause of nitrate loss from California rice systems is denitrification. When the field is reflooded and the soil becomes anaerobic, microbes convert a portion of the nitrate into nitrogen gas (denitrification), which is lost to the atmosphere (Buresh and De Datta 1991). In some rice systems, nitrate leaching can be a significant loss (Yoon et al. 2006; Zhu et al. 2000); in California, however, rice soils are very impermeable, and under such conditions it is likely that soil nitrate denitrifies before it leaches (Bowman et al. 2002).

Finally, nitrate and ammonium can be lost in water runoff from rice fields. These losses are usually small, unless nitrogen fertilizer is applied just before or during a runoff period. Shortly after fertilization, nitrogen levels in rice floodwaters are low. Patrick and Reddy (1976) found that rice floodwater contained only 1.4 pounds nitrogen per acre 6 days after a surface nitrogen application. In another study, only 0.3% of nitrogen fertilizer was lost via leaching and runoff (Zhao et al. 2009).

Although these nitrogen transformational processes are well understood in theory, less is known about how much nitrogen is lost or if nitrogen management practices can be improved to reduce losses. We conducted research from 2006 through 2008 with the objectives of (1) better understanding nitrogen dynamics in drained/reflooded cycles in rice systems, (2) predicting the amount of nitrogen lost and (3) developing improved management strategies to reduce nitrogen losses.

**Some experimental rings were maintained with water, *right*, during the period when the rest of the field was drained.**

## Early-season nitrogen dynamics

On-farm experiments were conducted in 2006 and 2007 in rice fields that were drained early in the season for herbicide applications (table 1). In each year, experiments were conducted in two adjacent fields, one where rice straw was burned following the previous harvest, and the other where rice straw was incorporated and then the field flooded during the winter. In 2006, the fields were located west of Live Oak (Sutter County), and in 2007 they were west of Gridley (Butte County).

Two treatments (drained and undrained) were evaluated in each field, with both treatments replicated three times in a completely randomized block design. The treatments were imposed in the fields by forcing 30-inch-diameter metal rings 8 inches into the soil, with 4 inches remaining above the soil surface. For each treatment and replication, two sets of rings were used. One set of rings was for early-season soil sampling and the other for the final harvest. The rings were forced deeply enough to penetrate the heavy clay layer, creating a seal so that water could be managed effectively within the rings. Both the drained and undrained treatments were tested within rings to eliminate any artificial effect of the rings on soil nitrogen dynamics and plant growth.

The drained treatment was the standard farmers' practice in which the fields were drained 1 to 2 weeks after planting and remained drained for 11 (2006) and 10 (2007) days. At the end of the drain period, herbicides were applied by land by the grower, and then the fields (including rings) were reflooded and remained flooded for the remainder of the growing season. In the undrained treatment, floodwater was maintained inside the ring throughout the growing season, including the time the rest of the field was drained. During the drain period, water was periodically added to each ring to maintain a water depth of 2 to 4 inches. Just before the herbicide application, water in the undrained treatment rings was siphoned off for the herbicide application, and then water was added back into the rings within 4 hours to avoid any experimental artifacts due to a difference in herbicide application or weed control.

In each treatment, the soil and plants were sampled to determine soil nitrogen dynamics, plant nitrogen uptake and crop yield. The soil (0 to 6 inches) was sampled just after the herbicide application (at the end of the drain period, in the drained treatment). The sampled soils were stored in an ice chest or cold room, and within 24 hours of sampling, mineral nitrogen was extracted using 2-molar potassium chloride and analyzed for ammonium (Forster 1995) and nitrate (Doane and Horwath 2003). The bulk density of the soil was determined in order to express the amount of nitrogen on the basis of area. At harvest, the plants within each ring were sampled to determine crop yield. Straw and grain were ground and analyzed for total nitrogen content.

In 2006 and 2007, the rice varieties were M-205 and M-206, respectively, both Calrose types with similar genetic backgrounds. In 2006, nitrogen was applied by the grower with a preplant rate of 105 pounds per acre as aqua-ammonia ($NH_3$) and 28 pounds per acre in a liquid starter blend. The aqua-ammonia was injected 3 to 4 inches below the soil surface, and the starter blend was applied to the soil surface. In addition, 26 pounds nitrogen per acre as ammonium sulfate was aerially applied later in the growing season. In 2007, the researchers imposed the nitrogen treatments instead of the grower. The subsurface nitrogen rate was 100 pounds urea-nitrogen per acre applied in bands 3 to 4 inches below the soil surface, and the surface rate was 40 pounds nitrogen per acre. Phosphorus and potassium were applied to all treatments to ensure

**TABLE 1. Site description, nitrogen (N) rates, rice planting dates and water management for drained and undrained ring studies, 2006 and 2007**

| | 2006 | | 2007 | |
|---|---|---|---|---|
| | Burned | Incorporated | Burned | Incorporated |
| Variety | M-205 | M-205 | M-206 | M-206 |
| Planting date | May 18 | May 18 | May 18 | May 18 |
| Drain initiated | June 4 | June 4 | May 24 | May 24 |
| Drain duration (days) | 11 | 11 | 10 | 10 |
| Subsurface nitrogen (lb N/acre)* | 105 | 105 | 100 | 100 |
| Surface nitrogen (lb N/acre) | 28 | 28 | 40 | 40 |

* In 2006, the grower applied subsurface nitrogen as aqua-ammonia. In 2007, the researchers applied it as urea. In both years, nitrogen fertilizer was applied 3 to 4 inches below the soil surface.

that these nutrients were not limiting. All fields were flooded for planting immediately after the preplant nitrogen applications.

### Fate of nitrate

Linquist et al. (2006) reported that shortly after flooding for planting, most nitrate is lost from the soil plow layer, and most mineral nitrogen is in the form of ammonium. The nitrate present prior to flooding the fields for planting would most likely have been lost via denitrification (Buresh and De Datta 1991). Therefore, before the fields in this study were drained for the herbicide application, the soil mineral nitrogen would have been predominantly ammonium. Total soil mineral nitrogen was highly variable among fields and years, and ranged from approximately 40 to 185 pounds per acre (fig. 1). High variability is expected since most fertilizer nitrogen is banded below the soil surface. When soils are sampled, it is not possible to know if the samples are taken from within a band or between bands. Over time, however, this nitrogen moves laterally through the soil (Obcema et al. 1984), and subsurface nitrogen levels become less variable.

At the end of the drain period, the form of soil mineral nitrogen differed significantly between the drained and undrained treatments. By the end of the 10- or 11-day drain period, there was less than 1 pound nitrate-nitrogen ($NO_3$-N) per acre in the undrained treatment, but a significant amount of nitrate had accumulated in the drained treatment (fig. 1). In 2006, 31 pounds nitrate-nitrogen per acre accumulated in the straw-incorporated field and 25 pounds accumulated in the straw-burned field during the 11-day drain period. In 2007, 4 and 18 pounds nitrate-nitrogen per acre had accumulated in the straw-incorporated and burned fields, respectively. In 2007, we attribute the low nitrate accumulation during the drain period in the incorporated field to less soil drying relative to other treatments (based on soil moisture measurements).

Of primary interest in this study is the fate of nitrate that had accumulated in the drained treatment during the drain period. Was it taken up by the plant or lost? At harvest there were significant differences in crop nitrogen uptake between the two water-management treatments. In 2006 and 2007, total nitrogen uptake in the undrained treatment of both fields was 15 and 12 pounds per acre higher on average than in the drained treatment, respectively (fig. 2). Soil nitrate accumulation averaged 25 pounds per acre in the drained treatment, and plant nitrogen uptake was 14 pounds per acre less than in the undrained treatment. This suggests that approximately 60% of the nitrate was not taken up by the crop but was lost. We surmise that the reduced nitrogen uptake was due to nitrogen losses via denitrification, since losses through leaching and surface runoff are believed to be minimal (Zhao et al. 2009).

In the burned fields in both 2006 and 2007, lower nitrogen uptake in the drained treatment resulted in lower grain yields (on average 680 pounds per acre; $P < 0.07$) relative to the undrained treatment (fig. 2). In the straw-incorporated fields, grain yields were similar between the drained and undrained treatments. Soil nitrogen is higher in soils where straw is incorporated compared to where straw is burned (Linquist et al. 2006; Eagle et al. 2000). Therefore, in the straw-incorporated fields, even though nitrogen uptake was less in the drained treatment in 2006, the crop yields were not compromised.

These studies indicate that prolonged draining of rice fields early in the growing season promotes nitrification. Nitrate that accumulates during this period is then subject to losses, which results in reduced nitrogen uptake and

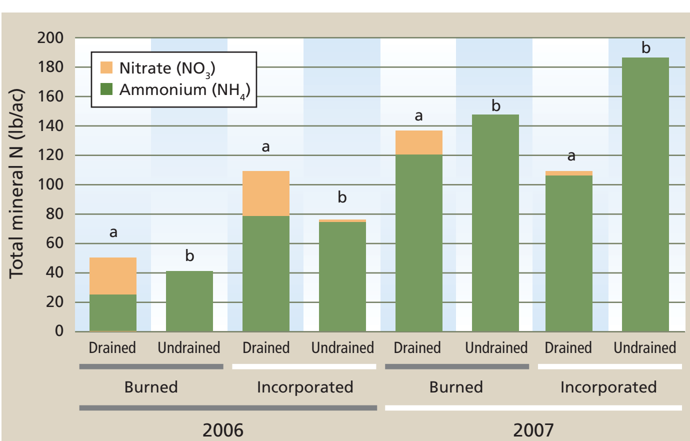


Fig. 1. Nitrate ($NO_3$) and ammonium ($NH_4$) in soils in undrained and drained treatments. Soil samples were taken at the end of the 10- or 11-day drain period from the 0- to 6-inch topsoil layer. Different letters above each pair of bars indicate significantly different nitrate values ($P < 0.05$).

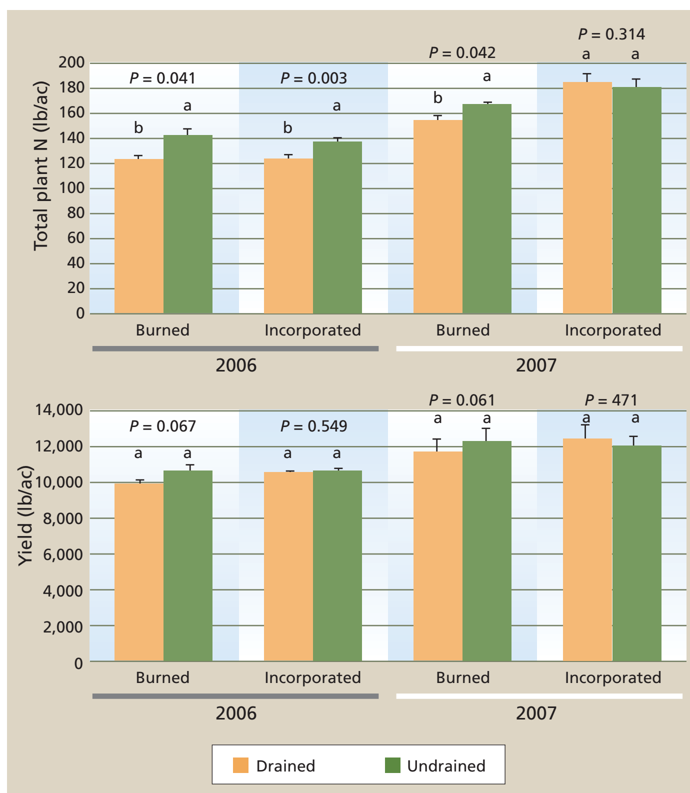


Fig. 2. Total plant nitrogen uptake and rice yields (14% moisture) in 2006 and 2007 from treatment rings that had been drained or undrained earlier in the season. Different letters above a pair of bars indicate significantly different values ($P < 0.05$).

potentially lower yields. Two questions arise: How can we predict the amount of nitrogen that is lost, and how can we manage fertilizer nitrogen to reduce such losses?

### Soil nitrate accumulation

To predict how much nitrogen is potentially lost, we conducted a study across the Sacramento Valley region with the primary objective of quantifying soil nitrate accumulation rates during the drain period. We identified 22 rice fields where an early-season drain for an herbicide application was part of the weed management strategy. Soils were sampled from 0 to 6 inches every 3 or 4 days during the critical flood-drain-reflood phase to monitor changes in soil nitrogen status in all fields. Soil mineral nitrogen was extracted with 2-molar potassium chloride immediately after taking the soil sample, then analyzed for nitrate and ammonium. Bulk density of the soil was determined for each field. For analysis, the drainage period was standardized across fields — the first drain day was when the field had drained to no more than puddling on the soil surface and the soils were saturated with water.

In all fields, nitrate accumulated during the drain period and declined after reflooding (fig. 3), as observed in the ring study. There was a high degree of variation across fields in both the rate and total amount of nitrate accumulated. The high variability among fields may be due to some soils being less prone to drying, different fertilizer rates and management strategies used by growers, and temperature differences. Higher temperatures favor nitrification (Breuer et al. 2002), and it is likely that earlier-planted fields experienced lower daily temperatures than those planted later in the season.

When analyzed across sites, however, we found a significant correlation between the number of days a field had been drained and the amount of nitrate in the field (fig. 4). The linear regression equation indicates that nitrate increased at a rate of 1.8 pounds nitrate-nitrogen per acre per day. This value provides an approximate rule of thumb that growers can use to decide how much nitrogen to apply to make up for what was lost or became unavailable to the crop.

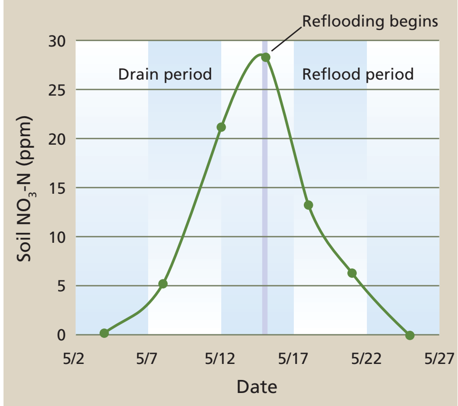


**Fig. 3. Soil nitrate-nitrogen ($NO_3$-N) during an early-season drainage period and subsequent reflooding period for one of 22 fields (Abel Road, Colusa) examined in 2007.**

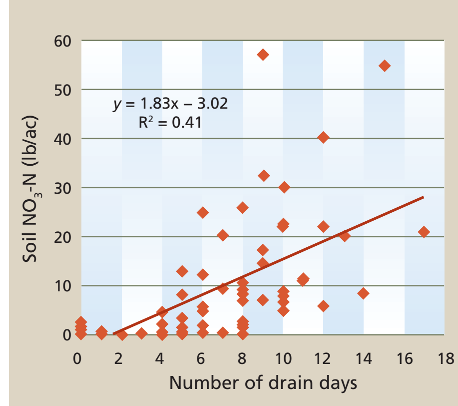


**Fig. 4. Soil nitrate-nitrogen ($NO_3$-N) as a function of the number of days a field is drained. Data is from 22 rice fields sampled every 3 or 4 days during 2007 drainage period.**

Interestingly, and likely because soils remain saturated for a period of time after draining, nitrate did not start to accumulate until the fourth day after the drain. Therefore, draining water for a short period (less than 4 days) of time for herbicide applications or other management practices results in little to no risk of nitrate-nitrogen losses.

### Nitrogen fertilizer management

Our results indicate the large potential for nitrogen losses in rice systems where an early-season drain is part of the weed management practice. Improved nitrogen management practices require changes in the timing or placement of nitrogen fertilizer to achieve acceptable nitrogen-use efficiency. We predict that surface-applied nitrogen is more susceptible to nitrification (and subsequently denitrification) than subsurface-applied nitrogen, since the surface soil remains aerobic for a longer period. If this is indeed the case, growers should apply fertilizer nitrogen below the soil surface (as aqua-ammonia) as much as possible.

To test this hypothesis, two field studies were conducted in 2006 and 2008 near Sheridan (Placer County) and Biggs (Butte County), respectively, on fields drained for an extended period early in the season. In these field trials, three fertilizer-nitrogen treatments were evaluated. With the exception of a no-nitrogen fertilizer control, similar amounts of nitrogen were applied in the treatments within each site (185 to 189 pounds per acre in Sheridan and 120 pounds per acre in Biggs), but the fertilizer treatments differed in timing and placement.

The treatments were (1) no nitrogen, (2) all preplant nitrogen fertilizer applied as aqua-ammonia to a depth of 3 to 4 inches (all subsurface) and (3) the conventional practice, where a portion of the preplant nitrogen was applied as aqua-ammonia and the remainder to the surface (subsurface plus surface) (table 2). At the Sheridan site, the grower also applied 42 pounds nitrogen per acre to the subsurface and subsurface plus surface treatments just after reflooding. The no-nitrogen treatment soil was covered with a tarp and did not receive nitrogen fertilizer. Treatments were replicated three times. The subsurface nitrogen was applied by the grower as aqua-ammonia to a depth of 3 to 4 inches using commercial equipment. All surface nitrogen was applied as urea by hand. The drain period in each field began 23 and 5 days after planting, and fields were reflooded 15 and 11 days later at Sheridan and Biggs, respectively. At harvest the plots were sampled for total aboveground biomass and yield. Grain and straw samples were analyzed for nitrogen to determine uptake in each treatment.

In both locations, when no nitrogen was applied, yields ranged from 3,500 to 3,700 pounds per acre, and there was a significant response to applied nitrogen (table 2). At both sites the highest yield and nitrogen uptake were in the treatment where all of the nitrogen fertilizer was applied preplant as

**A rice grower applies herbicide to a dried-down field. Drained fields must be dry enough to support application equipment with large tires, which can take 2 to 3 weeks.**

aqua-ammonia. Averaged across both sites, the all-subsurface treatment had higher fertilizer nitrogen-use efficiency, 59%, compared to 49% in the subsurface plus surface treatment. These results support our hypothesis that surface-applied fertilizer nitrogen is more susceptible to losses than nitrogen that is placed below the soil surface.

Consequently, our recommendation is to apply as much total nitrogen as possible as aqua-ammonia injected 3 or 4 inches below the soil surface. This is the same recommendation made by Linquist et al. (2009) for conventionally managed fields with no early-season drain. Their 3-year study on 12 California rice fields, varying in straw and water management, found that incorporating all nitrogen fertilizer below the soil surface resulted in improved yields and nitrogen-use efficiency, regardless of water management practices. Surface-applied nitrogen was used less efficiently, even when rice fields were continuously flooded. Others have reported similar findings (Mikkelsen and Finfrock 1957; Broadbent and Mikkelsen 1968; Obcema et al. 1984).

## Maximizing efficiency and yield

Draining rice fields for a prolonged period early in the season led to a buildup of nitrate in the soil. About 60% of this nitrate-nitrogen was subsequently lost when the field was reflooded, reducing nitrogen-use efficiency and uptake, and reducing grain yields. Nitrate accumulation begins about 4 days after the field has been drained and accumulates at a rate of about 1.8 pounds per acre daily. During a typical drain of about 10 to 14 days, this translates into an accumulation of roughly 20 pounds nitrate-nitrogen per acre. Field experiments supported the idea that incorporating fertilizer nitrogen into the soil (as growers routinely do for continuously flooded rice) increases nitrogen-use efficiency. Based on this research, we recommend that growers incorporate as much of their preplant nitrogen as possible below the soil surface, as aqua-ammonia. Furthermore, growers should limit the duration of the drain period as much as possible, since subsurface-applied nitrogen fertilizer remains susceptible to nitrogen losses when soils dry and become aerobic.

*B.A. Linquist is Professional Researcher, K. Koffler is Graduate Student, and J.E. Hill is Cooperative Extension Specialist and Associate Dean for International Programs, College of Agricultural and Environmental Sciences, UC Davis; and C. van Kessel is Professor and Chair, Department of Plant Sciences, UC Davis.* *The authors thank the many collaborating rice growers and the California Rice Research Board for funding this research.*

**TABLE 2. Fertilizer nitrogen (N) rate and timing treatments, and their effects on rice yield (14% moisture) and total nitrogen uptake in two field experiments, 2006 and 2008**

| Treatment designation | Preplant subsurface* | Preplant surface | Postdrain topdress | Total applied | Grain yield | Total uptake |
|---|---|---|---|---|---|---|
| | . . . . . . . . . . *lb N/acre* | . . . . . . . . . . | | | *lb/acre* | *lb N/acre* |
| **2006 (Sheridan)** | | | | | | |
| No nitrogen | 0 | 0 | 0 | 0 | 3,544b† | 53c‡ |
| Subsurface + surface | 113 | 34 | 42 | 189 | 10,325a | 149b |
| All subsurface | 143 | 0 | 42 | 185 | 10,653a | 163a |
| **2008 (Biggs)** | | | | | | |
| No nitrogen | 0 | 0 | 0 | 0 | 3,715b | 55c |
| Subsurface + surface | 80 | 40 | 0 | 120 | 9,801a | 109b |
| All subsurface | 120 | 0 | 0 | 120 | 10,904a | 125a |

* Preplant subsurface nitrogen applied by grower as aqua-ammonia.
† Yields followed by the same letter within the same site-year indicate no difference between treatments ($P < 0.05$).
‡ Total nitrogen uptake values followed by the same letter within the same site-year indicate no difference between treatments; $P < 0.05$ for 2006 (Sheridan) and $P < 0.06$ for 2008 (Biggs).

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# "Smart" sprayer technology provides environmental and economic benefits in California orchards

*by* Durham K. Giles, Parry Klassen, Franz J.A. Niederholzer *and* Daniel Downey

**A commercial sprayer retrofitted with a target-sensing spray system applies dormant spray in a prune orchard near Chico. These "smart" systems only apply sprays where a tree is detected.**

***Spray applications of pesticides to orchards are a common cultural practice; however, they present environmental concerns due to emissions of volatile organic compounds (VOCs), runoff that can allow pesticides to enter waterways, and spray drift onto nontarget areas. Advanced sprayer technology can address these concerns and improve application efficiency by reducing the amount of spray that does not reach the target. Target-sensing sprayers were evaluated in multiseason experiments. They reduced pesticide application rates by 15% to 40% and nontarget orchard-floor deposition by 5% to 72%, providing significant environmental and economic benefits.***

In California, orchard crops receive dormant and in-season applications of agrochemicals, including organophosphates and pyrethroids to control insect pests and fungicides to control diseases. For dormant applications, the winter rainfall, particularly storms, increases the potential for pesticides to reach rivers and tributaries (Kuivila and Foe 1995). Brady et al. (2006) reported the off-site movement and detection of two pesticides (diazinon and esfenvalerate) in California rivers. Werner et al. (2004) reported toxicity to several aquatic species when exposed to storm-water runoff collected in orchards following dormant-season applications of diazinon or esfenvalerate. These findings, coupled with concerns about the toxicity of organophosphate insecticides, have led to increased regulatory restrictions on their application in orchards.

Concurrently, concern over air pollution is increasing. The U.S. Environmental Protection Agency (EPA) classifies portions of the Central Valley as extreme nonattainment areas for the 8-hour ozone standard. The California Air Resources Board lists 21 counties, or portions of counties, as nonattainment areas (CARB 2010). Ozone is formed through the interaction of nitrogen oxides and volatile organic compounds (VOC). The California Department of Pesticide Regulation targeted a 20% reduction in VOC emissions from pesticide usage by 2010 (USDA 2009). The pesticides most commonly applied in dormant orchard spray applications are typically formulated as emulsifiable concentrations, often tank-mixed with dormant oils, which are identified as contributors to VOC emissions.

To reduce both air and water contamination resulting from orchard applications of pesticides while maintaining their pest control benefits, we examined candidate technologies that could meet the environmental goals yet remain attractive to growers. Often, improved technology to reduce emissions provides no direct economic benefit to the user or grower; however, with advanced agricultural spraying equipment, reducing pesticide use rates can provide potential economic benefits, primarily from pesticide savings but also from improved efficiency.

## Efficiency of orchard spraying

Previous studies have investigated orchard spraying and found significant opportunities for improving the process. Much of the released pesticide does not reach the target trees. Seiber et al. (1993) measured deposition from dormant spraying of diazinon in a peach orchard and found that 88% of recovered pesticide was on the orchard floor instead of the trees. Cross et al. (2001a, b) investigated the effects of spray droplet size and application volumes of 10 to 80 gallons per acre (94 to 748 liters per hectare) on spray deposition in an apple orchard; 43% to 61% of the applied spray was lost to ground deposit within 15 feet (4.6 meters) of the row being sprayed. The study also concluded that for most typical orchard applications, the liquid volume rate (gallons per acre) is so large that differences in spray droplet size have little effect on spray deposition, since the trees are essentially saturated with liquid and any additional spray volume simply runs off the tree foliage. Similarly, once the application rates are above the saturation level, the actual amount of applied volume has little effect on spray deposition. These findings suggest that simple changes in spray nozzle selection and setup may assist in reducing off-target movement but may not achieve significant improvements in application efficiency and pesticide use rates.

A study of semidwarf apples and pears measured spray deposits at an application rate of 50 gallons per acre (468 liters per hectare) (Vercruysse et al. 1999). Before bloom, approximately 44% of the applied spray was measured as spray drift or ground deposit.

**The basic concept of the sprayer operation is to apply the spray only to the target trees, allowing the sprayer to turn off between trees or in areas where trees are missing.**

After bloom, 32% of the spray failed to deposit on the crop. The authors concluded that during early growth stages, ground deposit was considerable and the presence of foliage on trees reduced airborne drift by 50% to 80%. A study in vineyards concluded that 37% to 62% of applied spray failed to deposit on target leaves (Pergher et al. 1997). An Ohio study determined that 57% of the spray applied to dwarf apples was deposited on the ground within 150 yards (137 meters) of the orchard (Fox et al. 1990).

In an almond orchard near Modesto, a target-sensing sprayer travels between rows.


To monitor the tree and ground deposition of spray applications, (A) 1-inch-diameter cylinders fitted with fiber filters were suspended from almond trees at different heights and (B) 4.25-inch glass filters supported by flat ceramic tiles were laid on the orchard floor.

### Sensor-equipped orchard sprayers

Sensor-equipped orchard sprayers, sometimes called “smart” sprayers, use multiple ultrasonic or optical detectors to sense the presence or absence of trees, and they activate the spray nozzles only when a target is present in the spray zone corresponding to each sensor. While still considered a new technology, the technique was developed more than 20 years ago (Giles et al. 1987) and has been on the market for over a decade. The initial patents on the ultrasonic systems have expired, allowing commercial competition among designs, prices and vendors and providing more options for growers.

The basic concept of the sprayer operation is to apply the spray only to the target trees, allowing the sprayer to turn off between trees or in areas where trees are missing, and to turn off portions of the sprayer where trees are short or foliage is sparse. Giles et al. (1987) found an average savings of 28% to 34% and 36% to 52% for applications to in-season peaches and apples, respectively, using the system. The study found that spray-volume savings were dependent on crop characteristics; when used in younger, smaller trees or in mature orchards with high proportions of replanted (young) trees, the savings increased correspondingly.

In principle, these sprayers maintain spray deposition equivalent to conventional sprayers on the target trees, while reducing wasted spray that would deposit on nontarget orchard floors and contribute unnecessarily to both VOC emissions and, potentially, runoff and water contamination. Moreover, reductions in applied pesticide provide economic returns to growers, helping to defray the capital investment in the sprayer.

### Testing smart sprayers

The objective of these studies was to determine how the use of smart sprayers provides benefits for reducing pesticide use and nontarget deposition. Particular emphasis was on reducing ground deposit and runoff during dormant-season spraying. Additionally, the economic return was projected for grower investments in the technology. The ultimate goal of the research was to reduce the amount of pesticide used, as well as the off-target movement of orchard-applied pesticides.

Three field studies were conducted in commercial orchards using commercial equipment, and with applications made by growers. Studies were conducted over three seasons, using registered insecticides applied during the dormant seasons. All applications were part of the cooperating growers' integrated pest management (IPM) and spray programs. Two studies addressed the reduction in application rate and ground deposit (Downey and Giles 2005), and the final study addressed the reduction of pesticide runoff from an orchard (Brown et al. 2008). All three studies compared the effects from conventional and sensor-equipped sprayers.

**The smart sprayer skips the spot where a new almond tree is planted, significantly reducing the amount of spray deposited on the ground. If necessary, growers can use the smart sprayer's manual override to treat small plantings, or they can be treated by hand.**

**Chico prunes.** The first experiment was conducted in a commercial prune orchard near Chico with trees approximately 20 years old. The spray application of diazinon was made with an engine-driven, axial flow sprayer (Model D2/40, Air-O-Fan, Reedley, Calif.), with an application rate of 2 pounds per acre (2.24 kilograms per hectare). Trees were approximately 12 feet (3.7 meters) high and planted at 160 trees per acre (395 trees per hectare) with row spacing of 15 feet (4.6 meters). The conventional spray application rate was 100 gallons per acre (935 liters per hectare) at a ground speed of 2 miles (3.2 kilometers) per hour. An ultrasonic control system (Smart Spray, Durand-Wayland, LaGrange, Ga.) was retrofitted to the machine.

Deposition samples were collected on glass fiber filters placed on flat plates within the target trees and on the ground between and within tree rows. For each treatment, four trees were sampled with four sample points per tree. Six ground samples were taken for each sprayer treatment. The area for each treatment was five rows wide by 0.25 mile (0.4 kilometer) long, equal to approximately 2.25 acres (0.9 hectare). After spraying, the filter samples were recovered from the trees and ground, preserved in airtight bags, placed on ice and transported to the California Department of Food and Agriculture (CDFA) lab for chemical analysis.

**Modesto almonds.** The second experiment was conducted in a mature commercial almond orchard near Modesto, where the majority of trees were approximately 20 years old and planted on a 23-foot (7-meter) diamond pattern. Each treatment (sensor-equipped versus conventional spraying) was applied to approximately 5.5 acres (2.2 hectares). The conventional application was a dormant spray of copper, oil and chlorpyrifos at the standard rate of 2 pounds active ingredient per acre (2.24 kilograms per hectare) and 100 gallons per acre (935 liters per hectare). The application was made using an AF500 Smart Sprayer (Durand-Wayland, LaGrange, Ga.) at 2.75 miles (4.4 kilometers) per hour.

Deposition samples were collected on glass fiber filters placed on cylindrical tubes within the target trees (four trees sampled) and on ceramic tiles positioned on the ground between and within tree rows, totaling eight ground samples per treatment. After spraying, the filter samples were recovered from the trees and ground, preserved in airtight bags, placed on ice and transported to the CDFA lab for chemical analysis.

**Oroville prunes.** The third field experiment was conducted in a 20-year-old mature prune orchard near Oroville where diazinon had historically been applied during the dormant season. The test orchard was approximately 40 acres (16 hectares), and the trees were planted on elevated berms. Tree spacing was 18 feet (5.5 meters) within the row, row spacing was 18 feet (5.5 meters), row length was 450 feet (137 meters) and density was 130 trees per acre (321 trees per hectare). The orchard was land-planed for surface irrigation.

The sprayer used was a power-take-off-driven (PTO), axial-flow fan orchard sprayer (AF505CPS, Durand-Wayland, Lagrange, Ga.). The ground speed for all applications was 3 miles (4.8 kilometers) per hour. The application rate of diazinon was 2 pounds per acre (2.24 kilograms per hectare) applied as an emulsifiable concentration. The conventional application rate of tank mix was 100 gallons per acre (935 liters per hectare). Each spray treatment was replicated six times, and 12 independent plots were randomly established within the orchard for the entire study. Each treatment plot consisted of seven row middles (corresponding to eight tree rows) running the length of the orchard.

After the spray application, simulated rainfall was applied to the sample rows, resulting in surface-water runoff. Rainfall was simulated using impact sprinklers set on risers above the orchard floor. A simulated rainfall rate was applied at approximately 0.25 inch (0.64 centimeter) per hour. This rate was used during the surface-water runoff trials; simulated rainfall occurred for 2 hours and 40 minutes after each spray application. Approximately 0.7 inch (1.8 centimeters) of rainfall was applied for each treatment. The rainfall event for the study was initiated 24 hours after the spray applications were completed. Runoff water samples were collected using apparatus and methods described by Brady et al. (2006). The automated system measured the volume of runoff and sequentially removed water samples for analysis (Brown et al. 2008).

**TABLE 1. Saving comparisons for conventional versus smart-spray applications**

| Orchard | Application: Conventional | Smart spray* |
|---|---|---|
| | *gallons/acre (liters/hectare)* | |
| Prunes (Chico) | 100 (935) | 85 (794) |
| Almonds (Modesto) | 100 (935) | 78 (729) |
| Prunes (Oroville) | 100 (935) | 60 (561) |

* Application rates determined from on-board electronic system of sprayer.

**TABLE 2. Average ground pesticide deposition for conventional versus smart-spray dormant applications**

| Orchard | Application: Conventional | Smart spray |
|---|---|---|
| | *micrograms/cm²* | |
| Prunes (Chico) | 5.2 | 4.9 |
| Almonds (Modesto) | 11.3a* | 3.2b |
| Prunes (Oroville) | 24.2a | 9.9a |

* Different letters indicate significantly different means ($P < 0.01$) within the same spray test.

## Less pesticide applied

In every field experiment, use of the sensor-equipped sprayer (with control system) resulted in spray savings, meaning that less pesticide was applied (table 1). The mature prune orchard near Chico had the least spray savings (15%). Its relatively dense and uniform trees — which presented a wall of foliage with smaller gaps between trees — reduced potential savings that the smart sprayer could achieve. Savings from smart sprayers are generally proportional to openings and gaps in the tree rows (Giles et al. 1987). In the mature almonds near Modesto — which had large trees with larger gaps, especially between the lower portions — there was a 22% reduction in applied spray. Finally, the mature prunes near Oroville, with a less-dense planting and wider gaps between trees, resulted in a 40% reduction.

These results reinforce previous research showing that savings from sensor-triggered spraying are related to orchard characteristics. Additionally, the smart-sprayer systems allow the operator to adjust the sensitivity and overspray settings; different applicators may use different settings, resulting in more or less savings. Applicators tend to be conservative, setting the control's sensitivity to overspray in order to prevent underspraying portions of trees.

Deposition on the trees was maintained at levels equivalent to or even greater than conventional spraying (data not shown). In the more-dense prune orchard, the target-sensed sprayer reduced ground deposit by 5% versus the conventional sprayer (table 2). This result indicates that the dense spacing of prune trees in this Chico orchard captured the majority of spray onto trees irrespective of application type. For the almond and more-open prune orchards, the reductions were 72% and 59%, respectively. The decreased ground deposition in these two orchards shows that increased tree spacing along rows minimizes ground deposition when smart-spray technology is used. When concentrations of pesticide were measured in the runoff water of the open prune orchard near Oroville (table 3), the reduction from sensor-controlled spraying was 54%, similar to the reduction in ground deposit.

**TABLE 3. Average recovery of diazinon from surface-water runoff (simulated rainfall) after conventional and smart-spray applications in Oroville prune orchard**

| Application | Concentration | Runoff volume | Diazinon |
|---|---|---|---|
| | *micrograms/liter* | *gallons (liters)* | *milligrams* |
| Conventional | 505a* | 976 (3,694) | 1,889a |
| Smart spray | 282b | 854 (3,232) | 911b |

* Different letters indicate significantly different means ($P < 0.01$).

## Reducing costs

Spray application technology reduces the amount of pesticide applied while maintaining the necessary levels of deposition on trees, providing direct economic benefits to growers while at the same time providing significant environmental benefits. Improved equipment productivity is an added benefit. By reducing the application rate of the pesticide mix, each tank load of material covers a greater land area, effectively reducing the number of refills, ferry trips and time spent spraying each orchard. This provides an additional economic return to the grower by reducing labor and fuel costs.

While the sensor technology provides environmental and pesticide savings benefits to the grower, the decision to invest in a new technology is often taken cautiously and is based on projections of economic return. The economic returns to the grower would come from two sources: first, the reduction in pesticide use, and second, improved equipment productivity.

The reduction in pesticide costs can be substantial. UC Cooperative Extension publications on the costs to establish and produce orchard crops were used to estimate pesticide costs per acre in common California orchard crops (Freeman et al. 2008). For Sacramento Valley almonds, pest control sprays (material only for diseases and insects) were estimated at $233 per acre ($575 per hectare). Similarly, the cost for San Joaquin almonds was estimated at $203 per acre ($500 per hectare); for Sacramento Valley prunes, $149 per acre ($368 per hectare); and for San Joaquin peaches, $283 per acre ($700 per hectare). These estimates are for material only and do not include variable application costs including labor and fuel, which we estimated at $9.50 to $10.00 per acre ($23.50 to $24.70 per hectare) for almonds and similar crops based on $2 per gallon ($0.53 per liter) for diesel fuel.

Based on the results of the field tests, we assumed materials savings of 20% and operating-cost savings of 10%. This resulted in a $1 per acre ($2.47 per hectare) operating-cost savings and material cost savings of $57, $47, $41 and $30 per acre ($141, $116, $101 and $74 per hectare) for San Joaquin peaches, Sacramento Valley almonds, San Joaquin almonds and Sacramento Valley prunes, respectively.

The current cost of a retrofit spray sensor and control system is approximately $15,000 (Niederholzer 2009). A rule of thumb in the agricultural electronics industry is that a new product has a reasonable chance of adoption and sales success if the payback period is 2 years or less. With the estimated purchase price and estimated economic savings, a 2-year payback would be achieved for prune, almond and peach growers spraying 250, 160 and 130 acres (101, 65 and 53 hectares) per year. For growers with larger areas, the payback period would be proportionally less.

**In a mature prune orchard near Oroville, the smart sprayer reduced application rates by 40 gallons per acre (40%) when compared with the conventional sprayer, and pesticides in the runoff water were 54% lower.**

### Investing in new technology

Use of the smart-spray technology is growing in the industry but remains a small part of the spraying equipment market. A further incentive for growers to invest in the technology is the U.S. Department of Agriculture's Environmental Quality Incentives Program (EQIP), authorized by federal law in 2002 (and reauthorized in the 2008 Farm Bill), which provides a voluntary conservation program for farmers and ranchers to promote agricultural production and environmental quality as compatible national goals. EQIP offers financial and technical assistance to eligible participants to install or implement structural and management practices on eligible agricultural land.

In particular, the California program includes an Air Quality Enhancement Program that is "designed to provide cost share incentives and technical assistance to farmers and ranchers for installation of practices which reduce air pollution" (USDA 2011). The program targets statewide "airsheds" where levels of ozone, VOC or fine particulate matter have been classified as serious, severe or extreme nonattainment areas as defined by the U.S. EPA. The EQIP program provides financial and technical assistance to address nitrous oxide, VOC and particulate matter emissions. For example, it states: "The application of pesticides through sprayers produces VOC emissions. Growers can reduce these targeted VOC emissions by adopting new precision spray application technologies."

The program guidelines further state: "Precision spray technology used must provide at least a 20% reduction in spray, based on peer-reviewed research documentation" (USDA 2011). In 2011, the financial incentive for these precision spray technologies is $30 per acre ($74 per hectare) for a maximum of 500 acres (202 hectares) — a total of $15,000 per contract. The amount is sufficient to adequately cover the cost of purchasing a typical target-sensing system for an orchard sprayer.

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*D.K. Giles is Professor, Department of Biological and Agricultural Engineering, UC Davis; P. Klassen is Executive Director, Coalition for Urban/Rural Environmental Stewardship, Dinuba, Calif.; F.J.A. Niederholzer is Orchard Systems Farm Advisor, UC Cooperative Extension, Sutter and Yuba counties; and D. Downey is Associate Project Engineer, Department of Biological and Agricultural Engineering, UC Davis.*

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RESEARCH ARTICLE

# Regulated deficit irrigation reduces water use of almonds without affecting yield

*by* William L. Stewart, Allan E. Fulton, William H. Krueger, Bruce D. Lampinen *and* Ken A. Shackel

***A plant-based regulated deficit irrigation (RDI) experiment in the northern Sacramento Valley determined that crop consumptive water use and irrigation could be reduced without significant detrimental effects on almond production. Tree stress was measured by recording midday stem water potential, a direct measure of tree water stress. With a water stress level of −14 to −18 bars during the hull-split period, average annual water savings were about 5 inches. Over 5 years, no significant yield reductions were observed, although average kernel weight was slightly lower. The results suggest that water savings can be achieved without affecting yield, even in soils with low water-holding capacity.***

**Microsprinklers are used in most almond orchards, allowing very precise measurements of how much water is being used by the trees. *Above*, Allan Fulton augured holes to install neutron-probe access tubes for monitoring stored soil moisture.**

Almonds are California's top agricultural export — 80% of those consumed worldwide are grown here. As water resources become increasingly scarce due to population growth, environmental needs and periodic drought, it will become more difficult both monetarily and politically to obtain sufficient water for crop irrigation. Drought tolerance in almonds has been documented in previous studies, but substantial irrigation is still required to maintain current production levels. Over the last 14 years there has been a steady increase in both bearing acres and yields — about 70 pounds per acre in almond yield improvement annually (USDA 2010), indicating a steady improvement in cultural practices, among them, irrigation.

There is a pressing need to reliably maintain current almond production with less water. Surface-water allotments for irrigation during drought are often significantly reduced because precedence is given to other uses (Fereres and Soriano 2006). Water reserves in California were low following the droughts of 2007, 2008 and 2009. In fact, spring 2008 was the driest on record (DWR 2009).

The current basis for estimating the irrigation need of a crop is to combine the water lost from the soil (evaporation) with the water lost through leaves (transpiration), into an overall loss, the crop evapotranspiration ($ET_c$). $ET_c$ is calculated by multiplying a weather-based reference crop ET (in California, mowed, irrigated grass pasture or tall turfgrass species, "$ET_o$," are used), by a crop coefficient (Kc), to give the final estimate ($ET_c = Kc \times ET_o$).

Research in the late 1980s and 1990s estimated the average seasonal $ET_c$ for almonds at 40 to 42 inches (102 to 107 centimeters), with estimated seasonal irrigation requirements of 36 to 38 inches (91 to 97 centimeters) under typical soil and rainfall conditions of the southern San Joaquin Valley (Goldhamer and Smith 1995). But later field research suggested that almond $ET_c$ may average from 48 to 54 inches (122 to 137 centimeters) (Sanden 2007). Reasons for the higher recent estimates probably reflect the many changes that have occurred in almond culture over the past two decades.

Almond orchards are now intensively managed with pressurized (e.g., microsprinkler) rather than surface (e.g., flood) irrigation systems, and crop water status can also be monitored directly using midday stem water potential (SWP). SWP is measured directly on leaves sampled in the orchard using a pressure chamber, and it indicates the level of physiological water stress that is being experienced by the trees at the time of sampling, much as blood pressure or temperature can be a measure of any physiological stress in humans

(Shackel et al. 1997). Furthermore, nitrogen fertility management is more intensive than it was when the earlier research was conducted, and pruning practices have changed to manage canopy light differently, both producing more foliage and potentially higher $ET_c$. In fact, a higher $ET_c$ rate and higher yields may both be responses to more-intensive almond management.

The $ET_c$ method of irrigation scheduling aims to maintain the crop in a nonstressed condition by supplying enough water to satisfy $ET_c$. Alternative methods have been proposed that attempt to reduce unnecessary vegetative growth in orchard and vine crops in order to make water use more efficient; they include deficit irrigation, partial root-zone drying and regulated deficit irrigation (RDI) (Costa et al. 2007).

The objective of regulated deficit irrigation is typically to irrigate so that trees experience mild-to-moderate levels of water stress, in order to achieve an optimal horticultural balance between vegetative growth, which is very sensitive to stress, and fruit production, which is less sensitive (Chalmers et al. 1986). Previous studies in almonds and other crops have shown the beneficial effects of regulated deficit irrigation, including control of excessive vegetative growth, reduced hull rot and improved hull split in almonds (Goldhamer et al. 2006; Teviotdale et al. 2001; Shackel et al. 2003), increased fruit density in prunes and pears (Lampinen et al. 1995; Marsal et al. 2002) and reduced vegetative growth in peaches (Chalmers et al. 1986).

Previous studies of regulated deficit irrigation have created stress by applying a fraction of $ET_c$, but for this 5-year study we used a plant-based indicator of stress (SWP) and set a target level of mild-to-moderate stress during the hull-split period. We undertook this study to determine whether meaningful reductions in consumptive water use (i.e., the total of irrigation and soil moisture used by the orchard in a season) could be achieved with minimal impacts on orchard productivity.

### Testing deficit irrigation

Our study took place in a microsprinkler-irrigated, 270-acre (109-hectare) almond orchard near Orland in the northern Sacramento Valley, which was planted with 'Nonpareil' and 'Carmel' trees spaced at 12 feet by 24 feet (3.7 meters by 7.3 meters). The orchard was divided into five approximately equal blocks; two were planted in 1993 and three in 1999. From the first year of the experiment (2004), the canopy shaded area in midsummer (mid-June) at noon was greater than 50% in all blocks, so all blocks were considered to exhibit fully developed (mature) crop water requirements (DWR 1986). The five blocks were each subdivided into two sections to match the existing irrigation system design, with control and regulated deficit irrigation treatments assigned to the sections on alternating sides.

Two rows of 'Nonpareil' almond trees in the center of each section were designated as the experimental plots, with two trees from each block used as the monitoring trees for SWP measurements. The rows averaged approximately 69 trees per block, and monitoring trees were positioned approximately one-third and two-thirds of the way into each row (at approximate tree positions 23 and 46).

SWP values were initially taken on weekly field visits using a pressure chamber, and were collected biweekly during the hull-split period. Leaves, still on the tree, were covered with an aluminized Mylar bag for a minimum of 10 minutes prior to measurements (Fulton et al. 2001). Meters were installed on a single lateral line in each irrigation section to measure water applications.

In 2004 and 2005, block-specific recommendations for regulated deficit irrigation were communicated to the grower, who was responsible for day-to-day irrigation management. In 2005, the orchard exhibited defoliation due to Alternaria leaf spot, and the grower was reluctant to withhold water from the large regulated deficit irrigation plots.

In 2006, a separate irrigation system that could be monitored and controlled via a satellite-linked Internet service (Automata, www.automata-inc.com) was installed for the experimental 'Nonpareil' row and the two adjacent

**Grids of neutron-probe access tubes allowed the researchers to take soil moisture readings at different depths. They found a shallow water table that receded throughout the growing season, especially during two drought years.**

pollenizer rows in each regulated deficit irrigation block. The system included flow meters to monitor irrigation and a weather station to measure rainfall, air temperature, humidity and other parameters. Picovale Services (www.picovale.com) developed and supported a program to remotely control the on and off times for each block independently via the Internet. Reference $ET_c$ ($ET_o$) from a nearby CIMIS (California Irrigation Management Information System) station (#61 at Orland; discontinued in 2010) was used to estimate crop water demand and was combined with published crop coefficients for mature almonds (DWR 1986) and adjusted for the full-bloom dates (Mar. 5, 2004; Feb. 20, 2005; Mar. 1, 2006; Feb. 21, 2007; and Feb. 29, 2008).

### Utilizing stem water potential

Midday SWP and water meter data were collected weekly from early April until the hull-split period. Visual surveys were made weekly starting in mid-June to anticipate the beginning of hull split. Irrigation was reduced once the onset of hull split was observed in blank nuts, generally about a week before the onset of hull split in normal (filled) nuts. Before and following the hull-split period, the water amounts applied to the regulated deficit irrigation and grower control (full irrigation) treatments were equivalent. During the hull-split period, SWP was measured twice weekly and irrigation was adjusted to achieve a target mild-to-moderate stress level of –14 to –18 bars (–1.4 to –1.8 megapascals [MPa]) in each block.

By the last year of the study (2008), block-specific irrigation was not necessary because the target SWP could be achieved using about the same level of deficit irrigation in all the treatment blocks. The target levels of midday SWP employed in this field trial were set to achieve mild-to-moderate water stress during the regulated deficit irrigation period. For almonds, Shackel (2007) reported about a 50% reduction in midsummer stomatal conductance with SWP values of –14 to –18 bars (–1.4 to –1.8 MPa) compared with a nonstressed (no soil water limitation) SWP above –10 bars (–1.0 MPa) (Shackel 2007; Shackel et al. 1997). Irrigation was returned to normal once visual surveys indicated 90% hull split in each block.

The grower commercially harvested entire rows, and a weighing trailer was used to determine gross harvest weight in the field. We collected a 4-pound (1.8-kilogram) subsample from each of the blocks and used them to convert harvest weights into nutmeat yields.


**William Stewart checked the evapotranspiration gauge on the almond orchard's weather station. These measurements are used to calculate the amount of water lost by the crop.**

In this field trial, regulated deficit irrigation was limited to the hull-split phase of almond growth and development. $ET_c$ is typically highest during midsummer, so the opportunity is greatest at this time to impose crop stress in order to achieve significant irrigation reductions. In addition, Teviotdale et al. (2001) reported that both hull split and nut harvestability are improved and hull rot is reduced when regulated deficit irrigation is imposed during the hull-split period. Other stages of almond growth and development have shown greater susceptibility to negative impacts on tree growth and nut production (Goldhamer et al. 2006). Crop stress is also difficult to impose from leaf-out through mid-May due to rainfall, lower $ET_c$ rates and generally sufficient soil moisture.

### Measuring soil parameters

**Soil moisture.** We installed neutron-probe access tubes to measure the change in stored soil moisture from early spring to late summer, in order to quantify the contribution of soil water to the crop's water needs (in addition to applied irrigation water). We installed two grids of 16 tubes (schedule 40 PVC) in a single block, each in the southwest quadrant of a single monitoring tree for both the regulated deficit irrigation and control treatments. The tubes were arranged in 4-by-4 grids with overall dimensions of 6 feet by 12 feet (1.9 meters by 3.7 meters). The grid spacing was measured from the center of the tube, with 2-foot (0.6-meter) spacing in the north-south direction and 4-foot (1.2-meters) spacing in the east-west direction.

We tried to install the tubes to an overall depth of 60 inches (152 centimeters) and measure volumetric soil water content at 1-foot intervals, at depths of 8, 18, 30, 42 and 54 inches (20, 46, 76, 107 and 137 centimeters). However, due to the widespread variability in soils — including areas with significant gravel content, soil stratification and a shallow, temporarily perched water table (particularly in March and April) — we achieved a depth of 54 inches (137 centimeters) for only 22 of the 32 tubes. The remaining tubes were installed to a depth of 42 inches (107 centimeters). Soil moisture readings were taken two or three times per season, typically around full bloom, in late summer and postharvest.

The shallow water table receded during the course of each growing season, especially during the drought years of 2007 and 2008; it did not appear to influence orchard water status significantly during our study. If capillary flow of water from the shallow water table had contributed significantly to crop consumptive use, midday SWP would not have responded to the withholding of irrigation water during hull split. In addition, the gravel content and hardpan appeared to be barriers to deeper root development, so the roots may not have reached the soil water.

**Soil type.** Soil types were variable throughout the orchard, but the majority of acreage consisted of three types: (1) Cortina very gravelly sandy loam, (2) Hillgate loam and (3) Redding gravelly loam (USDA 2009). These soils are described by a USDA land capability rating of 3 or 4, which generally groups soil types based on restrictions for field crops. The Redding soil typically has a restrictive layer at 20 to 40 inches (51 to 102 centimeters), and the other soils extend to below 80 inches (203 centimeters). Based on a nominal 60-inch (152-centimeter) soil profile, all have low available water — approximately 3.5 inches (9 centimeters) for the Cortina and Redding soils and 8 inches (20 centimeters) for the Hillgate soil (USDA 2009). The two grids of neutron-probe access tubes were positioned in either a Cortina or Redding soil type.

**Groundcover.** Groundcover varied between mowed resident vegetation in spring and winter, and bare ground in summer. Vegetation around the neutron-probe access tubes, where a mower could not be used, was controlled with herbicides each spring to match the surrounding vegetation.

### Reductions in water use

**Water savings.** An average water balance summary for 5 years of this study showed overall savings of 4.8 inches (12.2 centimeters) of applied water in the regulated deficit irrigation regime (table 1). The neutron-probe readings showed an average seasonal contribution of approximately 5.0 inches (12.7 centimeters) of stored water in the control and 4.5 inches (11.4 centimeters) in the regulated deficit irrigation treatment, amounting to about 11% of overall consumptive water use. All in-season precipitation was assumed to be an effective contribution. When the savings in applied water were combined with the contribution from soil storage, the regulated deficit irrigation regime resulted in a total average annual consumptive-water-use savings of 5.3 inches (13.5 centimeters) over the 5-year period, and yearly savings ranged from 10% to 15%, or 5.2 to 6.1 inches (13.2 to 15.5 centimeters) (table 2).

**TABLE 1. Average estimate of consumptive water use in control and regulated deficit irrigation (RDI) treatments, 2005–2008***

| Treatment | Seasonal applied water | Seasonal precipitation | Contribution from soil storage | Consumptive water use | Modeled $ET_c$ |
|---|---|---|---|---|---|
| | *inches (centimeters)* | | | | |
| Control | 39.3 (99.8) | 4.1 (10.4) | 5.0 (12.7) | 48.4 (122.9) | 44.4 (112.8) |
| RDI | 34.5 (87.6) | 4.1 (10.4) | 4.5 (11.4) | 43.1 (109.5) | 44.4 (112.8) |

* All in-season precipitation was assumed to be effective, and modeled ETc values were based on DWR 1986.

**Yield increases.** Yields increased in both treatments during the 5-year study, with no clear trend of any reduction due to regulated deficit irrigation (fig. 1). The orchard's increasing yields can be attributed to its relatively young age (9 to 14 years) and continuing canopy growth. Canopy growth is typically very sensitive to deficit irrigation, so it is noteworthy that plant-based regulated deficit irrigation did not have a negative impact on yields over time, presumably because the deficit period was after the main period of vegetative growth.

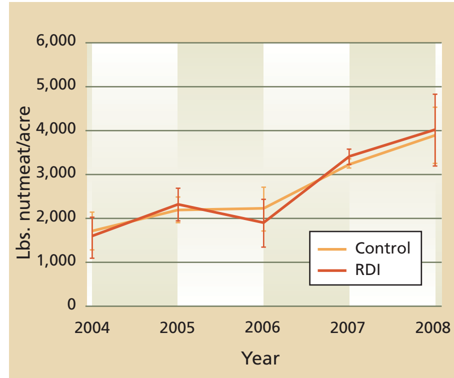


**Fig. 1. Annual pattern of nutmeat yield, 2004–2008. Error bars are ± 2 SE.**

**TABLE 2. Consumptive water use and overall percentage savings, 2005–2008**

| Year | Treatment | Consumptive use | Savings |
|---|---|---|---|
| | | *inches (cm)* | % |
| 2005 | RDI* | 34.6 (87.9) | 15 |
| | Control | 40.2 (102.1) | |
| 2006 | RDI | 36.0 (91.4) | 13 |
| | Control | 41.6 (105.7) | |
| 2007 | RDI | 47.1 (119.6) | 10 |
| | Control | 52.3 (132.8) | |
| 2008 | RDI | 42.6 (108.2) | 13 |
| | Control | 48.7 (123.7) | |

* Regulated deficit irrigation.

**Nutmeat production.** Even though regulated deficit irrigation consistently reduced applied water compared to the control (tables 1 and 2), variation was high enough to prevent the regulated deficit irrigation from having a statistically significant effect on the gallons of irrigation water used to produce 1 pound of nutmeat (table 3). Statistical analysis (ANOVA, not shown) for yield and irrigation water used per pound of nutmeat showed that both block and year effects were highly to very highly significant, presumably as a result of fixed block-to-block variability in the soils as well as the combined effects of year-to-year variation in weather conditions, especially during flowering, and the increasing yields over time.

**Nut quality.** Over 5 years, we found only two statistically significant effects on nut quality under regulated deficit irrigation: a decrease in kernel weight and an increase in the percentage of severe shrivel. Average nut size was 1.18 grams (SE ± 0.12) in the regulated deficit irrigation treatment and 1.21 grams (SE ± 0.12) in the control ($P > 0.02$). There was severe shrivel in 13.0% (SE ± 9.3) of nuts sampled from the regulated deficit irrigation treatment and 9.0% (SE ± 5.3) from the control ($P > 0.05$).

The nonsignificant effects measured were nut moisture; percentages of sealed sutures, doubled kernels, twin kernels, blanks, broken kernels, creases, slight shrivels, rupture calluses, gums, molds and stains; and damage by navel orangeworm, ants and peach twig borer. For most of the quality factors measured, the effect of year, but not block, was also highly to very highly significant (table 3; ANOVA not shown).

**Hull split.** Previous research showed that regulated deficit irrigation can increase the rate of hull splitting (Teviotdale et al. 2001), but in this study we observed no measurable differences in the duration or extent of hull split between treatments in any year (data not shown).

**Plant water deficit.** The SWP values in both treatments were approximately equivalent before and after the regulated deficit irrigation period, but were much lower (trees were more stressed) compared to the control during the hull-split period (fig. 2). This indicates that a well-defined and reproducible plant water deficit was achieved during hull split in the regulated deficit irrigation treatment.

For much of the growing season (14 to 32 weeks from full bloom),

**TABLE 3. Yield and irrigation water used per pound nutmeat for control and regulated deficit irrigation (RDI), and probability (*P* value) for treatment effect, 2004–2008***

| Treatment | Yield | Irrigation used |
|---|---|---|
| | *lbs. nutmeat per acre* | *gallons per lb. nutmeat* |
| Control | 2,640 ± 920 | 458 ± 193 |
| RDI | 2,640 ± 1090 | 428 ± 213 |
| *P* value | 0.99 NS | 0.22 NS |

* Based on three-way ANOVA (year, block and treatment).

particularly around harvest time (25 to 28 weeks from full bloom), SWP in the control was also lower than expected for almond trees with nonlimited water (the nonstressed baseline) (Shackel et al. 1997). This effect may be attributable to a small deficit in water applied by the grower as a result of cutbacks in water availability.

## Deficit irrigation in practice

The orchard site used in this study presented several difficulties in implementing regulated deficit irrigation as a management technique, in particular the site's relatively shallow and spatially variable soil with low water-holding capacity, and two comparatively dry years (2007 and 2008). Both of these factors might lead to an excessive and potentially damaging level of stress when irrigation is reduced, particularly just prior to harvest in almonds, when irrigation must be discontinued to allow for mechanized harvesting. However, using a simple, plant-based approach, consistent water savings of more than 5 inches (12.7 centimeters) or about 13% of applied water were achieved with no detectable effects on short- or medium-term orchard productivity. When regulated deficit irrigation was compared to the control, there was an annual water savings of 0.4 acre-foot (1.2 megaliters per hectare).

Although no significant reductions in overall yield or gallons of irrigation water used per pound of nutmeat were observed in our study, significant reductions in yield have been documented in previous deficit experiments with almonds. The negative effects in those studies were not extreme, and the yield reductions were generally associated more strongly with water deficits imposed during postharvest than during hull split. In a 4-year study by Girona et al. (2005), a statistically significant (20%) reduction in overall yield was associated with a 40% reduction in water application and a nonsignificant (3%) reduction in kernel dry mass. In our study, the overall treatment difference in kernel dry mass of 2.5% was

The study did not measure any almond yield reductions attributable to regulated deficit irrigation. Yields increased in both treatments due to the orchard's young age and ongoing canopy growth. *Above*, almonds are swept into windrows.

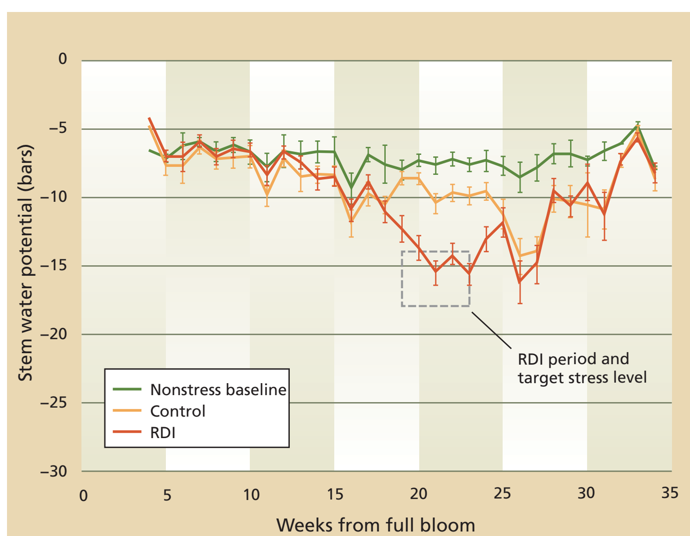


**Fig. 2. Seasonal average pattern of stem water potential (SWP) values for control and regulated deficit irrigation (RDI) treatments, with upper and lower limits of target water stress and average duration of RDI regime, and seasonal average expected SWP values for nonstressed almond trees, 2004–2008. Nonstressed baseline values (Shackel et al. 1997) were calculated using CIMIS data for atmospheric vapor pressure deficit; 2005 data was excluded from analysis.**

**Because of periodic drought and increasing competition for water resources, there is a pressing need to reliably maintain current almond production with less water.**

statistically significant but relatively minor.

At this site, even though the grower annually applied what many consider full $ET_c$, the SWP values indicated that the orchard trees were experiencing mild-to-moderate stress during much of the season, particularly around harvest. According to a previous study, mild-to-moderate stress may not be unusual in commercial almond production (Shackel 2001). Therefore, it is difficult to determine how much water might be saved statewide if our recommendations for regulated deficit irrigation were widely adopted.

Our plant-based strategy for regulated deficit irrigation is based on targeted stress levels at specific stages of crop development. If current grower practice already achieves this stress level, then the water savings shown in this study may not be realized. It will be important to further document current practices in terms of both $ET_c$ and SWP in order to have a more reliable estimate of the potential water savings from using regulated deficit irrigation in almond orchards.

The water savings in our study might also be improved upon. Depending on winter rainfall and soil type, a plant-based strategy might allow irrigation to be reduced for longer periods of the season in many almond-producing areas of the state. The contribution from rainfall is another important consideration; during this study there were 2 years of below-average rainfall, and the average annual contribution to crop consumptive water use from soil storage was only 11%. In less droughty years, or on soils with a higher water-holding capacity, water savings from plant-based regulated deficit irrigation might have been greater.

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*W.L. Stewart is Staff Research Associate, Department of Plant Sciences, UC Davis; A.E. Fulton is Irrigation and Water Resources Advisor, UC Cooperative Extension (UCCE) Tehama County; W.H. Krueger is Farm Advisor, UCCE Glenn County; B.D. Lampinen is Integrated Orchard Management/Walnut and Almond Specialist, Department of Plant Sciences, UC Davis; and K.A. Shackel is Professor, Department of Plant Sciences, UC Davis.*

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**A plant-based strategy for monitoring tree water stress allows growers to target deficit irrigation during specific stages of the growing season, possibly resulting in significant water savings.**

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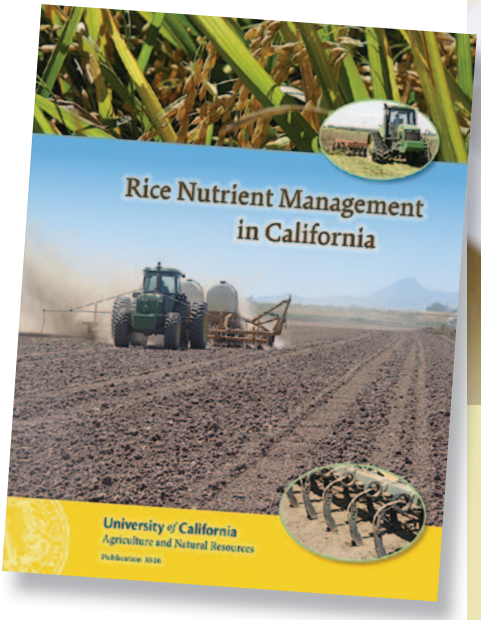


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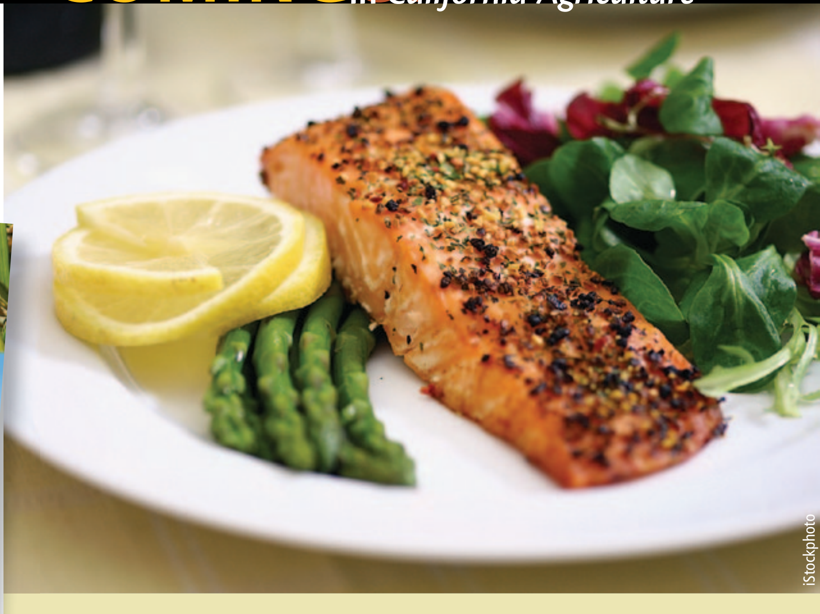

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