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California Agriculture

Life at the edge:

Farming, growth and conflict

New strategies deliver solutions-oriented science

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

In November 2009, the new director of the USDA's National Institute of Food and Agriculture (NIFA) Roger Beachy posed a challenge to public and land-grant universities: "I want USDA science, extramural and intramural, to focus most of its resources on accomplishing a few, bold outcomes with great power to improve human health and protect our environment." He also added, "The scientific knowledge learned from these efforts must be translated into real solutions for real people."

Beachy's comments marked a new emphasis on competitive grants in agricultural research and the first installment in a plan for a significant increase in funding. Through its Agricultural and Food Research Initiative (AFRI), NIFA will disburse approximately $262 million in competitive grants for the coming federal fiscal year; that amount could rise to $384 million in the year to follow. The AFRI competitive grants program will address five challenges: childhood obesity, climate change, food safety, global food security and sustainable bioenergy.

Also last year, in April 2009, UC Vice President Dan Dooley and UC Regent Fred Ruiz endorsed the "ANR Strategic Vision 2025." The document states that UC ANR must focus and apply its strengths to people, programs and science-based solutions "to connect and deliver resources from the entire University of California, forming integrated teams to work on complex issues and develop multidisciplinary solutions."

These complementary calls for solutions-oriented science, outreach and education are both disruptive and exciting. In ANR, new groups of collaborators are creating 5-year plans driven by the first four strategic initiatives: sustainable food systems, endemic and invasive pests and diseases, sustainable ecosystems, and healthy families and communities (http://ucanr.org/sites/anrstaff/Strategic_Initiatives).

For *California Agriculture* journal, these strategic shifts, along with upheavals in scholarly communication and the breakneck pace of technology, have spurred creativity, new collaborations and a renewed sense of the importance of reporting peer-reviewed, policy-relevant science integrated with the best practical information available.

In the world of scholarly communications, the same pressures are at work. Today, more than 3,000 disciplinary journals publish under some form of open-access model. *California Agriculture* and other land-grant publications have long been in the vanguard of open-access information, delivering original, peer-reviewed research to subscribers, virtually without charge. Increasingly, scientists also post articles in repositories such as the UC California Digital Library's eScholarship Repository, and use copyright alternatives to increase access, such as Creative Commons.

At the same time, journal consolidation and soaring prices for some scholarly journal subscriptions have intensified the struggle of public university libraries to maintain viable information resources (http://osc.universityofcalifornia.edu/news). Both open-access models and journal pricing controversies emphasize the importance of the freely available, peer-reviewed research found at *California Agriculture* Online, and the other communication tools that support ANR programs and make research accessible.

Recently, *California Agriculture* completely digitized and indexed the full text of its 64 years of publication. Collaborating with technology and communications colleagues in ANR Communication Services and Information Technology, the *California Agriculture* staff designed a more powerful and attractive search and display Web site to provide access to these resources (http://californiaagricutlure.ucanr.org). The results have been remarkable. Launched in the last quarter of 2009, *California Agriculture* Online opened the entire publication database to researchers, agencies and the public, and also made it visible to general and scholarly search engines. The information is now easily discovered, searched and cited. As a result, *California Agriculture* Online generated over 13 million page views in 9 months.

This growth is not just evidence of the editorial and production quality we expect of *California Agriculture* journal. It is also evidence of the public's appetite for scientifically sound, accessible content. Additional efforts to digitize publications such as *Hilgardia*, and to enhance electronic publishing of ANR publications, are under way.

In a 2005 *Society and Natural Resources* article, Carr and Wilkinson noted, "For many years agricultural science assumed that research was done by scientists, repackaged by extension offices, and launched at farmers. Nowadays, their roles are converging and the boundaries are eroding." We, too, must increasingly create crosswalks between academic and extension publishing, and increase information dissemination.

The opportunity to bring these tools to bear on ANR's strategic vision and initiatives is exciting. The rapid collection and delivery of the best information available on emerging issues, and new ways to foster collaborative research and build science literacy, are within reach. Using these new tools while ANR restructures and adapts to major budget cuts, faces major funding challenges and competes for resources, is both sobering and motivating: sobering because critical resources have diminished due to decreased public support; and motivating because the opportunity to deploy powerful technologies enables us to support ANR academics — and to make a difference here and worldwide.

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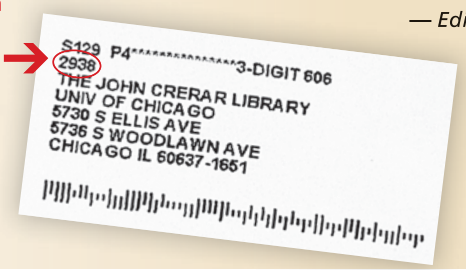
— Editor



About California Agriculture

California Agriculture is a quarterly, peer-reviewed journal reporting research, reviews and news. It is 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 circulation is currently about 15,000 domestic and 1,800 international.

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. We post peer-reviewed articles to the California Digital Library's eScholarship Repository.

Authors. 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.

Reviewers. In 2008 and 2009, 14% and 50% (respectively) of reviewers came from universities and research institutions or agencies outside ANR.

Rejection rate. Our rejection rate ranged between 20% and 25% in the last three years, and in the year ending May 31, 2009, editors 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: 1301 S. 46th St., Bldg. 478, Richmond, CA 94804, or calag@ucdavis.edu. Include your full name and address. Letters may be edited for space and clarity.

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WHAT DO YOU THINK?

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

Blast from the past

What a blast from the past. One of my co-workers e-mailed me the April-June 2010 issue of *California Agriculture* after seeing my picture in it, and there I was, feeding calves (page 61). I was actually a student intern that spring in plant taxonomy at the Sierra Field Station at Browns Valley, and stayed the summer feeding cows and calves. My name was Marla Shapiro at the time, it was the summer of 1974, I was 20 years old, and I believe my mom took that picture while visiting.

Knight in 1974

I was a sophomore at UC Davis, had just failed organic chemistry, and was looking for a break from math, chemistry and physics! My interest in botany led me to the internship, where I was one of two students creating the herbarium at the station. It changed my life. I've been a botanist now for 30 years at the Klamath National Forest in northern California (I repeated organic chemistry successfully).

My co-workers are tickled at this part of my life that they knew nothing about, especially my friends at the county agriculture department. Thanks for bringing back memories of a great time.

Marla A. Knight
Botanist, Klamath National Forest
Fort Jones

Cal Ag moves to Richmond

The *California Agriculture* journal staff, and ANR warehouse and customer service staff, have moved to UC Berkeley's Richmond Field Station in the former Forest Products Lab, from their previous headquarters at the Marchant Building in Oakland.

Our new contact information is:

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(510) 665-3427 (fax)

Suckow hired as Cal Ag's new art director

Will Suckow is the new art director for *California Agriculture* journal. Suckow was the principal producer/director for Communication Services from 1997 until 2003, when he left to run his design and illustration business. Suckow will be designing and laying out *California Agriculture* journal (replacing Davis Krauter) and other ANR publications. He earned a Bachelor's and Master's of Fine Arts in graphic design from California State University, Fullerton. Prior to joining ANR in 1997, he worked as a graphic artist for UC Davis University Extension, Claremont University and Cal State Fullerton. Suckow can be reached at (510) 665-2198 and wsuckow@ucdavis.edu.

Climate change issue, Cal Ag Web site, Byron win ACE awards

April–June 2009

California Agriculture journal received two awards from the Association for Communication Excellence in Agriculture, Natural Resources, and Life and Human Sciences (ACE), at the June 2010 ACE conference in St. Louis.

The silver award for technical publications was awarded to Executive Editor Janet White, Managing Editor Janet Byron and Art Director Davis Krauter (retired) for the special issue, "'Unequivocal': How climate change will transform California" (Vol. 63, No. 2).

Our redesigned Web site, California Agriculture Online (http:californiaagriculture.ucanr.org), won a bronze award for electronic publications. The development team included White, Byron, Krauter, Web Editors Andrea Laue and Michael Talman, Web Developer Dave Krause and Web Action Team Manager Karl Krist.

http://californiaagriculture.ucanr.org

Byron was also selected to receive the 2010 ACE Western Region Pioneer Award, recognizing individuals "whose hard work and vision helped establish ACE."

Budget cuts threaten the Williamson Act, California's longstanding farmland protection program

Alvin D. Sokolow
Cooperative Extension Public Policy Specialist Emeritus, UC Davis

Thousands of California farmers and ranchers, owning about half of all the agricultural acres in California, have their properties enrolled in the Williamson Act. Many of them and others are worried about the continuity of the 45-year-old, state-local government program that restricts the conversion of farms and ranches to urban uses by providing property-tax reductions to landowners. At issue is the elimination in the state budget of the subventions (fiscal aid) that compensate counties for all or a part of their property-tax losses.

Intense lobbying by agricultural and other groups has opened up the possibility that subventions could be restored in the 2010-11 state budget as a temporary measure, pending agreement on a permanent way to fund the program that does not rely on the state's general fund. The problem is rooted in the current fiscal crisis that overwhelms both state and county governments. This is not the first time that Williamson Act subventions have been threatened by budget shortfalls, but with a continuing state government deficit of about $20 billion and big funding gaps for counties, the current crisis is the most severe since the state began paying subventions in 1971.

Even without the subventions, the core part of the program — long-term contracts between landowners and county governments and a few cities that link land restrictions to property-tax benefits — could continue to exist. The landowner-county contractual relationship is legally independent of the state-county fiscal relationship. But in practice, the two processes are closely connected. For if they permanently lose fiscal support, most counties probably would reluctantly exit from the program by not renewing existing contracts to gain back the foregone property-tax revenues. As

Fresno County Farm Bureau

The 45-year-old Williamson Act has helped to preserve farmland throughout California.

contracts wind down, farmland owners would automatically lose their tax benefits and in 9 years could begin to develop their properties.

How it works

Enacted in 1965 and named after its legislative sponsor, Assemblyman John Williamson of Kern County, the program now covers 16.6 million acres, about half of California's agricultural land and one-third of all privately owned land in the state. Fifty-three of 58 counties currently participate (except Alpine, Del Norte, Inyo, San Francisco and Yuba counties).

Participation in the Williamson Act is voluntary for both landowners and counties (see sidebar). The contracts run for a minimum of 10 years and are automatically renewed every year unless either party takes action to terminate.

State spending on subventions totaled about $37 million annually until recently. For individual counties in the program, the annual subvention has ranged from a few thousand dollars to between $1 million and $5 million for the nine large agricultural counties in the Central Valley. In relation to total budgets, these are not large amounts. But because they represent precious discretionary (general fund) dollars, the lost subventions are big hits for already distressed counties, which for several years have had to lay off large numbers of employees and drastically cut general fund programs.

County and landowner impacts

As much as county officials support the farmland protection objectives of the Williamson Act, many say they cannot afford the property-tax hits. One county, Imperial, has already started the nonrenewal process, and others have announced that they will probably follow if subventions are not restored in the 2010-11 state budget. A few counties may bite the fiscal bullet and continue the program. Much depends on how county boards of supervisors balance their commitments to farmland protection with the condition of their general funds. In the meantime, some counties have stopped accepting new applications from landowners, according to a February survey of its members by the California State Association of Counties, with the general mood described as a "holding pattern" pending further state government action or inaction.

What will landowners do if they lose the property-tax benefits? An unknown number certainly will try to sell their agricultural properties for future development, judging from anecdotal accounts in several newspapers. But "cash out" opportunities are limited by location and other factors. Most acres under contract are in remote areas not suitable for major urban development. Of course, there is a market in California for scattered, country home sites, but landowner opportunities for parcelization are restricted by requirements such as water supply and road access, and by other county planning and land-use regulations.

Much depends on how county boards of supervisors balance their commitments to farmland protection with the condition of their general funds.

How effective?

The objectives of the Williamson Act and the complementary subventions are widely supported by agricultural groups, landowners, county

Major features of the Williamson Act

Agricultural preserves. Enrolled land must be located within county-designated agricultural preserves of at least 100 acres, a provision intended to create large concentrations of acres under contract.

Farmland security zone. Added to the basic Williamson Act in 1998, this version of the program provides for 20-year contracts in return for greater landowner property-tax reductions.

Long-term contracts. Participating landowners sign 10-year contracts with their counties restricting their properties to agricultural or other open space uses. Unless either party takes action to terminate a contract, it is automatically renewed every year for another year — resulting in a rolling 10-year term.

Not mandated (voluntary). Participation is voluntary for both counties (and cities) and agricultural landowners.

Subventions. Up until 2009-10, the state compensated counties for their property-tax losses according to a per-acre formula that paid more for prime than nonprime land.

Termination. The most commonly used technique for removing land from the program is contract "nonrenewal," initiated either by the landowner or county and resulting in a 9-year phase-out. Contracts can also be terminated in other ways, including: (1) immediate "cancellation," requiring findings of unusual circumstances and landowner penalty payments; (2) "acquisition" of property by public agencies; and (3) "city annexation" in certain cases.

Use value assessment. Enrolled land is assessed for property-tax purposes at the value of its agricultural production, instead of the generally higher market or Proposition 13 value.

Edward Thompson Jr.

Working farms and grazing land can play an important role in preserving wildlife habitat. In Fresno County, herons stand in vernal pools.

governments, environmentalists and others. For its backers the program is a successful case of converging public and private interests, achieving long-term land conservation while helping the economic bottom line of farmers and ranchers.

Yet there are critics who question the program's effectiveness in holding the line on farmland conversion. For example, the Legislative Analyst, the fiscal advisor to the California Legislature, has recommended on several occasions the deletion of subventions on the grounds that the program does not narrowly focus on lands actually at risk of development.

In part the critics are correct: The Williamson Act has done little to limit the rate and volume of farmland conversions in the path of city expansion. Two historic conditions are responsible: (1) the reluctance of landowners on city edges, anticipating development opportunities, to enroll in the program; and (2) the ability of cities in the past to protest enrollments within 1 mile of their borders, effectively terminating such contracts when city annexation occurs. (The latter condition has had less impact in recent years, because as cities grow beyond the 1-mile limit they increasingly are adjacent to contracted land that they did not protest at the time of original enrollment.)

On the other hand, the program has been more effective in less visible terms, as suggested by a 1989 UC study. In areas remote from cities and other population centers where most land covered by the Williamson Act is located, the program has helped to control farmland conversions and block development — reducing the extent of leapfrog development and sprawl in rural California (see pages 121 and 129).

The Williamson Act is not solely responsible for this outcome; other policies and programs have contributed. Since its enactment in 1965, the preferential tax program has been supplemented by such state-local measures as: (1) environmental review of development proposals under the California Environmental Quality Act (CEQA), (2) regulation of city expansion, (3) restrictive agricultural zoning in some counties, (4) urban growth boundaries created in some jurisdictions and (5) agricultural easement programs. Some of these other policies and programs are more or just as effective in maintaining farmland in particular areas, but the Williamson Act still stands out in the sheer volume of agricultural acres it covers throughout California.

What is next?

Not restoring subvention funds in the 2010-11 budget signals a virtually permanent elimination of this aid to counties. Without other assistance to protect their budgets, most counties with substantial acres in the program probably would pull out through contract nonrenewals. This is a process that takes 9 years to complete, delaying any landowner efforts to convert their agricultural properties to urban use.

The subvention crisis has stimulated much discussion about changing the method by which landowner tax benefits are funded. In spring 2010, agricultural organizations and state government officials were considering a variety of alternatives to save the program by shifting county aid away from the state's general fund. These included having landowners pay for a portion of their property-tax benefits; funding subvention payments from one or more dedicated revenue sources, such as oil severance taxes or property transfer fees; and allowing counties to capture certain local revenues such as parcel fees. Such proposals, as well as providing state income tax credits to participating landowners in place of the property-tax benefits, were suggested in a hearing conducted by the Senate Local Government Committee in March.

With the 2010-11 state budget year due to begin July 1, the one certainty is that the time for resolving the subvention problem is running out.

Fresno County Farm Bureau

While the Williamson Act has not necessarily helped to preserve farmland near urban edges, it has been more effective in areas remote from cities and population centers.

California communities deal with conflict and adjustment at the urban-agricultural edge

by Alvin D. Sokolow, Sonja Varea Hammond, Maxwell Norton, *and* Evan E. Schmidt

About 2.5 million agricultural acres are located adjacent or in close proximity to nonfarm residences in California, leading to widespread farm-residential conflicts. This exploratory study compared high- and low-conflict edges in four crop-growing communities in two counties. (A separate analysis of San Diego County in a sidebar compares two edge situations involving animal and nursery operations.) We present tentative generalizations about conflict variations, sources and solutions. High conflict levels were largely due to residents' unfamiliarity with agricultural activities, although conflict levels were also related to specific farming practices. We also pose questions to guide further and more systematic research on the edge issue in California agriculture.

In California, an estimated 2.5 million agricultural acres are located within one-third mile of an urbanized area. *Above*, in south Salinas a landscaped driveway faces irrigated fields.

California agriculture is substantially affected by ongoing urban growth. While sustaining the nation's largest agricultural economy, the state continues to add about 350,000 new residents each year. As well as converting farmland to nonagricultural uses, urbanization creates serious residential-farm conflicts — the so-called "edge" problem (see box). In many agricultural areas, residential populations in close proximity impede the productivity, efficiency and profitability of farm operations.

California newspapers offer numerous accounts of edge issues in particular locales (Levin 2000; Morain 1991; Price 1994; Vellinga 2007; Sokolow 2003). The harm to agriculture includes limitations on routine practices such as chemical applications and cultivation, liability for trespassers, theft, vandalism, imported pests and increased traffic on rural roads. Negative impacts also occur on the other side: Residential neighbors have problems with odors, noise, nighttime operations, dust, pesticide sprays and other nuisances, or even health problems associated with agricultural operations. The edge problem is not unique to California. It appears in many other parts of the nation where urbanization extends into commercial agricultural areas (Jackson-Smith and Sharp 2008; Abdalla and Kelsey 1996; Larson et al. 2001; Van Driesche et al. 1987).

These accounts are usually anecdotal or prescriptive in nature, lacking a systematic examination of the causes and effects of agricultural-residential conflicts, especially one that builds on a comparison of different edge situations. We present a comparative case analysis focusing on two alternative explanations for conflict variations: (1) the nature of specific commodities grown and (2) the characteristics of residential neighbors. This exploratory study was based on edge situations in

Conversions and edges: How much farmland is affected?

Close to 40,000 acres of agricultural land — a little more than one-tenth of 1% of California's total — are converted to urban uses annually (CDC 2006). Far more farm acres, however, are located in close proximity to residential neighbors. An estimated 2.5 million agricultural acres throughout California are within one-third mile of urban edges (Sokolow 2003). In 2004, this estimate was updated based on a calculation in that year of 12,137 edge miles statewide where agricultural land bordered residential and other urban land; cropland edges totaled 7,886 miles. These numbers actually underestimate the true extent of edges, since they are based on the state definition of "urban and built-up" land as six or more structures per 10 acres and do not account for separated, single residences in rural areas.

two localities in each of two California counties with significant crop production.

Research in sample communities

From 2003 to 2005, we conducted open-ended interviews, in person and by phone, with county agricultural commissioners and their staffs, county government officials, agricultural leaders and individual farmers in Merced and Monterey counties, which are located in the Central Valley and Central Coast, respectively. Along with San Diego County on the southern coast (see sidebar, page 127), these farm counties rank among the top 10 in the state in agricultural income, each with more than $1 billion in commodity sales annually. All have growing urban populations in their agricultural areas that suggest the potential for significant edge conflicts.

The sample counties were selected because they are the field locations of co-authors who are UC Cooperative Extension advisors. Thoroughly familiar with local agricultural conditions, the advisors also chose the persons interviewed, conducted some of the interviews and helped select the specific communities for study. For each of the two sample counties, we selected two communities to compare — one relatively "high" and the other relatively "low" in the degree of perceived conflict between farmers and residential neighbors (table 1).

TABLE 1. Sample edge segments

	Merced County		Monterey County	
	Los Banos	Livingston	Prunedale	Salinas
Relative degree of edge conflict	High conflict	Low conflict	High conflict	Low conflict
Type	City	City	Unincorporated	City
Edge segment studied	N, W, S borders	S border	Entire community	SW border
2000 population	25,869	10,473	16,432	151,060*
Population increase entire community, 1990–2000 (%)	72.8	43.1	122.2	38.8
Agricultural commodities produced	Cattle, dairy, forage crops	Almonds, peaches, sweet potatoes	Strawberries, cut flowers	Vegetables, strawberries, animals

*Entire community.
Sources: US Census 2000; interviews.

Three of the communities are incorporated cities, governed by municipal governments; the fourth, Prunedale in Monterey County, is unincorporated and most of its local government services and regulations — including land-use planning — are provided by county government. There are notable differences among the four communities in size, recent population growth and principal agricultural commodities. Two San Diego County communities, the unincorporated area of Ramona and the city of Oceanside, are the subject of a separate analysis (see sidebar, page 127).

Conflict variations and issues

In distinguishing between high- and low-conflict situations among the four sample edges, we looked for evidence of the relative intensity of disagreements between farmers and residential neighbors. The indicators included: (1) the volume, variety and duration of perceived problems about agricultural practices raised in residents' complaints, as described by county officials and other interviewees and (2)

TABLE 2. Perceived edge conflicts

	Merced County		Monterey County	
	Los Banos	Livingston	Prunedale	Salinas
Relative degree of edge conflict	High conflict	Low conflict	High conflict	Low conflict
Problems perceived by residents, approximate order of severity	Airplane, helicopter noise Defoliant smell Air quality Pests Dust Pesticide drift on vehicles	Night agricultural work Pesticide drift Odor	Drainage Soil erosion Fumigation Pesticide drift Animals and related noise or illegal activity	Odor
Problems perceived by farmers, approximate order of severity	Trash on farms, roads Trespassing Theft Vandalism Operational restrictions	Vandalism Trespassing Theft Operational restrictions Traffic congestion	Theft Drainage Operational restrictions Ranchettes Competition for water Dumping	None or minimal
Persons interviewed	Seven farmers Two agricultural commissioner staff Three aerial pesticide applicators Three city planners Chamber of Commerce official		Four farmers One agricultural commissioner staff Three staff of agricultural organizations Four county government staff One aerial pesticide applicator Two agricultural consultants	

Source: Interviews.

farmers' perceptions about the negative impacts of adjacent residents on their agricultural operations, as expressed in interviews.

Our data generally cover a 5-year period, starting in the late 1990s and concluding in about 2004. Edge-conflict patterns can fluctuate over time as farming practices and/or residential populations change, so the conflicts identified here are not necessarily longterm.

The study identified and compared high- and low-conflict segments within each of the two counties, rather than comparing them overall (table 2).

Merced County. The volume and variety of complaints by residents about nearby farm operations marked the Los Banos edge as much more conflictual than the Livingston edge in the late 1990s and early 2000s, according to two staff members of the Merced agricultural commissioner assigned to the Los Banos and Livingston field offices. They and other interviewees noted that residential complaints had greatly increased in recent years in Los Banos as a result of the city's rapid population growth and expansion into surrounding farmland (fig. 1). While we lack specific numbers, interviewees said that the list of residents' complaints was topped by noise from airplanes and helicopters spraying chemicals, the smell of defoliants and other chemicals applied to cotton fields, and poor air quality. In the late summer, people complained about respiratory problems attributed to the application of cotton defoliants and other farm practices.

In contrast, complaints from residential neighbors of farms around Livingston were relatively few and mild during the same period. Pesticide-related objections were infrequent, according to one agricultural commissioner's staffer, not exceeding five per year. The top issue was noise and dust from the blast sprayers used to spread pesticides on orchard treetops.

On the agricultural side of the edge, problems were generally similar around the two cities, and included trespassing, theft, vandalism and restrictions on farming practices (table 2). Farmers in Los Banos regarded edge issues as more serious than in Livingston. Theft and trash dumped on farmland and local roads were cited as a bigger problem for agriculture in the Los Banos area than around Livingston.

Monterey County. The consensus among Monterey County interviewees was that edge problems were more pronounced in unincorporated Prunedale in northern Monterey County than on the southern border of the city of Salinas (fig. 2). With single rural home sites interspersed among small strawberry, flower and other farms, there were ample opportunities for edge conflicts in Prunedale. The most serious problems expressed by residents in the early 2000s concerned soil erosion, poor drainage of runoff water, and the smell and health hazards of fumigating strawberry fields with methyl bromide. A small group of residential opponents to agricultural practices in the north county had organized as the "Code Rangers." They monitored local conditions and reported perceived violations of county codes to county officials. One target was erosion created by strawberry fields.

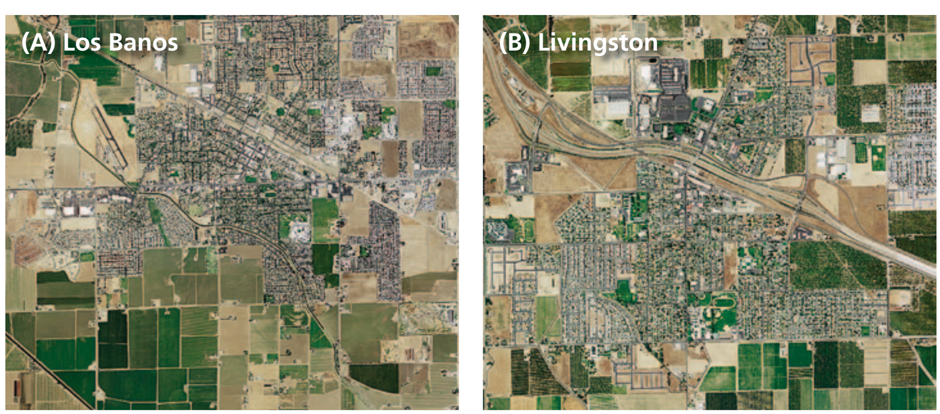
In comparison, the agricultural area on the southern edge of Salinas, a relatively stable locale with little population growth since the 1970s and with more distinct farm-residential borders, was relatively problem free. In fact, interviewees could not recall any substantial complaints from residential neighbors in recent years, with the exception of some protests about odors.

Problems perceived by farmers paralleled the residents' complaint pattern, with no issues recorded for south Salinas. Some of the same problems — drainage, erosion and fumigation — that were the basis of residents' complaints also bothered farmers, although from a different perspective. Runoff problems were seen by farmers in Prunedale as partially caused by home and road construction, and fumigation restrictions led to increased costs and operational adjustments for strawberry growers. Theft also was a major problem, as one farmer reported: "We had a truck parked on the ranch and they actually stole the radiator and the four-wheel-drive mechanism . . . We had trailers broken into, probably about a thousand dollars of small tools lost. We keep nothing out there anymore, not even a shovel. That's the hardest part about farming in north Monterey County now. I know that everybody who farms in the area has had that problem" (phone interview, Jan. 28, 2005).

Residents living near active farms may complain about drift and noise from spray applications, dust from plowing and odors. *Above*, a pesticide warning sign is posted near apartments in south Salinas.

Commodity production and practices

What accounts for the variations in edge conflicts from place to place?



Photos: USDA-NRCS

Fig. 1. Aerial photo comparisons of (A) Los Banos and (B) Livingston in Merced County in 2009 suggest that urban-agricultural borders were more irregular around Los Banos than around Livingston, possibly helping to generate higher levels of edge conflict in Los Banos.

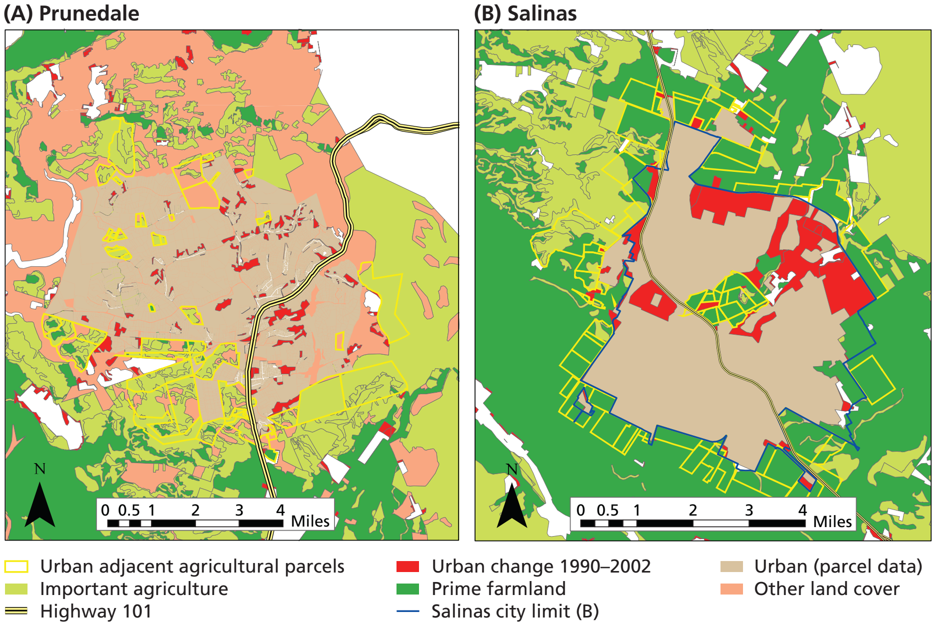


Fig. 2. The GIS-mapped relationship of urban and agricultural parcels in Monterey County in 2002 shows a fragmented pattern in (A) unincorporated Prunedale as compared to the relatively straight line on the southern edge of (B) the city of Salinas. Urban-agricultural conflicts were much more intense in the latter than the former area in the late 1990s and early 2000s. Source: Nathaniel Roth, Information Center for the Environment, UC Davis, based on information from Monterey County and the California Department of Conservation Farmland Mapping and Monitoring Program.

The case studies suggest two contrasting explanations, one concerning the nature of agricultural practices and the other related to the degree that edge residents are newcomers with urban backgrounds. On the one hand, more intense conflicts at the edge can be attributed to specific farming activities that generate extensive negative impacts (Connell 1999; Levin 2000; Vellinga 2007). On the other hand, new residents who are unfamiliar with country life and agriculture may have relatively little tolerance for farm operations (Morain 1991; Leavenworth 2000). These explanations have been separately identified in newspaper accounts and academic research, but without comparing the two factors.

Virtually all agricultural operations have the potential to disturb nearby residents. But the potential may be greater for certain kinds of farm commodities — such as crops that require heavy applications of pesticides or other chemicals, or that involve intensive cultivation and harvesting that generate dust, noise and nighttime impacts. Confined-animal facilities such as dairies, poultry ranches and hog farms are especially conducive to negative impacts, largely because of their waste products (Baca 2002; Castle 1998; Henderson 1998; Hirschl and Long 1993; Schwab 1998; Turner 2003) (see sidebar, page 127).

Farmers and ranchers have some ability to increase or reduce edge problems, depending on how they operate.

Some of these crop conditions were present in our study's four edge segments, but were more pronounced in the high-conflict than the low-conflict edges, as seen with concern about the smell of defoliants used in cotton production around Los Banos (Merced County) and the use of methyl bromide on strawberry fields in Prunedale (Monterey County).

The issue may not be about the particular commodity grown, as some interviewees suggested, but rather how it is grown — including management practices such as pesticide applications, the timing of noisy harvest activities and equipment maintenance. Farmers and ranchers have some ability to increase or reduce edge problems, depending on how they operate.

New residents from urban areas

People who occupy homes adjacent to agricultural operations vary in their tolerance of farming practices. The conventional wisdom repeated in newspaper reports is that newly arrived edge residents with urban backgrounds are more likely to be upset by local farm operations than residents with rural backgrounds and longer tenure in a locality. Our research supports this observation. Indeed, differences in background characteristics and the duration of local residence offered the strongest explanation for the conflict variations in the two study counties.

Los Banos-Livingston. The most solid evidence came from the Los Banos-Livingston comparison in Merced County. Both cities have traditional agriculture-dependent economies, and both have experienced substantial population increases since the 1980s. But the extent and character of this growth differed in major ways. The population of Los Banos (the high-conflict community) more than doubled from 1990 through 2004, from 14,519 to 30,650 residents. Growth in Livingston (the low-conflict community) was more modest, with a 59.9% increase, from 7,317 to 11,700 residents, during the same time.

The origins of growth differed significantly. In Los Banos, it stemmed mostly from the more urban Santa Clara County/San Jose area and other parts of the Bay Area. In Livingston, it was mostly from other areas of the relatively rural San Joaquin Valley.


SATURDAY, APRIL 8, 2000

The buzz in Los Banos

New subdivision caters to the Bay Area commuter buyer

A newspaper article describes the conflicts that can arise when commuters purchase homes in primarily rural communities such as Los Banos, located about 60 miles from employment centers in the South Bay and East Bay.

Los Banos is located on the west side of Merced County near Interstate 5, about 60 miles from major employment centers in the South Bay and East Bay, making it a long but manageable commute for urbanites seeking relatively inexpensive housing and small-town ambience. The result has been the development of a newcomer/old-timer divide in Los Banos. Newer residents have higher incomes, are residentially concentrated in new subdivisions on the edge of town and adjacent to farms, and are more likely to work in occupations not associated with agriculture. Livingston, by contrast, is in the central part of the county, closer to other San Joaquin Valley communities and less accessible to Bay Area commuters. Its newer residents are more similar to their longer-term neighbors, and Livingston seems to lack the social and occupational divisions that have developed in Los Banos.

A staff member of the agricultural commissioner's office said: "New residents in the Los Banos area are not originally from the valley and have a very low tolerance to ag practices and consider them threatening. New residents in the valley communities grew up in the valley and they are accustomed to ag practices . . . Bay Area people are very confrontational compared to those who grew up here. They like to carry complaints on up the chain of command" (phone interview, Sept. 20, 2004).

A comparison of U.S. Census data supports these perceived differences between Los Banos and Livingston (table 3): (1) between 1995 and 2000, proportionately more Los Banos residents had moved there from another county; (2) Los Banos residents had longer commutes to jobs in 2000; (3) there was a sharp decrease in the proportion of Los Banos workers employed in agriculture in 2000; and (4) Los Banos had higher income levels and faster income growth (median household income) in 1990–2000 than Livingston.

Prunedale-Salinas. Similar differences help explain the conflict variations between the two Monterey County edge segments. Prunedale, the high-conflict unincorporated community, experienced a population increase from 1990 to 2000 of 122%, from 7,393 to 16,432 residents. The southern border of Salinas, the low-conflict edge, has been relatively stable in recent decades, with the last appreciable residential development occurring in the 1970s. In part because of proximity to good agricultural soils south and west of Salinas, city policy has limited further residential expansion in this area in favor of extending urban development to the north and east. All of Salinas had only a 39% population increase in the 1990s, much smaller than Prunedale. Several interviewees pointed to the role of new residents in escalating the levels of perceived agriculture-related problems in Prunedale. One farmer noted: "The problem we have is that . . . people who move to rural areas but who are basically from the city don't understand that water flows downhill. They also complain about dust. But everybody else is used to living down there, and they don't create problems" (phone interview, Jan. 28, 2005).

In 2000, larger percentages of Prunedale than Salinas residents reported: (1) living in other counties 5 years earlier; (2) workplace locations

TABLE 3. Demographic patterns, Merced County cities, 1990–2000*

	Los Banos (high conflict)		Livingston (low conflict)	
Different residence in 1995, as % of 2000 population:				
Different house	53.1		39.2	
Different county	33.8		7.0	
	1990	2000	1990	2000
Workplace location outside county of residence (% of employed)	12.9	44.5	21.1	27.8
Mean commute time (minutes)	17.4	44.5	16.7	20.7
Increase in commute time (%)	155.7		23.9	
Occupation in agriculture (% of employed)	12.8	8.6	na†	20.7
Median household income ($)	24,649	43,690	26,707	32,500
Increase in income (%)	77.2		21.6	
Increase in median home value ($)	140,200		92,700	

* Data for entire cities of Los Banos and Livingston.
† Not available.
Source: US Census 2000.

TABLE 4. Demographic patterns, Monterey County communities, 1990–2000*

	Prunedale (high conflict)		Salinas (low conflict)	
Different residence in 1995, as % of 2000 population:				
Different house	38.2		54.1	
Different county	33.8		13.2	
	1990	2000	1990	2000
Workplace location outside county of residence (% of employed)	20.4	25.6	6.1	11.0
Mean commute time (minutes)	8.6	28.2	18.7	24.2
Increase in commute time (%)	227.9		29.4	
Occupation in agriculture (% of employed)	13.8	4.8	19.1	15.2
Median household income ($)	44,638	62,963	31,271	43,270
Increase in income (%)	41.0		38.3	
Increase in median home value ($)	281,400		195,700	

* Data for Prunedale CDP (census-designated place) and entire city of Salinas.
Source: US Census 2000.

in other counties; and (3) employment in nonagricultural industries, with a sharp decrease in farm employment from 1990 to 2000 (table 4). Prunedale residents also had longer commutes to work, with a steep increase in mean commute times within the decade.

Adjustments to avoid conflicts

As others have suggested, the most effective efforts to limit the scope and incidence of conflict with residential neighbors may be farmer adjustments to their normal agricultural practices (Coppock and Kreith 1997).

Regulations. Adjustments in California are largely due to county government regulation on the farm use of pesticides and other health-related chemicals. The restrictions originate in state health protection laws administered by county agricultural commissioners. County environmental health and county or regional air-quality programs also regulate local agricultural practices. As noted by Merced County agricultural commissioner's staff, pesticide use close to residences is more closely monitored than applications elsewhere. Depending on the hazard level of the chemicals employed and particular edge configurations, farmers are sometimes required to use buffers of varying widths between houses and the fields where pesticides are applied.

Voluntary actions. Agricultural operators also engage in voluntary adjustments intended to head off potential problems. Interviewees described such "good neighbor" actions as:

- Notifying nearby residents of upcoming operations with the potential to generate substantial noise, dust or other annoyances.
- Conducting dusty or noisy field operations on days and at times when the fewest number of neighbors are likely to be affected.
- Operating harvest equipment to minimize dust spray.
- Installing decorative fences and landscaping buffers.
- Sharing produce with neighbors.

Aerial applications of pesticides onto fields and orchards are especially vulnerable to residential edge problems. The four aerial applicators we interviewed who worked in Merced and/or Monterey counties described modifications to their operations in recent years due to residential development in agricultural areas. While such technological advances as quieter aircraft and GPS (global positioning systems) as a substitute for ground-flagging could be the inevitable progress of an industry seeking more efficiency, they appeared to be hastened by the need to improve the precision of spray applications in problematic areas. The applicators reported that they turned down jobs where edge configurations posed liability concerns; they also noted that about half of the aerial applicators in California had gone out of business or consolidated in recent years. One applicator who works in Merced County said: "Small (agricultural) parcels created by lot splits are more difficult and expensive to treat and also present more opportunities for off-site drift problems . . . Liability insurance costs are skyrocketing. When they hear a plane nearby, people just assume they are being poisoned. We receive lots of noise complaints" (phone interview, October 2004).

As population expands into agricultural areas, growers may complain about theft, vandalism and restrictions on farming practices. Such concerns were generally less common in Livingston, *above.*

Neighbor adjustments. Generally seen as the victims of harmful agricultural practices, residents can also be the perpetuators of problems experienced by some farm operators, such as theft, vandalism and trespassing. However, we found no direct evidence of efforts by edge residents to avoid such impacts and respect agricultural property, since this was not a focus of the research and no interviews were conducted with residents. It is possible that individual adjustments may occur with, for example, families restraining unruly youngsters and controlling their dogs. Still, the incentives for adjustments by residents are far less obvious and compelling than the economic and regulatory factors that cause farm operators in edge locations to be careful about their production practices and protect their assets.

Public policies and programs

California local governments have considerable regulatory and other powers to limit or even prevent edge conflicts (Sokolow 2003). Perhaps the most effective are planning and zoning actions that determine the location and configuration of new residential developments (Handel 1994). Available policies range from overall strategies, such as county-city agreements to divert new growth away from agricultural areas by concentrating it in cities (see page 129), to more specific requirements such as buffers and large minimum parcel sizes in agricultural zones. Nonregulatory measures, such as right-to-farm ordinances and educational programs, are generally regarded as less effective because of their voluntary and general nature (Wacker et al. 2001).

We have no evidence that such policy measures helped to control or

(continued on page 128)

Confined facilities create conflicts in San Diego County communities

by Alvin D. Sokolow, Ramiro E. Lobo *and* Kristen Hukari

Edge conflicts often concern agricultural production methods that are different than the typical open field-crop operations found, for example, in Merced and Monterey counties. In particular, confined-animal production facilities can adversely affect residential neighbors, as recent events in the San Diego County communities of Ramona and Oceanside illustrate. The conflict associated with two poultry ranches in Ramona was relatively severe, as marked by its longevity, persistence of formal neighbor opposition and local government regulatory activity. Issues concerning a plant nursery in Oceanside were mild by comparison.

Ramona poultry farms. Twenty-five miles northeast of San Diego, Ramona is an unincorporated community that has lived with the odors and other impacts of major turkey and chicken facilities for most of a century. But residents' complaints starting in 2000 about two particular egg ranches, introduced a new level of agricultural-residential conflict. Criticism focused on health and air-quality problems, and odors and flies emanating from the two egg ranches, part of 10 such facilities in San Diego County owned by a family that had been in the poultry business for three generations. The two ranches were relatively older facilities, and some interviewees attributed the problems to a lapse in ranch management related to the recent death of the father of the family and a shift in control to two young brothers.

Nearby residents protested to the county supervisor, who became personally involved in the issue, as well as to the San Diego County Department of Environmental Health (DEH) and other agencies. Residential neighbors filed numerous complaints between 2000 and 2002, including four during a 3-day period in May 2002. At the same time, the two ranches came under increasing scrutiny from DEH staff, who reported excessive fly populations resulting from accumulated manure piles during regular inspections, and who issued violation notices in 2000 and 2001. In May 2001, the ranch owners and managers were ordered to appear before the county's Fly Abatement Appeals Board (FAAB) for failure to correct the problem. Twenty-five residents attended the hearing, which produced an order to abate the fly-breeding hazard and required manure-management procedures. After a second FAAB hearing in August 2001, the county filed a civil action in Superior Court against the owners, seeking penalties and injunctive relief for violations of county codes and the creation of a public nuisance.

A settlement agreement in November 2001 called for certain manure disposal and sanitary measures and a $25,000 civil penalty. However, the neighbors' complaints continued, and the supervisor met several times with area constituents. In June and July 2002, the two parcels were sold to nonfarmers and ranch operations ceased.

Oceanside nursery. In this coastal city 30 miles north of San Diego, the involvement of residential neighbors in edge issues was relatively subdued and limited. Shortly after a large flower nursery was established in the Morro Hills area in 1998, neighbors began to complain to the greenhouse operator about noise, truck traffic, late hours, outdoor lights, litter and other problems.

The edge conflicts in Ramona and Oceanside resulted entirely from commodity production and facility management issues.

The conflict eventually led to the revision of Oceanside's zoning ordinance in summer 2000, which (1) distinguished between open ground agriculture and operations in structures, (2) specified where nursery activities could be located on a farm site and (3) established new development standards. Fearing more burdensome restrictions than had been proposed, growers joined in the negotiations with homeowners and city planning staff that led to the new policy.

The conflict was constrained by city and county procedures. Oceanside deliberately supports commercial farming, particularly in designating an agricultural district — which includes South Morro Hills — where large-scale agriculture is encouraged and only low-density housing is permitted. San Diego County also has a mechanism intended to moderate edge problems, the Agricultural Interface Board. In early 2000, some of the parties involved requested that the agricultural commissioner convene the board, which is composed of technical experts, to mediate the greenhouse conflict. This effort was not successful.

Urbanization conflicts. How do these events compare with edge conflicts in in the four Central Valley communities (see page 121)? Unlike Merced and Monterey counties, the urban orientations of new residents were not noticeable factors in the development of conflicts. Newcomers were not prominent among the residential neighbors who complained about the egg ranches and nursery operation. The edge conflicts in Ramona and Oceanside resulted from commodity production and facility management issues.

The second important difference is that the two San Diego County communities made substantial use of local government policies and mechanisms that were largely absent in Merced and Monterey counties. County government regulatory agencies were actively involved in both the Ramona and Oceanside situations, and Oceanside's agriculture-friendly policies that seek to protect farming as a desirable long-term land use helped to limit the conflict. Indeed, San Diego County and the city of Oceanside are exceptional in this regard, because few other California local governments have comparable programs for dealing with agricultural-residential conflicts.

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(continued from page 126)
limit edge conflicts in the four sample communities. While some complaints from residential neighbors were submitted to county agencies, there is no indication from interviewees or other sources that they led to specific regulatory or other governmental actions. However, county governments were prominent in edge conflicts in two San Diego County communities (see sidebar, page 127), showing how public policies and their implementation can influence the incidence and intensity of edge conflicts.

What dollar amounts can be assigned to the costs of farming in edge locations?

Further questions

Several conclusions about the patterns of edge conflict in six communities in three counties (Merced, Monterey and San Diego) emerge from this exploratory study. Conflicts varied considerably by community or edge segment. Two factors explain conflict variations in particular cases: (1) the perceptions and backgrounds of residential neighbors and (2) farming practices. The most frequent and effective efforts to limit the scope and incidence of edge problems in the sample communities were farmers' adjustments — either mandated or voluntary — in their agricultural practices, at some cost to their bottom lines.

Considering the small sample size and the exploratory nature of this study, these are tentative conclusions or informed hypotheses. They lead us to the following list of questions for more systematic research that would require larger samples of communities and interviewees, including residential neighbors:

(1) What do residential neighbors in edge locations say about the impacts of nearby agricultural operations, and how do these perceptions compare to those of neighboring farmers?

(2) When, how and to whom do residential neighbors express their complaints about agricultural operations? Do organized and individual forms of opposition achieve different results?

(3) What dollar amounts can be assigned to the costs of farming in edge locations, in lessened efficiency, productivity and profitability?

(4) Do conflicts at particular edges lessen over time, as these areas become more stable and former newcomers become settled old-timers?

(5) How do spatial patterns — residential locations in relation to agricultural activity as revealed by geographic information system (GIS) mapping — affect the extent of edge conflicts?

(6) Finally, what is the relative effectiveness of various public policy measures — such as grievance procedures, right–to-farm ordinances, required buffers for new development and zoning — in avoiding or reducing edge conflicts?

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A new method is used to evaluate the strategic value of Fresno County farmland

by Evan E. Schmidt, James H. Thorne, Patrick Huber, Nathaniel Roth, Edward Thompson Jr. *and* Michael McCoy

Fast-growing Central Valley counties are collaborating to accommodate regional population growth while conserving farmland. *Above*, a subdivision in the Sacramento Valley.

Fresno County is a rich agricultural area that faces rapid urbanization and farmland conversion. The county is participating in a strategic, multi-county planning initiative aimed at making sustainable and regionally cohesive land-use decisions. To inform this effort, we conducted a farmland conservation assessment and identified strategic farmlands for prioritization in future conservation efforts. We identified environmental and human predictor variables that affect the viability of existing farmland, used a geographic information system (GIS) to integrate them, and created a countywide strategic farmland conservation map. We compared our analysis to status quo methods of prioritization and found that with our model the spatial output of highly valued farmland was shifted, narrowed and located adjacent to some of the county's most urbanized areas. These findings are influencing growth policies and farmland conservation planning in Fresno County.

Throughout the United States, land consumption and the conversion of farmland to urban development are rising (Heimlich and Anderson 2001). Nationally, cropland declined by 52 million acres between 1982 and 2003, while developed land increased by 35 million acres (NRCS 2007). Farmland loss to conversion and fragmentation can deteriorate agricultural economies and communities, and contribute to other social and environmental problems (Schiffman 1983). One aspect of this problem is the lack of long-range land-use planning processes to conserve agricultural lands. Land assessment is a critical tool for the development of strategic plans that address farmland conservation, but many regions lack the infrastructure and resources to conduct them. Geographic information systems (GIS) provide significant opportunities to improve land assessment and farmland conservation planning. This study expands current frameworks by integrating GIS into a landscape-scale farmland conservation assessment of Fresno County.

Farmland assessment frameworks

LESA. In 1981, the U.S. Department of Agriculture (USDA) adopted the land evaluation and site assessment (LESA) strategy to guide federal land-assessment efforts. LESA scores and values land parcels according to soil quality, water availability, proximity to sewer and urban services, and other localized characteristics (Pease and Coughlin 1996). LESA can determine a particular parcel's appropriateness for conservation efforts; however, it is not designed for assessment at a landscape scale. Some studies have applied GIS to the LESA system as a way of creating a more strategic land-use planning tool and have found the approach versatile and efficient (Hoobler et al. 2003; Dung and Sugumaran 2005). Another study found that combining GIS with LESA increased transparency in the land-assessment process (Tulloch et al. 2003). Additionally, GIS analyses have been used to identify cost-effective conservation strategies (Machado et al. 2006) and locations that could be useful in managing urban growth regionally (Stoms et al. 2009).

Access to data is an important limitation to integrating GIS and LESA (Dung and Sugumaran 2005). While LESA assessment is required for federal projects, it is not generally required for state, county and local projects, although a few local jurisdictions use the methodology. As a result, localities usually do not have the resources or motivation to implement LESA (King and Lamb 2001). However, GIS modeling of urban development can potentially identify future zones of conflict between urban and agricultural uses more accurately than sewer lines and service areas. Additionally, GIS allows for the broader generalization and analysis of larger geographic areas.

FMMP soils. California policymakers often rely on soil classifications from the Department of Conservation's Farmland Mapping and Monitoring

Program (FMMP), which tracks changes in agricultural and other land uses on a biennial basis, statewide and by county. FMMP classifies soil characteristics as prime, statewide importance, unique, local importance or grazing based on technical soil ratings and current land use (FMMP 2007). FMMP prime soils are defined as those with "the best combination of physical and chemical features able to sustain long-term agricultural production" (FMMP 2007). FMMP soil classifications offer important information about soil quality, the maintenance of agricultural lands and current irrigation characteristics. However, other factors should be considered when determining future farming viability.

Strategic farmland approach. We strove to improve the utility of LESA and FMMP by developing a strategic farmland approach to farmland assessment for Fresno County. Strategic farmland is defined as "land most likely to remain economically viable for high-value commercial agriculture in the long term, given its inherent characteristics and surrounding conditions" (Thompson 2008). This approach combines many variables to more accurately identify likely important farmlands. We compare the results of our approach with status quo LESA and FMMP-soils approaches to identify spatial changes in farmland conservation priorities.

Fresno County Farm Bureau

Farmlands designated as "strategic" had the highest soil productivity, access to affordable water, favorable microclimate for growing high-value crops such as citrus, and limited environmental sensitivity and urban growth pressure. *Above*, a water canal in the Fresno Irrigation District.

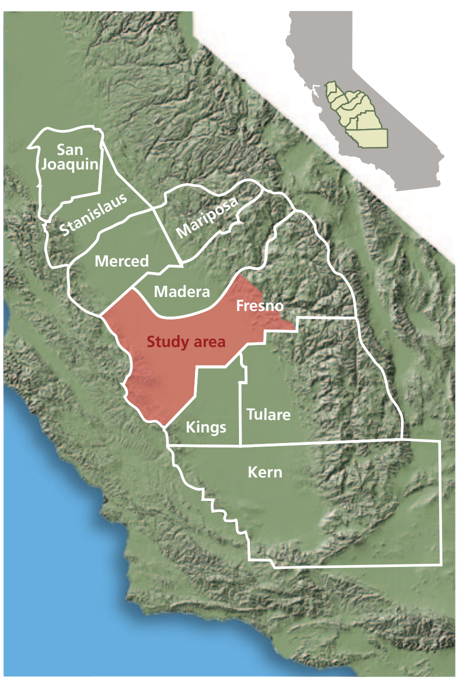

Fig. 1. San Joaquin Valley counties, and the Fresno County study area.

Fresno County study

The development of agricultural lands to urban uses is a particular problem in Fresno County. Located in the San Joaquin Valley (fig. 1), Fresno County has the highest market value of agricultural goods sold in any county in California or the United States (Census of Agriculture 2007). Between 1990 and 2004, 12,524 acres of high-quality agricultural land were converted to urban development in Fresno County, the third-highest conversion rate in California (AFT 2006). Fresno County's population is projected to increase from more than 900,000 in 2008 to nearly 2 million by 2050 (DOF 2007), which will increase its urban footprint. This growth may also fragment existing farmland, increase restrictions on farming methods and provide further economic incentives for conversion (Sokolow 2003; Jackson-Smith and Sharp 2008).

In recognition of potential impacts from human population growth, Governor Schwarzenegger established the California Partnership for the San Joaquin Valley (SJV Partnership) to attempt to mitigate negative outcomes. The Land Use, Housing and Agriculture work group created by the SJV Partnership is assessing current land use and suggesting policy changes (Schwarzenegger 2005). Fresno County participates through the San Joaquin Valley Blueprint Planning Process. This voluntary effort includes the eight San Joaquin Valley county councils of governments (COGs), the San Joaquin Valley Air Pollution Control District and the Great Valley Center, a nonprofit organization. The process is intended to chart a 50-year course for land-use planning and transportation in the region.

This process provides an opportunity to create a regionally cohesive and strategic farmland conservation plan with specific targets and priorities. To complement the San Joaquin Valley Blueprint Planning Process, and in order to avoid future losses of world-class farmland and the decline of agriculture as a major source of revenue, Fresno County is conducting regional land assessments and developing its strategic plan for agricultural conservation, urban development and transportation (SJV Partnership 2006).

Modeling farmland conservation

In 2007 and 2008, the Council of Fresno County Governments (Fresno COG) commissioned the American Farmland Trust (AFT), a nonprofit farmland-conservation organization, to design a model farmland conservation program that facilitated public participation in the program design, documented and assessed current agricultural conditions and trends, and made policy recommendations. For this effort, and in conjunction with AFT, we developed a strategic farmland-conservation assessment model for Fresno County by identifying environmental and human variables that have an impact on the viability (the potential to maintain agricultural productivity in the future) of existing farmland.

The highest ranked and most viable farmland, based on these variables, was determined to be strategic farmland that would be prioritized for conservation (Thompson 2008). We integrated a series of environmental and human variables into a GIS, ranked the results and excluded lands classified as nonagricultural by the FMMP (2007) to create a countywide strategic map of Fresno County farmland.

The factors that we considered were land characteristics that typically influence future farming viability, and were identified by agricultural professionals and local experts who participated in the San Joaquin Valley Blueprint Planning Process. The five most influential factors for the long-term economic viability of agricultural land were selected (table 1).

The first three — soil productivity, water cost and reliability, and microclimate — have a positive influence on agriculture. Soil productivity reflects soil quality as described by the FMMP. Water cost and reliability reflect its availability and vulnerability to restrictions and/or service interruptions. Microclimate, a variable chosen by local experts as critical to citrus crops, describes locations where climatic factors enable the growth of citrus, an important and high-value crop in Fresno County.

The remaining two factors, environmental sensitivity and urban growth pressure, have potentially negative impacts. Environmental sensitivity refers to the regulations accompanying the presence of wetlands, vernal pools and/or endangered species. The projected urban growth pattern was based on a model to identify areas of expected urbanization over the next 50 years, based on a zoning policy scenario selected by the SJV Partnership (2006) that concentrates future growth into and around existing urbanized areas. The Partnership's policy aims to use the benefits of increased urban density as an incentive to reduce land consumption and environmental impacts, and increase mass transit. Urban growth is assigned to occur within or adjacent to existing cities. This scenario would reduce the consumption of agricultural land compared with the status quo (i.e., no change in current land-use policy).

We used the UPlan land-use allocation model, a spatially explicit urban growth model, to project future urban growth (Johnston et al. 2002). UPlan uses county and city general plans (including zoning), projected human population growth, and development attractor and detractor values to model where development is likely to occur. We believe that the UPlan approach is preferable to traditional methods of assessing threats to farmland, such as proximity to a city's sphere of influence, which in California has legal meaning as a plan for the probable physical boundaries and service area of a local agency, sewer lines or other urban development. UPlan permitted us to more completely assess conditions that influence future development patterns.

Blueprint planning participants in Fresno County — who selected the key variables used in this study — identified similar drivers to those noted in the literature. Zurbrugg and Sokolow (2006) identified soil productivity and urban growth pressure as important variables in determining parcel suitability for national agricultural conservation easement programs. Soil productivity and urban growth pressure were also identified as key variables in this study. Additionally, according to Zurbrugg and Sokolow, conservation-easement program directors often value flexibility for individual programs to determine important and locally unique variables. The other variables in this study, including microclimate, water accessibility and environmental regulatory actions, were local features that blueprint planning participants agreed were specifically influential to future farming viability in Fresno County.

We developed GIS maps of the five model variables by combining the multiple data sources for each into a single GIS layer (table 1). Each variable layer was converted to a 100-by-100-meter grid. The variables were classified by scoring them from 0 to 12 for each grid cell, with positive factors weighted on an increasing scale and negative factors on a decreasing scale. Scores from all grids were added, producing an aggregate value for each grid cell, which was portrayed as an output grid scaled from

TABLE 1. Factors and data used to calculate strategic farmland values*

Factor	Data set
Soil productivity	Farmland Mapping and Monitoring Program (FMMP) important farmland data, 2006. Values given: Prime farmland = 12 Farmland of statewide importance = 10 Unique farmland = 8 Farmland of local importance = 6 Grazing land = 4 Urban land = 0
Water cost and reliability	Agriculture commissioner's office mapped the county based on existing knowledge of water availability and cost. Members of the agricultural community reviewed the findings at meetings throughout the county. Values given: Good water availability and affordability = 12 Marginal water = 6 Grazing land or no water = 0
Microclimate	Citrus crops in Fresno County require a unique microclimate. Department of Water Resources crop data (DWR 2000) was used to identify areas where citrus is now grown. 1990 PRISM data (PRISM Group 1990) was used to determine the range of values for January low temperature, July high temperature, annual precipitation and relative humidity in these areas, which was assumed to define the optimum microclimate for citrus crops. PRISM data for all other areas was compared to the optimum conditions, with aggregate scores recalibrated to a 12-point scale with the highest scores representing the most strategic land for citrus production.
Environmental sensitivity	This layer combined data for vernal pools (USFWS 1998), other wetlands (USFWS 2007) and endangered species (DFG 2006). Vernal pools and wetlands were all given a score of 0. The likelihood that endangered species were present was given a score from 0 (very high probability) to 12 (little or not likely). The three factors were overlaid and given the minimum value of any of the three factors on a 0 to 12 scale.
Urban growth pressure	The UPlan model (Johnston et al. 2002) directed urban growth, projected to 2050, to occur primarily within city spheres of influence. Excess growth was to occur immediately adjacent to existing cities and all projections occurred with densities ranging from five to 16 dwelling units per acre or a gross residential density of 7.1 dwelling units per residential acre. All grid cells where UPlan-modeled growth was projected received a score of 6; all other land received 12.

* Strategic farmland values: Low (0–34), medium (35–49), high (50 to 54) and very high (55–60).

0 to 60. The output values were classified into four categories representing strategic farmland values: low (0 to 34), medium (35 to 49), high (50 to 54) and very high (55 to 60).

We reclassified FMMP prime soil as present or absent (1 or 0), and high and very-high strategic farmland designations as present (10) or absent (0). Using spatial analysis, we then summed the two classifications, which resulted in four farmland categories: 0, no prime or strategic land present; 1, prime land present; 10, strategic land present; and 11, prime and strategic land present. We then compared the location and extent of FMMP prime soil and strategic farmland model outputs.

Value of farmland estimated

The strategic farmland analysis identified the extent and location of very-high, high-, medium- and low-value farmlands, representing the combined soil, water, citrus microclimate, urban pressure and environmental sensitivity values (fig. 2).

Very-high-value farmland (55 to 60) makes up about 343,321 acres (8.9%) of the total study area, concentrated in the eastern and southeastern portion of Fresno County (fig. 3), in areas without existing or projected urban

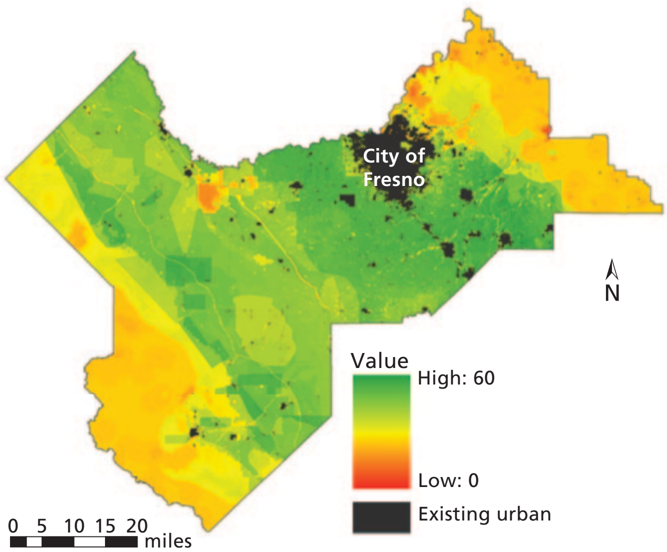

Fig. 2. Raw scores for the Fresno County strategic farmland assessment, combining soil quality, water quality, presence of citrus microclimate, urban pressure and environmental sensitivity.

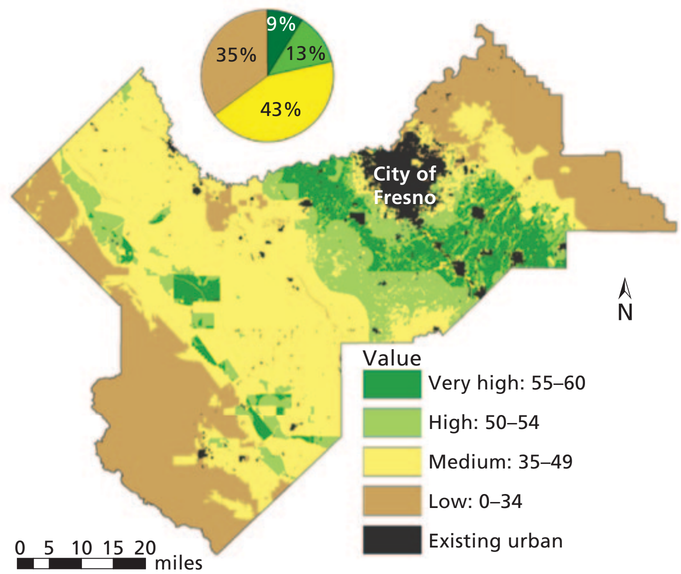

Fig. 3. Fresno County strategic farmland results interpreted and designated into classes.

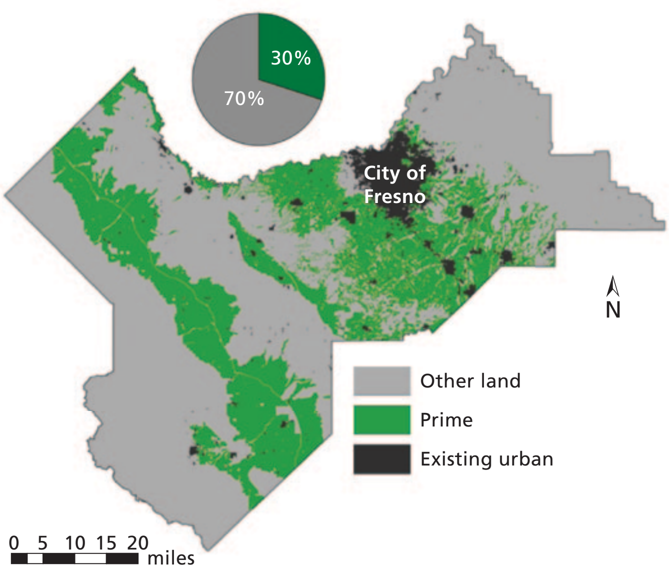

Fig. 4. Farmland Mapping and Monitoring Program (FMMP) prime soil classification for Fresno County.

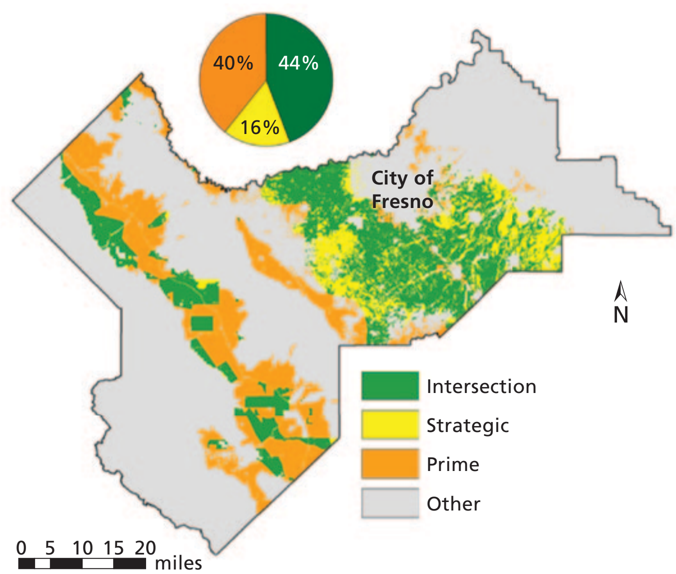

Fig. 5. Comparison map of FMMP prime soil and strategic farmland designation (scored 50 to 60). "Intersection" describes locations where both FMMP soils and strategic farmland results overlap; "strategic" is where only strategic farmland is present; "prime" is where only FMMP prime soil is present; and "other" is all other land in the study area.

development. Very-high-value farmland is located in places with high-quality soil, reliable and low-cost water, and a citrus microclimate. Some areas with values of 55 to 60 extend to the west of the city of Fresno, and one very-high-value band runs through the western side of the county, reflecting locations where high-quality crops are being grown along an aqueduct.

High-value farmland (50 to 54) displayed similar patterns but had a wider extent than the very-high-value farmland. It extends further to the west and has a larger band along the county's western side. High-value farmland totaled 491,613 acres (12.8%) of the total study area. Very-high- and high-value farmland were combined to constitute the strategic farmland designation, or farmland that is given top priority in conservation efforts; 22% of the total study area fell in this category (fig. 3).

FMMP prime soils represent existing farmland conservation targets that make up 30% of the total land area and occur throughout the study area (fig. 4).

We found an 821,722-acre (44.1%, excluding the "other land" category from the calculation) overlap between FMMP prime soils and the strategic farmland designation (fig. 5). The greatest area of intersection was in the study area's eastern portion, which contains prime soils, a high degree of water reliability and a citrus microclimate (southeast portion). There was also a commonly identified area along an aqueduct on the western side, although FMMP prime soils identified a wider extent of coverage than did strategic farmland. Some 13,212 acres (16.3%, excluding "other" land) were exclusively strategic farmland, while 1,271,891 acres (39.5%, excluding "other" land) were exclusively FMMP prime soil. The strategic farmland designation identified the highest-valued land in the eastern portion of the study area. It had a wider extent in the east than FMMP prime soils, in recognition of the other positive variables, including water and microclimate. FMMP had a wider extent in the west, where prime soils are present but water is more costly or unreliable. The FMMP maps also identified some prime soils surrounding the cities of Fresno and Clovis in the northeast section of the study area. These were not designated as strategic farmland because UPlan model outputs indicated that the area was likely to be developed by 2050.

Enhancing existing frameworks

This strategic farmland analysis contributed critical information about future farmland viability compared to the prime soil assessment. The presence of prime soils was an important value for farming viability; however, water availability and microclimates were also important. Urban pressure and environmental barriers had existing and potential negative influences on long-term farmland viability. For Fresno County, where so much farmland is designated as prime soils, the use of additional assessment criteria to support farmland conservation decisions was critical.

Our study expanded on the application of GIS methods to a LESA framework. Maps for the variables used here — soil quality, climate, water availability and environmental sensitivity — can be developed regionally, and urban-development pressure can be modeled to explore how it affects farmlands. Finally, local agricultural experts and stakeholders can supply critical information about local conditions and help to fill data gaps. This combination of existing data, trend modeling and specialized local knowledge created a more nuanced and detailed map of where future farming is likely to be successful than did the FMMP prime soil classification by itself.

One important contribution to the LESA framework was the inclusion of modeled urban development to evaluate urban growth threats. Standard LESA methods examine the proximity to sewer systems and other development as a measure of potential future conflict. This approach is limited because these factors cannot always accurately predict the location of future development. UPlan modeling predicts future development more accurately by integrating current development patterns with planning policy and other development attractor and detractor variables. The urban growth outputs from UPlan illustrate how current planning policy, as defined by zoning designations in a county's general plan, can affect agricultural viability. The UPlan scenario we used allocates growth by considering compact growth densities and filling spheres of influence first, before allowing growth to overflow sphere-of-influence boundaries. In Fresno County, we found that the majority of growth to 2050 could fit into existing spheres of influence. This important information challenges decision-makers to set and maintain policies that encourage compact growth

San Joaquin Valley applications

The American Farmland Trust (AFT) used the strategic farmland analysis to make three main policy recommendations to the Council of Fresno County Governments (COG). The Fresno COG advisory committee subsequently integrated these recommendations and the strategic farmland analysis into their county and blueprint planning processes:

Create a strategic agricultural reserve. This reserve would be made up of land designated as strategic farmland. Nonagricultural development, transportation projects and public construction projects would not be permitted within the reserve unless there were no feasible alternative locations.

Set objective criteria. Fresno County policymakers and the Fresno County Local Agency Formation Commission (LAFCo) should set objective criteria for expanding each local agency's sphere of influence and evaluating development in unincorporated areas. This would ensure that infill growth and compact development are prioritized before the development footprint is expanded. These policies would severely limit a city or unincorporated area from expanding its sphere of influence or development zones, except in rare circumstances.

Establish a stewardship council. A nonregulatory, public-private stewardship council consisting of 15 community leaders should be created to oversee the strategic agricultural reserve, provide accountability and facilitate the effective implementation of policies.

Land assessment for future farming viability is a critical component of farmland conservation and land-use planning.

and infill development in order to preserve Fresno County's highest-value farmland (see box, page 133).

This assessment served as a pilot for a regionwide strategic farmland analysis of the San Joaquin Valley. The methods tested in Fresno County are usable in other counties, and reactions to the strategic farmland analysis by the agricultural community in Fresno have helped guide efforts to analyze farmland prioritization in the San Joaquin Valley. One problem that was noted in Fresno County was incorporating the urban growth pressure layer into the model as one of the five variables. A preferred approach would have been to add the other four layers, and then overlay the urban pressure layer to look for intersections. This change is being made in the San Joaquin Valley assessment.

Making informed decisions

Land assessment for future farming viability is a critical component of farmland conservation and land-use planning. Policy programs and local planning agencies must assess farmland before implementing policies and programs aimed at farmland conservation. Decisionmakers need to account for multiple types of variables when making assessments. LESA provides a framework for land assessment, but is not designed as a strategic planning tool. The application of GIS to existing land-assessment practices can update and reinvigorate these techniques. The landscape modeling approach presented here can provide informed decision support for regional planning efforts.

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RESEARCH ARTICLE

Mitigation techniques reduce sediment in runoff from furrow-irrigated cropland

by Rachael F. Long, Blaine R. Hanson, Allan E. Fulton *and* Donald P. Weston

Irrigation tailwater can transport sediments and sediment-associated agricultural pollutants to nearby waterways. To help protect the biota of surface waters, we evaluated the use of polyacrylamide (PAM, a synthetic material that flocculates sediments when added to water), vegetated ditches and sediment traps to mitigate sediment losses from furrow-irrigated fields. In a 2-year study, liquid PAM injected into irrigation source water most effectively reduced suspended-sediment concentrations in runoff from different soil types. Dry tablet and granule PAM formulations were also effective, as long as their placement in the furrows promoted their dissolution in irrigation water. Vegetated ditches resulted in intermediate reductions in suspended sediments in tailwater. The sediment traps were limited in their effectiveness by insufficient holding time for fine-grained particulates to settle out of the runoff.

Runoff from crop irrigation can cause sediment, nutrients and pesticides to flow into surface waters, degrading their quality. *Above*, a furrow-irrigated dry bean field in Chico was used to evaluate various methods of runoff mitigation to improve water quality.

The erosion of soil from cropland and transport of sediments via irrigation runoff can degrade the quality of surface waters by increasing turbidity and sedimentation. Beyond the physical impacts of sediment itself, sediment particles may potentially carry nutrients and pesticides and degrade surface-water quality.

In California's Central Valley, for example, there are 11 water-body segments listed as "impaired" under the draft 2008 Clean Water Act Section 303(d) list, due to sediment toxicity of agricultural origin. Many other segments are impaired due to specific particle-associated pesticides, such as DDT, dieldrin, lindane and pyrethroids. Pyrethroid insecticides, in particular, are widely used in California agriculture and are commonly found in sediments in creeks and agricultural drains at concentrations toxic to sensitive aquatic species (Weston et al. 2004, 2008; Phillips et al. 2006). Pyrethroid insecticides are extremely water insoluble and bind tightly to finer particulate sediments. After being applied to fields, pyrethroids primarily move off-site attached to suspended sediments in irrigation and stormwater runoff (Gan et al. 2005).

Practices used successfully to retain soil on croplands and mitigate the transport of sediments to surface waters include the use of polyacrylamide (PAM, a liquid or solid material synthesized from propylene) added to water to stabilize the soil (Sojka et al. 2007), vegetated ditches (Bennett et al. 2005; Lacas et al. 2005; NRCS 2008; Moore et al. 2008) and sediment traps or basins that retain tailwater long enough to allow particles to settle (NRCS 2010). We evaluated PAM using a variety of application methods, and contrasted its effectiveness in concurrent trials with vegetated ditches and sediment traps.

Experimental sites and design

This project was conducted in 2006 and 2007 in furrow-irrigated fields at the University of California, Davis, and California State University, Chico. The Davis soil type was loam with 40.2% sand, 37.2% silt and 22.6% clay, and the Chico soil was clay loam with 27.7% sand, 46.6% silt and 25.7% clay. Both sites consisted of four to six plots with nine to 10 furrows spaced 5 feet apart (depending on the site and year) that were 600 feet long. Each plot was set up and managed separately so that irrigation inflow, tailwater, sediment and pesticide movement were measured independently. In both years, Davis was planted with processing tomatoes and Chico with lima beans.

Gated aluminum pipe (Davis) or polypipe (Chico) was used to deliver

Sediment particles may potentially carry nutrients and pesticides and degrade surface-water quality.

groundwater to the test plots at an average flow rate of 12 to 20 gallons per minute per furrow, with a turbidity reading of 3.5 nephelometric turbidity units (NTU). McCrometer (McCrometer, Inc., Hemet, Calif.) flow meters were used to measure the total irrigation water applied to each plot. Irrigation surface runoff from each plot flowed into a toe drain at the end of the furrows, then through either broad-crested weir flumes (Davis) or trapezoidal flumes (Chico) equipped with a stilling well (Plast-Fab, Inc. Tualatin, Ore.) and pressure transducer and data logger (Global Water Instrumentation, Gold River, Calif.) to measure the runoff flow rate every minute.

The irrigation tailwater was then directed into either an earthen (unvegetated) ditch to represent an untreated control, or into vegetated ditches or sediment traps, depending on the irrigation event and runoff treatment under evaluation. All runoff was then directed into a main drain that provided a holding area with no outlet to percolate the runoff and avoid any contamination of surface waters. The following treatments were evaluated and replicated in repeated irrigations to measure the impact on sediment reduction in furrow-irrigated crops.

PAM. Treatments consisted of control plots (no PAM application) and liquid PAM injected into the irrigation water using an aqueous (PAM 25, 25% PAM, Terawet, San Diego, Calif.) or oil-based formulation (Soilfloc 300E, 37% PAM, Hydrosorb Inc., Orange, Calif.), and dry PAM formulations (Hydrosorb) using both granules (88% to 90% PAM) and tablets (40% PAM). The liquid PAM was injected into the source water by a peristaltic pump to achieve PAM concentrations (active ingredient) of usually 1 to 7 parts per million (ppm, or milligrams per liter), or up to 30 ppm in one trial.

In early trials, we placed PAM tablets and granules in the furrows within a few feet of the gated pipe at both sites, but the PAM was quickly buried due to turbulence and resulting soil erosion caused by the incoming water, rendering it ineffective. Subsequently, the PAM granules (1 or 2 ounces) or tablets (one or two) were placed in each furrow at either 100 feet, 300 feet or both distances from the gated pipe at the Davis site. This resulted in less turbulent flow and erosion and dissolved the PAM granules and tablets as the water flowed over them in the furrows. The concentration of dry PAM formulation in the surface runoff was 0.2 to 0.5 ppm, but was not determined in the water as it flowed down the furrows. Some of the PAM originally placed in the furrow was left over after each irrigation event. We did not investigate different dry PAM placements at the Chico site, but instead evaluated several methods of suspending PAM tablets in source water.

Water infiltration was calculated as the difference between the cumulative inflows and outflows during irrigation. We only discuss results of the 2007 PAM experiments because of problems with the liquid PAM injection in 2006.

Vegetated ditches. In 2006, three vegetated ditches 160 feet long by 5 feet wide and about 8 inches deep were established at both Davis and Chico with tall fescue sod *(Festuca arundinacea).* This ditch length was designed to handle the amount of tailwater expected for the scale of this study. In 2007, one vegetated ditch with similar dimensions was seeded with a mix of perennial ryegrass *(Lolium* spp.*)* and tall fescue at Chico the prior fall, at about 18 pounds (8 kilograms) per acre. For both sites and years, the grasses formed a thick thatch, visually covering nearly

Vegetated ditches 160 feet long, 5 feet wide and 8 inches deep were constructed in Chico and Davis, and planted with fescue sod (2006) or fescue and ryegrass seed (2007). Irrigation tailwater flowed through flumes and then into the ditch to capture sediment.

100% of the ground. The irrigation tailwater flowed through the flumes, then through the vegetated ditch at or below the height of the grasses.

Sediment traps. In 2007, three sediment traps approximately 60 feet long, 2 feet deep (at the water line) and 6.5 feet wide with sloped sides were installed at each site. The traps provided about 60 to 90 minutes of holding time, which was sufficient for course particulates to settle out. In addition, the traps were lined with plastic to prevent sidewall sloughing.

Irrigation and sample collection

Each field site was irrigated once prior to evaluating the mitigation practices, and sediment in the runoff was found to contain no detectable pyrethroids (< 1 nanogram per gram). Subsequently, the fields were cultivated and a pyrethroid insecticide was applied at each site at recommended field rates. Lambda-cyhalothrin (Warrior) was used at Davis at 0.03-pound active ingredient per acre, and zeta-cypermethrin (Mustang) was used at Chico at 0.05-pound active ingredient per acre. Within a few days of insecticide application, the experimental fields were irrigated and runoff was collected under the different mitigation practices. Each irrigation event included a control plot with no mitigation. This process (field cultivation, pesticide application and irrigation, unless otherwise noted) was repeated with five to six irrigation events per growing season.

Tailwater samples were collected from each plot approximately every 30 minutes from the onset of surface runoff until the water was turned off and flow had nearly ceased. Water samples were collected from the control and PAM plots just above the flumes used to measure surface runoff flow rates. For the vegetated ditches and sediment traps, tailwater samples were collected both before and after runoff passed through the mitigation measure. Water samples (16.9 ounces [500 milliliters]) were taken for total suspended-sediment concentrations and analyzed by filtering a known volume of water on a Whatman 934-AH glass fiber filter and weighing the dry particulate matter retained on the filter. The suspended-sediment-concentration data was combined with the flow measurements to estimate the average flow-weighted suspended-sediment concentration when integrated over the entire irrigation event. Suspended sediment was also collected by continuous-flow centrifugation of large-volume water samples (10 to 60 gallons [37.8 to 227 liters]), and the pyrethroid content was analyzed by the methods of You et al. (2008).

Sediment mitigation comparison

Suspended-sediment concentrations. Suspended-sediment concentrations in the control treatments (no mitigation) were highest for the first irrigation event at both Chico and Davis and declined with subsequent events during the season. They also were highest at the start of surface runoff for each irrigation event and decreased over time. For example, concentrations at Davis typically were 0.5 to 2 grams per liter at the beginning of each irrigation and declined to 0.1 to 0.3 gram per liter. At Chico, initial concentrations were 1 to 4 grams per liter and 0.3 to 0.7 gram per liter in the later stages of an irrigation.

The duration of the irrigation events ranged from 228 to 314 minutes at Davis and 260 to 435 minutes at Chico. Maximum tailwater flow rates ranged from 80 to 90 gallons per minute at Davis (43% average runoff) and 30 to 72 gallons per minute at Chico (18.9% average runoff). The runoff rates were more variable at Chico, depending upon whether and how deeply or lightly the soils were cultivated.

PAM. Liquid PAM at concentrations of about 2.1 ppm (estimated from PAM injection and irrigation-water flow rates) greatly reduced suspended-sediment concentrations (fig. 1). In subsequent irrigation events, both liquid PAM (about 5 ppm) and PAM tablets placed 300 feet down the furrow substantially reduced sediment concentrations (fig. 2). For the tablets, the initial sediment concentrations were higher shortly after runoff began, but after about 50 minutes the sediment concentrations were similar for both liquid and dry PAM formulations.

Suspended-sediment concentrations were similar for both PAM tablets and granules during the Aug. 14 irrigation at Davis (fig. 3). Dry PAM placed at both

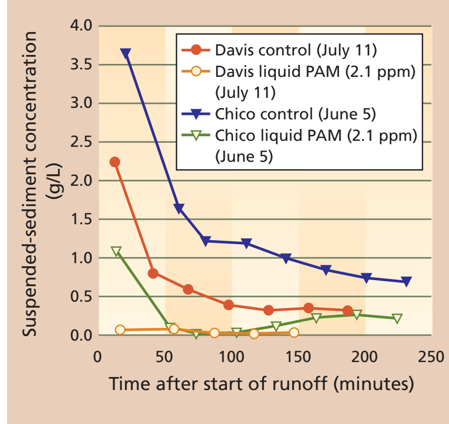

Fig. 1. Suspended-sediment concentrations (g/L) in irrigation tailwater during individual irrigation events for control (no PAM) and liquid PAM at about 2.1 ppm in source water, Chico and Davis, 2007.

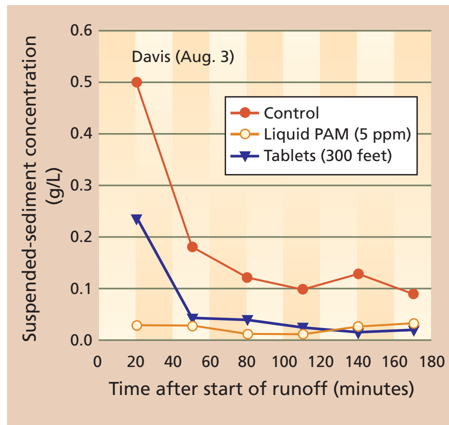

Fig. 2. Suspended-sediment concentrations (g/L) in irrigation tailwater during one irrigation event for control (no PAM), liquid PAM at about 5 ppm in source water, and two PAM tablets per furrow placed at 300 feet from the gated pipe delivering the source water, Davis, 2007.

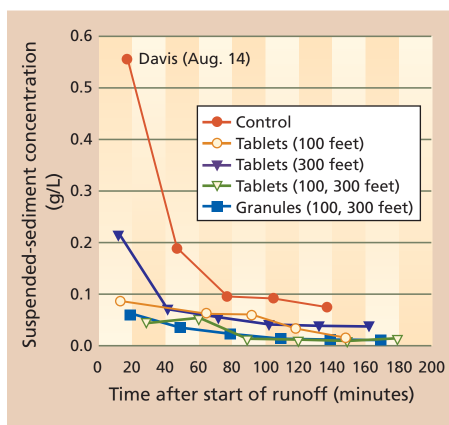

Fig. 3. Suspended-sediment concentrations (g/L) in irrigation tailwater during one irrigation event for control (no PAM) and two PAM tablets, or 2 ounces of PAM granules, per furrow placed at 100 feet, 300 feet or both distances from the gated pipe delivering the source water, Davis, 2007.

100 feet and 300 feet down the furrow from the source water was slightly more effective compared to a single-location placement, but this result was not consistent during other irrigation events (table 1).

In 20 combined PAM trials (15 at Davis, five at Chico) involving liquid and dry PAM (excluding placements at the head of the furrows and tablet suspensions in the water), the percent reductions in total sediment load due to the PAM treatments ranged from 57% to 92% (table 1). In 60% of the trials, suspended-sediment concentrations were reduced more than 80%, and more than 90% in 25% of the trials.

PAM concentrations ranging from 1.1 to 30 ppm in the source water achieved sediment reductions between 57% and 92% (table 1). The smaller value resulted from terminating the PAM injection when the source water reached the end of the furrows, after which sediment concentrations increased to those of the control. The average sediment reductions of liquid (86.7%) versus dry (77.9%) PAM treatments were statistically indistinguishable (t-test = 0.05, P = 0.108). The number of placements for dry PAM in the furrows was also statistically indistinguishable ($P = 0.217$) with sediment reduction values of 73.6% and 83.0% for the single- versus two-placement treatments, respectively.

TABLE 1. Suspended-sediment reduction in irrigation tailwater with different polyacrylamide (PAM) treatments, Davis and Chico, 2007

PAM treatment	Sediment reduction*	Details†
	%	
Davis, July 11		
Liquid	84.2, 91.8	Two plots: oil-based, 7 ppm, 2.1 ppm
Tablets	−66.1	Two per furrow at 10 feet, covered by sediment
Granules	23.4	1 ounce per furrow at 10 feet, mostly covered by sediment
Davis, July 24		
Tablets	86.7	Two per furrow at 300 feet
Davis, Aug. 3		
Tablets	71.5	Two per furrow, one each at 100 feet and 300 feet
Liquid	81.5	Oil-based, 5 ppm
Tablets	77.7	Two per furrow at 300 feet
Residual	45.4	Uncultivated furrows; liquid residual from July 24
Davis, Aug. 14		
Tablets	57.4	Two per furrow at 300 feet
Tablets	68.1	Two per furrow at 100 feet
Tablets	84.4	Two per furrow, one each at 100 feet and 300 feet
Granules	85.8	2 ounces per furrow, one each at 100 feet and 300 feet
Liquid	78.0	Water-based, 30 ppm
Davis, Aug. 30		
Granules	90.5	2 ounces per furrow, one each at 100 feet and 300 feet
Granules	79.3	1 ounce per furrow at 100 feet
Davis, Sept. 26		
Liquid	84.1, 91.9	Two plots: water-based, 5 ppm each
Chico, June 5		
Tablet	−42.7	One per furrow at furrow head, covered by sediment
Liquid	81.1	Oil-based, 2.1 ppm
Chico, June 15		
Tablet	38.9	One suspended in a porous bag at furrow head
Liquid	57.0	Oil-based, 5.9 ppm, terminated after water reached end of furrows and thereafter sediment levels increased
Chico, June 26		
Liquid	90.4	Oil-based, 1.5 ppm
Chico, July 6		
Tablets	75.6	Two per furrow in 10-foot-long uncultivated area at furrow head
Liquid	91.6	Oil-based, 1.1 ppm
Chico, July 17		
Tablets	69.4	20 suspended in water inside source mainline
Residual	47.8	Uncultivated furrows, liquid residual from July 6

* Negative values indicate sediment concentration from the PAM treatment greater than the control (no PAM).
† Distances (in feet) refer to how far dry PAM was placed from the gated pipe delivering the irrigation source water.

Suspending PAM tablets in the source irrigation water at the Chico site reduced the sediment load, but these treatments were not very effective compared to liquid PAM (table 1). Previous applications of PAM, in soil left undisturbed, reduced the sediment load in a subsequent irrigation by 45.4% at Davis and 47.8% at Chico (table 1). No statistically significant differences were found in the infiltrated amounts of water between the control and PAM-treated plots (Davis $P = 0.419$; Chico $P = 0.925$). The average infiltration was 0.89 inch for the control and 0.98 inch for PAM at Davis, and 1.85 inches for both the control and PAM at the Chico site.

Vegetated ditches. Combining results from Chico and Davis, the vegetated ditches significantly reduced total suspended sediments by 62% at 160 feet ($P < 0.1$, $n = 9$, analysis of variance [ANOVA]) (fig. 4). There was a gain in sediments in the earthen ditch due to erosion within the ditch, though nonsignificant ($P > 0.1$, $n = 7$, ANOVA). The average total suspended-sediment concentration was 0.34 gram per liter at the beginning of the vegetated ditch compared to 0.13 gram per liter at 160 feet. A typical irrigation of about 5 hours in our study resulted in an average of 42 pounds [19 kilograms] of sediment moving from the field to the head of the vegetated ditches. As the tailwater flowed through the vegetated ditches, 62% (26 pounds [12 kilograms]) of the total sediment was removed per irrigation event.

Sediment traps. In 2007, the sediment traps significantly reduced suspended sediments by 39% in the first irrigation event ($P < 0.05$, $n = 3$, ANOVA) but not in the second or later irrigation events (fig. 5). For the first irrigation event, the average sediment level above the traps was 0.98 gram per liter compared with 0.60 gram per liter below the traps. For the subsequent irrigation events, the average sediment level above the traps was 0.21 gram compared with 0.19 gram per liter below the traps ($P > 0.05$, $n = 3$, ANOVA). With an average of 51 pounds [23 kilograms] of sediment (all sites and years combined) reaching the sediment traps during our typical 5-hour irrigation, the trap retained 39% of this sediment (20 pounds [9 kilograms]) in the first irrigation, and almost none in the second and later irrigations.

Pyrethroid chemistry

Background concentrations of lambda-cyhalothrin and zeta-cypermethrin in suspended sediment in surface runoff at both Chico and Davis, prior to applying these insecticides in our trials, were below the minimum detection level of 1 nanogram per gram in both years of our study. After applying the pesticides, for all treatments combined, the lambda-cyhalothrin-treated plots at Davis had a median concentration of 431.5 nanograms per gram of dry sediment in the surface irrigation runoff, whereas runoff from the zeta-cypermethrin-treated plots contained 162.5 nanograms per gram.

There were no statistically significant differences in pyrethroid concentrations between the different treatments ($P > 0.05$). The treatments altered suspended-sediment concentrations, but not the pyrethroid concentration on that sediment. As a result, the reduction in particle-adsorbed pyrethroid achieved by the different treatments was equivalent to the amount of sediment reduced by the different treatments during an irrigation event. This relationship assumes that the vast majority of pyrethroid is present on the suspended sediment rather than dissolved in the water, a reasonable assumption given the strong tendency of these insecticides to bind to soils and be transported with suspended sediments.

Reducing sediment in runoff

Both the liquid and dry PAM formulations were highly effective in reducing sediment losses in surface runoff, with a reduction of more than 80% in suspended-sediment loads with most uses. Water-based liquid PAM is recommended because it is nontoxic, whereas carriers in the oil-based PAM are toxic to some aquatic invertebrates at recommended field application rates (Weston et al. 2009). A liquid PAM concentration of about 1 to 5 ppm in irrigation source water is recommended, depending on the soil type and degree of soil erosion. For dry PAM, 1 to 2 ounces of granules or one to two tablets per furrow appear suitable, as long as the material is placed at least 100 to 300 feet from the furrow head where it will not become covered with eroded sediment as water enters a field.

The vegetated ditches in our trials reduced sediment concentrations in surface runoff by 62%. This filtering process protects water quality by removing sediments and sediment-associated pollutants through sedimentation, soil infiltration and adsorption of pesticides on plant surfaces. These pollutants are then mostly degraded to nontoxic forms by physical and microbial processes (Lacas et al. 2005; Moore et al. 2008).

When vegetated ditches are installed on farms, they should be wide and dense enough to maintain a shallow, sheetlike flow depth at or below the vegetation height to provide adequate contact between flowing water and vegetation. In our trials with surface runoff ranging from 30 to 90 gallons per minute from the field, a 160-foot-long by 5-foot-wide, grass-filled ditch with

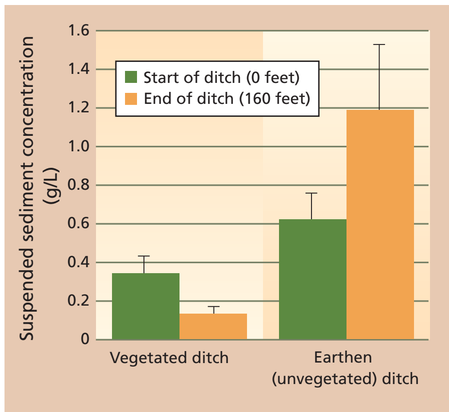

Fig. 4. Suspended-sediment concentrations (g/L) in irrigation tailwater in vegetated ditches compared with an earthen (unvegetated) ditch. Suspended sediments were significantly reduced by 62% in ditches at 160 feet, whereas unvegetated ditches showed a gain (though nonsignificant) in sediments due to soil erosion.

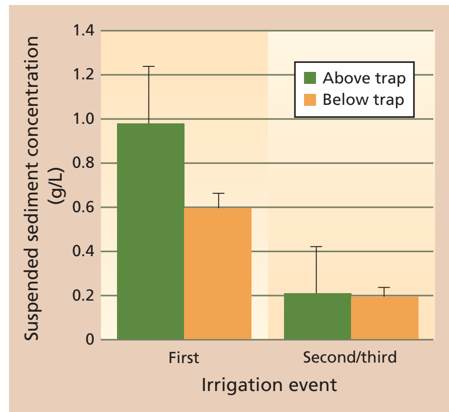

Fig. 5. Suspended-sediment concentrations (g/L) in irrigation tailwater at the sediment trap inlet and outlet. Suspended sediments were significantly reduced by 39% in the first irrigation, but not in second and later irrigation events.

In this study, traps reduced sediment in surface runoff after the first irrigation but not subsequent irrigations. The efficacy of this mitigation technique will depend on soil types and runoff flow rates.

a water depth of about 5 inches was sufficient to reduce sediments in irrigation tailwater by 62%.

The sediment traps resulted in some sediment reductions in surface runoff in the first irrigation but not in subsequent irrigation events. Such traps function by temporarily retaining irrigation surface runoff, which reduces the flow velocity and turbulence, and enables suspended sediments to settle out. Coarser-grained or larger-aggregated soil particles settle out of the runoff much more rapidly than finer-grained silt and clay particles, on which the majority of pyrethroids or other sediment-associated pesticides would be carried. As a result, the efficacy of the traps will depend on soil types and flow rates.

With higher flow rates and silty-loam soils, the retention time in sediment traps was not high enough in our study to retain the water long enough to allow the fine silts to settle out before the water was released into drains. In these cases, larger tailwater ponds or return systems would be recommended. The sediment traps may have been more effective during the first irrigation event in our trials because the disruption in aggregate stability, particularly in the beginning of the season when fields are extensively cultivated for planting, resulted in higher levels of coarser particulates coming off fields, though we did not measure particle-size distributions in our traps.

PAM is commercially available, and costs per acre are within reason. Growers are already using it to mitigate sediment loss from furrow-irrigated fields; ours is the first study that shows it can be used to mitigate pyrethroids. Vegetated ditches and sediment traps are also being used on some California farms for this purpose.

The use of PAM, vegetated ditches and/or sediment traps will help prevent sediments and sediment-associated pesticides such as pyrethroids from moving off-site in irrigation tailwater. However, the degree to which these mitigation practices protect water quality will depend on soil type and the volume and velocity of the tailwater. As a result, site-specific guidelines will need to be developed and implemented for individual farms to best protect water quality when irrigation runoff occurs in furrow-irrigated crops, as found in Long et al. (2010).

Polyacrylamide (PAM) — a commercially available, nontoxic soil stabilizer — was highly effective in reducing sediments and pyrethroids when added to irrigation water in liquid or tablet form. *Left,* untreated runoff; *right,* runoff resulting from PAM-treated irrigation source water runs clear.

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Dry-season soil water repellency affects Tahoe Basin infiltration rates

by Erin C. Rice *and* Mark E. Grismer

Lake Tahoe's declining clarity makes the identification of runoff and erosion sources and evaluation of control measures vitally important. We treated relatively undisturbed, native, forested sites of 10% to 15% slope with surfactant and used a rainfall simulator to investigate the effects of repellency. We compared infiltration measurements made by the simulator and a mini-disk infiltrometer (MDI). Runoff was produced by all plots with untreated water, but only two of 12 plots with surfactant. At volcanic soil sites, infiltration rates using surfactant exceeded those with water by only 20% when there was little litter cover, but with substantial litter the infiltration rates increased threefold. Similarly, at the granitic soil sites surfactant-enhanced infiltration rates were four times greater with scant litter, and eight times greater with substantial litter cover. Postsimulation soil moisture content and wetting depths were greater with the surfactant treatment. Excavations under surfactant treatments revealed that discontinuities in the soil's hydrophobic organic layer resulted in preferential infiltration zones in the mineral soils below.

Lake Tahoe's famed clarity is declining due to increases in sediments and nutrients, which coincide with nearly a half-century of urban growth in the region. Soil repellency may be a factor contributing to erosion and runoff into the lake.

Lake Tahoe is a spectacular, deep mountain lake of exceptional clarity, historically maintained due to low nutrient (ultra-oligotrophic) conditions. Since continuous water-quality monitoring began in the early 1960s, algal growth has increased by more than 5% per year, with a corresponding 1-foot-per-year decline in water clarity.

The consensus among researchers is that: (1) the documented decline in clarity coincides with more than 40 years of growth in urban areas (now 10% of total land area), which contribute 72% of fine particles to the lake (TERC 2008); (2) lake-floor sediment accumulations correspond with periods of human activity (Heyvaert 1998); (3) annual phosphorus loading to the lake depends directly on sediment concentrations (Hatch 1997); and (4) fine (1 to 8 microns [μm]) particles diminish the lake's clarity by transporting adsorbed nutrients and scattering light while in suspension (Swift et al. 2006). Understanding the sources, transport and means of controlling fine-particle delivery is essential to stem the water quality decline.

Infiltration, runoff and erosion near Tahoe have been studied extensively, yet knowledge of repellent (hydrophobic) soil conditions often remains anecdotal or oversimplified. Soil water repellency can be induced by fire (Doerr et al. 2010) and also occurs during late-season dry conditions. The commonly acknowledged paradigm that hydrophobicity is responsible for greater runoff and erosion after fires (Robichaud 2000), while accurate in some locales, has not always been verified (Doerr and Moody 2004).

Larsen et al. (2009) noted that high-severity fires alter the vegetative cover and characteristics of mineral soil, making it difficult to separate the effects of fire-induced soil water repellency from other changes in soil characteristics and surface cover. In the Western states, Pierson et al. (2008) found that repellency was greatest on unburned slopes and that dry-season variability had a more substantial impact than fire. Postfire hydrologic responses were not attributed to intensified repellency, but rather to the increased connectivity of runoff sources following the removal of vegetation and soil cover. Seasonal, non-fire-induced repellency has been considered a function of soil moisture, but its recurrence following wet periods appears to depend not only on soil drying, but also on input or

Researchers studied soil repellency with and without surfactant treatments at four sites in the Lake Tahoe Basin.

the redistribution of hydrophobic substances (Doerr and Thomas 2000).

The realization that few studies actually isolated the hydrologic effects of repellency prompted new research directions. Leighton-Boyce et al. (2007) modified earlier methods developed in Southern California, in which surfactants were applied during rainstorms on burned slopes. Surfactants may be used as wetting agents to induce infiltration and mimic normal infiltration conditions. The 2007 study in Portugal used surfactant-treated water in a rainfall simulator to isolate hydrophobic effects.

We investigated plot-scale hydrologic responses — including infiltration, runoff and sediment yield — due to seasonal hydrophobicity at four relatively undisturbed, native, forested sites in the Tahoe Basin (fig. 1). (The entire basin was logged in the 1850s, and partially again in the 1920s.) We present baseline hydrologic responses to repellency that may be used for comparison to similar data gathered at disturbed sites targeted for erosion-control measures. Data from two infiltration measurement devices, a rainfall simulator and the more readily deployed mini-disk infiltrometer (MDI), was also compared and evaluated.

Lake Tahoe study areas

The Truckee and Blackwood Canyon sites had volcanic soil, and Bliss State Park and Meyers road cut were granitic. The sites were similar in slope (10% to 15%), and rainfall simulations had been conducted previously at all four under similar conditions to those considered here (Grismer et al. 2009) (table 1).

Surfactants reduce water surface tension, are commonly used (e.g., detergents) and generally nontoxic. We modified methods presented by Leighton-Boyce et al. (2007), and used Pro-Spreader Activator surfactant (Target Specialty Products, Fresno, Calif.) mixed with available groundwater to a concentration of 0.25%, the upper limit of the manufacturer's recommendation. Initial field tests showed that this concentration was suitable to induce infiltration through repellent soils in the Tahoe Basin.

After plots were established at each site, we measured initial soil moisture (Campbell Scientific TDR moisture meter) and soil strength (cone penetrometer depth to refusal, 350 pounds per square inch).

Following the artificial rainfall test to determine infiltration and runoff rates, moisture and density (using cone penetrometer depths as an index) were again measured along with litter depth and composition, which was visually estimated. Measurements were taken with an MDI in areas adjacent to the rainfall-simulator plot frames at each site. Soils were hand-excavated to 10 inches, to observe wetting patterns and depths.

The rainfall-simulator tests were also slightly modified from the description by Grismer and Hogan (2004). Without foreknowledge of the treatment to be applied, 6.9-square-foot (0.64-square-meter) plot frames were installed, and simulated rainfall was applied at 4.7 inches per hour (120 millimeters per hour) for the duration necessary to produce steady runoff and fill sequential 6-ounce (175-milliliter) sample bottles. This sometimes took more than 70 minutes.

Rainfall simulations. Infiltration rates were calculated as the difference between the applied rainfall and runoff rates, and were assumed to be greater than the application rate when no runoff occurred. Three replicates of each treatment were conducted at each site for a total of 24 rainfall simulations. Following a series of surfactant treatment simulations, all equipment was cleaned with a mild bleach solution prior to the untreated-water simulations. Collected runoff samples were filtered in the lab (Whatman #541 and 0.45-micron filters). The sediment samples were oven-dried at 221° F (105° C) and then combusted at 806° F (430° C) to determine organic matter content (Grismer et al. 2008).

MDI. An MDI (Decagon Devices, Pullman, Wash.) was also used at each site to determine infiltration rates. These devices have been deployed by the U.S. Forest Service to evaluate hydrophobicity. Water held in a chamber resembling a graduated cylinder infiltrates when suction is sufficient to break

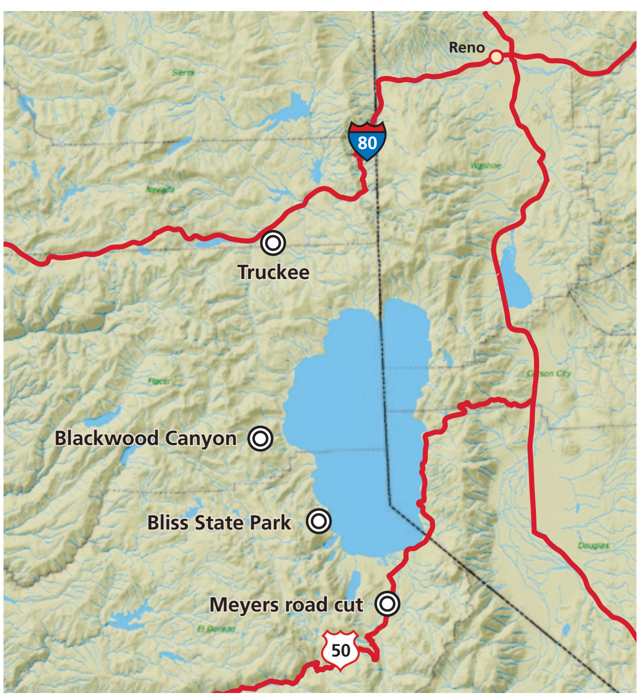


Fig. 1. Tahoe Basin site map. Source: relief map, mytopo.com.

TABLE 1. Site information and soil classifications									
Site	Soil series	Soil type	Location	Elevation	Aspect	Slope	Taxonomic classification*	Surface texture	Vegetative cover
				feet (meters)		%			
Truckee	Inville	Volcanic	39°19′37.75″ N 120°09′12.76″ W	5,806 (1,770)	N	14.7	Loamy-sketal, isotic, frigid Ultic Haploxeralfs	Gravelly coarse sandy loam	Jeffrey pine (*Pinus jeffreyi*) with some lodgepole pine (*Pinus contorta*)
Blackwood Canyon	Waca	Volcanic	39°04′44.01″ N 120°12′39.63″ W	7,020 (2,140)	N	10.2	Medial-skeletal, amorphic, frigid Humic Vitrixerands	Cobbly coarse sandy loam	White fir (*Abies concolor*) and lodgepole pine
Bliss State Park	Meeks	Granitic	38°58′39.30″ N 120°06′16.88″ W	6,872 (2,095)	NE	11.4	Sandy-skeletal, mixed, frigid Humic Dystroxerepts	Very stony loamy coarse sand	Pine needle cover
Meyers road cut	Gefo	Granitic	38°53′00.0″ N 120°00′09.6″ W	6,298 (1,920)	E	13.9	Sandy, mixed, frigid Humic Dystroxerepts	Gravelly loamy coarse sand	Scattered, large lodgepole and Jeffrey pines

* Source: USDA-NRCS Soil Survey 2007.

surface tension across a porous disk at the base (Robichaud et al. 2008). The constant-head (water level) adjustment was set at 0.79 inch (20 millimeters), and measurements were taken for 1 minute with the difference in volume used to calculate the infiltration rate. At each site surfactant and untreated water were each replicated 10 times.

Smaller sequential samples were also collected for texture analysis. The Coulter LS-230 particle-size analyzer uses laser-light scattering to produce particle-size distributions by volume. A revised version of the protocol developed by Eshel et al. (2004) was used to process the runoff samples. In the field, we collected 48 runoff samples from both volcanic and granitic sites and made composites for each site as needed for the analyses.

Statistics. Factorial analyses were conducted to test for significant interactions between site and treatment effects for rainfall simulation, MDI and particle-size distribution. For the rainfall simulation results this interaction was nonsignificant, providing the rationale to use a randomized design. No transforms were required to achieve normality. Infiltration rates by site and treatment were separated using Tukey's HSD test. The Spearman correlation was used to test for the correlation between rainfall simulator and MDI infiltration results. MANOVA repeated measures analysis was used to detect significant changes in some soil conditions following the rainfall simulations.

Analytical findings

We considered the results in terms of soil, runoff, infiltration and particle-size distribution. The soil section included measurements of several soil properties, which were repeated to test for changes before and after rainfall simulations. Runoff timing, sediment yield and organic matter content were contrasted between the two treatments (surfactant and untreated water). Infiltration rates were compared between and within (by treatment) each site for both methods. The MDI and rainfall-simulator data were also compared. Finally, particle-size distribution analysis revealed differences by soil type and any correlations between particle-size fractions and infiltration.

A rainfall simulator, *above*, at Bliss State Park was used at different rates to generate runoff and measure its sediment content.

TABLE 2. Pre- and post-rainfall simulation site conditions						
		Cone penetrometer depth†		Soil moisture		
Site	Treatment*	Initial	Final	Initial	Final	Mulch depth
		inches to 350 psi		········· % ·········		*inches*
Truckee	W	8.4 [9]	10.8 [9]	1.6 [9]	9.7 [9]	3.5
	S	6.2	9.4	1.8	17.3	3.7
Blackwood Canyon	W	3.8	5.0	2.3	16.4	0.6 [19]
	S	6.9	9.5	1.6	14.3	0.4 [19]
Bliss State Park	W	7.9	7.1	2.7	4.3	0.6
	S	9.2	11.1	3.0	19.7	0.6
Meyers road cut	W	15.3	17.5	2.0	3.7	4.3
	S	12.3	12.3	2.2	12.0	2.8

* W = water; S = surfactant.
† *n* = 24, except where noted by [ ].

Soils. Soil physical properties were measured before and after each treatment (table 2). Mulch depth did not differ significantly by site or treatment. Cone penetrometer depths, used as an index of soil strength, usually slightly increased following treatment, presumably as a result of increased soil moisture. The within-subjects MANOVA test comparing the results of depth-to-refusal measurements before and after treatments resulted in nonsignificant differences between means — thereby removing treatment as a variable affecting soil strength.

Averaged initial soil-moisture levels ranged between 1.6% and 3.0%. At all sites except Blackwood Canyon (volcanic soil), surfactant treatments resulted in higher final soil-moisture levels than untreated water. This difference was most pronounced on granitic soils, where postsimulation soil moisture was more than four times higher with surfactant than with water at Bliss, and three times higher at Meyers. The depth to continuous wetting differed significantly by soil type ($P = 0.0355$), treatment ($P < 0.0001$) and soil type/treatment interaction ($P = 0.0078$).

At every site, the surfactant caused deeper wetting than untreated water. The untreated water was more effective in wetting volcanic soils than granitic soils, which were nearly completely resistant to wetting (these soils had significantly less wetting with untreated water than the other soil type/treatment combinations). When surfactant was used, the virtually unwettable granitic soils were wetted to a depth of approximately 6 inches (15 centimeters). While dry "pockets" or layers above wetted soil were observed at all sites, preferential flow was most obvious at Meyers with the surfactant treatment.

Runoff. The effectiveness of surfactant treatment on runoff rates was obvious in the field and samples collected during runoff simulation (table 3); runoff was produced by all 12 untreated-water plots, but only two of 12 plots that received surfactant. The lack of runoff data from many surfactant plots made the statistical analysis of some variables difficult or impossible, but several comparisons are worth noting.

While the granitic soils produced no runoff when surfactant was used, each of the volcanic soils produced runoff from one surfactant treatment plot. Though runoff occurred from these two plots with surfactant treatment, the time to runoff was different. At Truckee, the single runoff-producing surfactant plot took 16 times longer to run off than the average time for the untreated-water plots. At Blackwood Canyon, the surfactant required about four times longer to produce runoff than the average from the untreated-water plots. Sediment yield and concentration was highest at Bliss State Park, followed by the Blackwood Canyon, Truckee and Meyers road

TABLE 3. Rainfall-simulation runoff results

Site	Treatment*	Depth to continuous wetting†	Time to runoff‡	Sediment yield‡	Sediment concentration‡	Organic matter‡§
		cm	*sec*	*lb/ac/inch*	*ppm*	*%*
Truckee	W	3.7 [15]	198	7,870	220	34.9
	S	6.7 [3]	3,270¶	4,460¶	170¶	81.3¶
Blackwood Canyon	W	6.6 [19]	723	22,800	850	43.5
	S	9.3 [3]	2,700¶	3,150¶	100¶	55.7¶
Bliss State Park	W	0.8	96	35,100	960	35.1
	S	6.6 [19]	NA#	NA	NA	NA
Meyers road cut	W	0 [3]	211	4,460	80	64.7
	S	5.8 [10]	NA	NA	NA	NA

* W = water; S = surfactant.
† *n* = 24, except where noted by [ ].
‡ *n* = 3, except where noted.
§ Organic content (% by mass combustion) of sediment collected during rainfall simulations.
¶ Only one of three simulations with surfactant treatment produced runoff at Blackwood Canyon and Truckee (*n* = 1).
# NA = not applicable (no runoff).

TABLE 4. Mini-disk infiltrometer (MDI) and rainfall-simulator infiltration rates

		MDI (*n* = 10)		Rainfall simulator (steady state)						
				Water				Surfactant		
Site	Statistic	Water	Surfactant	1	2	3	SE	1	2	3
		inches/hour								
Truckee	Mean	16.2	51.6	3.46	3.38	4.70	0.74	4.1	> 4.7*	> 4.7*
	SE	20.3	21.9							
Blackwood Canyon	Mean	28.7	34.3	4.05	4.58	4.70	0.35	4.4	> 4.7*	> 4.7*
	SE	12.4	11.8							
Bliss State Park	Mean	14.0	54.6	3.03	2.60	3.93	0.68	> 4.7*	> 4.7*	> 4.7*
	SE	17.5	24.3							
Meyers road cut	Mean	5.6	43.0	3.85	3.61	4.47	0.44	> 4.7*	> 4.7*	> 4.7*
	SE	2.5	18.5							

* No runoff occurred; infiltration rate was greater than rainfall rate of 4.7 inches/hour (120 millimeters/hour).

cut sites. Comparison of similar soil types showed that Blackwood Canyon produced about four times as much sediment as Truckee, while runoff from Bliss contained more than seven times as much sediment as Meyers. Runoff sediment organic-matter fractions were highest at Meyers (65%), followed by Blackwood Canyon (44%) then Bliss and Truckee (35%).

Infiltration. Rainfall-simulator-determined infiltration rates differed significantly by treatment at the Bliss site only (table 4). Factorial analysis revealed a significant interaction between site and treatment for the MDI results; treatment had different effects depending on the site. Additional analyses indicated that there was also an interaction between treatment and soil type, suggesting that whatever controlled the treatment effect at different sites was associated with soil type.

This was also confirmed by a similar treatment effect at the granitic sites, although Truckee and Blackwood differed from one another. Water treated with surfactant infiltrated much more efficiently than untreated water at all sites except Blackwood ($P = 0.2747$), where the infiltration rate with surfactant exceeded that for water by only 20%. The surfactant rate was greater than the untreated-water rate by a factor of about three at Truckee ($P = 0.0029$), four at Bliss (P = 0.0003) and eight at Meyers ($P < 0.0001$). The greatest infiltration rate was found at Blackwood Canyon using untreated water, but that site had the lowest rate with surfactant. The untreated-water infiltration rate at Blackwood was about twice that of Truckee or Bliss, and five times higher than at Meyers. Surfactant infiltration rates at Bliss and Truckee, which were nearly equal, were 25% higher than those at Meyers and 60% higher than Blackwood Canyon. MDI infiltration rates were much greater than those from the rainfall simulator, though they were significantly correlated (Spearman $R = 0.83$).

TABLE 5. Runoff sample sediment particle-size distributions for Tahoe Basin soils

Site	Statistic	D_{10}*	D_{25}	D_{50}	D_{75}	D_{90}
Volcanic (*n* = 7)	Mean	7.67	20.67	50.78	122.00	344.29
	SE	4.80	9.97	21.28	61.18	231.62
Granitic (*n* = 4)	Mean	28.18	71.80	208.00	568.00	1,021.50
	SE	12.52	25.21	83.00	179.20	235.33

* D_{xx} is the percentage of particles less than a given size (xx = µm).

Particle-size distributions. As found by Grismer et al. (2008), volcanic soils were much finer than granitic soils at each particle-size percentile (D_{10}, D_{25}, D_{50}, D_{75}, D_{90}), and particle sizes differed significantly by soil type (table 5). Volcanic particles were typically about one-fourth the size of granitic particles. Ten percent of particles occurring in runoff from volcanic soils were less than 8 μm, a size fraction considered detrimental to lake clarity (Swift et al. 2006). The relationship between particle-size distribution and infiltration rate appeared to be nonlinear, making the Spearman correlation an appropriate test. All particle sizes were strongly, negatively correlated with infiltration rates. For the rainfall-simulator-based infiltration rates, Spearman correlations for the D_{10}, D_{25}, D_{50}, D_{75} and D_{90} particle sizes were R = −0.86, −0.91, −0.83, −0.89 and −0.69, respectively; similarly, for the MDI-based infiltration rates, the Spearman correlations were R = −0.80, −0.70, −0.74, −0.68 and −0.76, respectively.

At the Meyers road cut site, a soil excavation shows water infiltrating the soil in "fingers" of flow.

At the Truckee site, dry patches or layers of organic material remained above the wetted mineral soil.

Surfactants and repellency

Differences in infiltration rates due to the surfactant treatment were unmistakable, as rates always increased — by a statistically significant margin at one site for the rainfall simulators, and at three of four sites for the MDIs. Increased infiltration rates with surfactants demonstrated the importance of soil hydrophobicity to possible runoff and erosion, and, if surfactant is a good model of wettable conditions, that repellency has a substantial effect on infiltration rates into mineral soil. However, the infiltration rates found with the MDI remained very high with untreated water, suggesting that the persistence of repellency in mineral soil upon contact with water is minimal. Much lower infiltration rates resulted from the rainfall simulators when native covers were maintained. Therefore, surfactant efficacy and the actual magnitude of the infiltration rate depended to a large degree on the soil cover conditions.

Surface litter. Surface litter layers were an important factor affecting wetting patterns following rainfall simulation. Native litter cover was most substantial at Truckee and Meyers. Beneath a layer of identifiable pine needle mulch was a layer of decomposed organic material (hemic/sapric ≤ 16% plant material still discernible) with a high degree of fungal activity mats (fungal mycelia with organic matter). Excavations following rainfall simulation indicated that this layer was different from the pine needle mulch because it was neither a storage zone delaying runoff nor a structural barrier encouraging lateral rather than downward movement. The highly decomposed organic layer was strongly and persistently hydrophobic, restricting infiltration into the mineral soil below. Discontinuities in this layer were responsible for preferential flow and wetting.

These wetting patterns were most obvious at the sites with the most litter, Truckee and Meyers. "Fingered" flow was most evident in the Meyers surfactant plots, while at Truckee there was considerable wetting below a large, dry, mineral layer. In the finer-textured Truckee soil, it appeared that runoff had preferentially infiltrated several inches into the mineral profile and then began to wet upward via capillary action. Sites with less litter, Blackwood and Bliss, had correspondingly less developed or nonexistent decomposed organic layers. Infiltration was not as concentrated, and preferential zones were not as obvious, although upon excavation it was apparent that dry patches or layers of organic material remained above the wetted mineral soil.

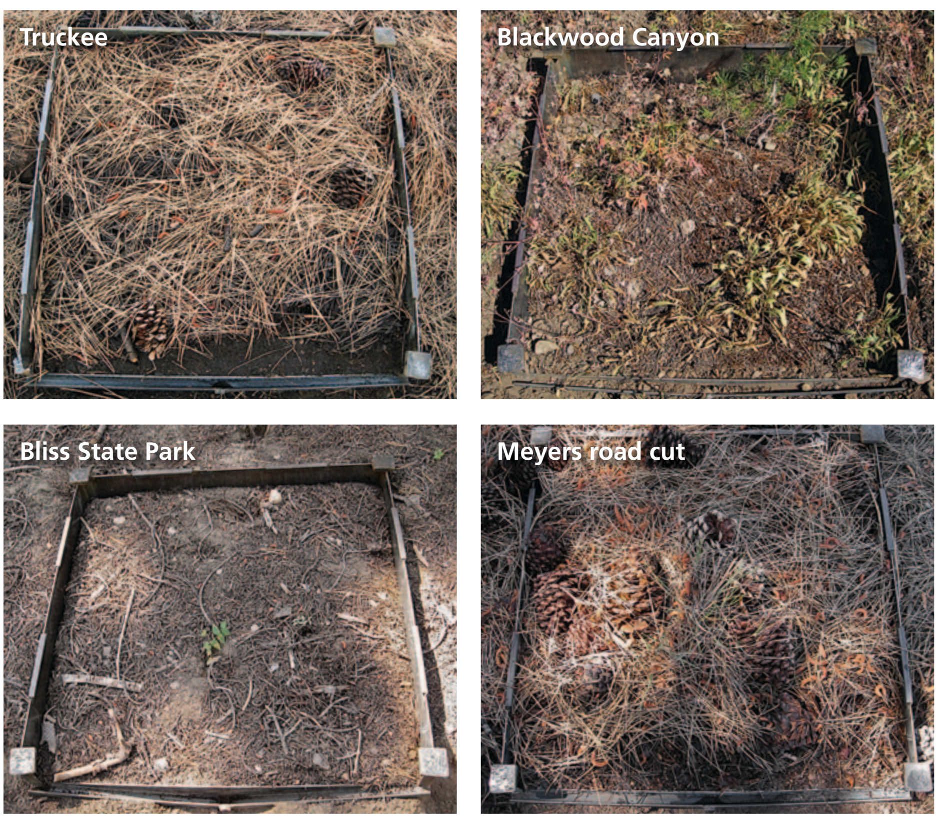
Meeuwig (1971) originally underscored the litter layer's importance as an infiltration-limiting factor, linking eight distinct wetting patterns and corresponding infiltration curves on bare and covered sites northeast of Lake Tahoe. At forested sites, the hydrologic effects of mineral-soil repellency are at some level subsumed by those of the partially decomposed organic layer. The differences in wetting of mineral soil between treatments were most pronounced on coarse, granitic soils, indicating that hydrophobicity plays a more important role with these soils compared to volcanic soils. Granitic soils exhibited almost no wetting by untreated water, but about 6 inches (15 centimeters) of continuous and more than 10 inches (25 centimeters) of intermittent wetting with surfactant.

Soil moisture and texture. The changes in soil moisture content also revealed the impact of the surfactant treatment on granitic soils. Following water treatment moisture contents doubled, but with the surfactant treatments they increased sixfold. The effects of soil texture on the establishment and degree of repellent conditions are complex. Coarse-textured soils have been associated with repellency because coarse particles have less surface area per unit volume than finer particles, making them more susceptible to coating by a limited supply of hydrophobic substances (Crockford et al. 1991). However, repellency is not exclusive to coarse soils; if fine-textured (25% to more than 40% clay) soils form aggregates (presumably with greater organic-matter content) they, too, are susceptible to the development of repellency conditions (Wallis et al. 1991). In some cases, very fine fractions have the highest degree of repellency (de Jonge et al. 1999).

Texture alone does not imply a degree of repellency because aggregation and the supply of hydrophobic material are controlled by many other factors; contradictions in the relationship between soil texture and repellency may also be due to confusion between the effects of texture and structure (Fox et al. 2007). Further confusion results because fine fractions are not necessarily associated with fine textures, nor are coarse fractions necessarily associated with coarse textures; the effects of soil aggregate formation must be considered. Fine-textured soils have exhibited the highest degree of repellency, while coarse soils appear to be more susceptible to developing fire-induced or other repellency (de Jonge et al. 1999; Doerr et al. 2000).

Though the Blackwood site comprised finer-textured volcanic soils with scant litter cover, its untreated-water infiltration rates (MDI) were nearly twice as high as those of any other site, and the response to surfactant was relatively subdued. The limited response to surfactant suggests that the litter at Blackwood was neither physically inhibiting infiltration nor providing hydrophobic substances adequate to coat the relatively fine mineral particles.

Untreated plots. All of our untreated-water plots produced runoff. At the volcanic soil sites, infiltration rates were similar to previous studies and ranged from 3.4 to 4.7 inches (86 to 119 millimeters) per hour at Truckee and 4.0 to 4.7 inches (103 to 119 millimeters) per hour at Blackwood. The average sediment concentrations were 0.22 gram per liter at Truckee and 0.85 gram per liter at Blackwood. In previous studies conducted on plots with pine needle cover at Bliss State Park, and at Rubicon on granitic Meeks series soils (about 60% slopes), infiltration rates were about 2



The texture and moisture content of soils at each site did not necessarily correlate with the degree of repellency found in the study. For example, at Blackwood Canyon infiltration rates with untreated water in the finer-textured volcanic soils were twice as high as any other site, and the response to surfactant was relatively subdued.

inches (51 millimeters) per hour, and sediment concentration was 1.21 grams per liter at both sites.

At Bliss, untreated-water plots yielded infiltration rates of 2.6 to 3.9 inches (66.0 to 99.8 millimeters) per hour and an average sediment concentration of 0.96 gram per liter from plots having much gentler slopes of roughly 12%. At Meyers in 2007, the average rainfall-simulator-measured infiltration rate of about 4 inches (100 millimeters) per hour was practically identical to that measured in this study.

Studying native forest sites

Ours is the first among recent rainfall-simulation projects to focus exclusively on native sites. In some cases, previously conducted rainfall simulations used lower application rates and the sites had different slopes, making comparisons difficult. Our Northstar (data not shown) and Truckee sites produced similar results where native cover was intact. These granitic sites generally had higher infiltration rates than those with volcanic soils, reinforcing the observed trend of susceptibility to hydrophobicity among coarse soils. Previous studies at Bliss conducted on steeper slopes and using a lower rainfall rate reported higher sediment concentrations, probably due to the greater slope (Grismer and Ellis 2006; Grismer et al. 2008).

Grismer et al. (2008) studied particle sizes in runoff from the Tahoe Basin. From disturbed soils, the D_{10} particle sizes were 70.4 μm (granitics) and 3.98 μm (volcanics), while the D_{90} particle sizes were 1,589 μm (granitics) and 1,227 μm (volcanics). These values are much larger than those found in our study (table 5). Although several factors, such as slope, influence particle-size distributions, this may indicate that soil cover is most effective in removing large particles from runoff. Comparison of particle sizes between water and surfactant treatments could be useful, but runoff from the surfactant plots did not provide adequate samples to allow for such analysis.

The MDI is easy to use and has become increasingly popular to determine field infiltration rates in the Tahoe Basin, suggesting that comparing rates from the MDI and rainfall simulator is valuable. The primary differences between the two are: (1) the MDI requires the removal of litter for the porous disk to form a seal with the mineral soil surface and (2) the MDI provides constant-head water pressure conditions at the surface, while the rainfall simulator produces constant flux at the surface. MDI-derived infiltration rates were several times greater than those from the rainfall simulator, not unlike those in early studies using the constant-head permeameter ("Amooz-a-meter" or Johnson permeameter) in the Tahoe Basin. We found a significant correlation between infiltration rates measured by both methods; however, those from the rainfall simulator were dramatically smaller than those from the MDI for water and surfactant treatments across all sites. In this study, higher infiltration rates measured by the MDI indicated the importance of the litter layer, which was confirmed by post-rainfall-simulator excavations.

Granitic sites generally had higher infiltration rates than those with volcanic soils.

An infiltrometer can provide a quantitative measure of flow rates to estimate a repellency index in the field. Generally, infiltrometers facilitate a more sensitive and physically meaningful field test than the water drop penetration test (WDPT). The U.S. Forest Service developed methods including the MDI for studying postfire infiltration (Robichaud et al. 2008) in which MDI and WDPT results were well correlated, allowing the use of existing WDPT repellency classifications to classify MDI results. MDI-measured infiltration rates of less than 9.5 inches (240 millimeters) per hour were considered strong repellency, while rates of 9.5 to 24.8 inches (240 to 630 millimeters) per hour were weak. Based on these classifications, repellency existed at both our granitic soil sites. It was strong at Meyers (5.7 inches [142 millimeters] per hour) and weak at Bliss (14.2 inches [356 millimeters] per hour) despite differences in the litter layers.

Similarly, there was weak repellency at the litter-thick Truckee site (16.2 inches [412 millimeters] per hour), but none at Blackwood (28.7 inches [728 millimeters] per hour). Surfactant seemed to confirm this classification of Blackwood, because infiltration only increased 20%; however, it is doubtful that repellency was truly weak at Truckee or Bliss, as use of the surfactant caused infiltration rates to triple or quadruple. Future use of MDI results in the Tahoe Basin to index repellency appears promising, but classifications based on the WDPT may not be the best option, especially in locations where decomposed surface cover is intact.

Following the Angora fire near South Lake Tahoe in 2007, the Lake Tahoe Basin Management Unit of the U.S. Forest Service (Tolley and Norman 2008) used the MDI method to assess postfire hydrophobicity. Interestingly, three of six sites had postburn infiltration rates (31.5 to 43.3 inches [800 to 1,100 millimeters] per hour) higher than any of the untreated-water infiltration rates recorded on unburned sites during our study. These sites experienced moderate to high burn severity, so their high infiltration rates may indicate that the heat was sufficient to mobilize or destroy substances causing repellency. Pierson et al. (2008) also suggested that burn temperatures reduced background repellency on several Western sites. Events such as the Angora fire may intensify hydrophobicity in some places while weakening it at others; hydrologic response is not simply due to intensified hydrophobicity, but also the loss of vegetation and cover.

Larsen et al. (2009) underscored that postburn hydrophobicity is patchy and dramatically decreases within a year after a fire, and that loss of soil cover appears to be the primary factor affecting postburn erosion rates. Future research in these areas would improve understanding of how fire behavior affects infiltration, runoff and erosion, allowing for the more precise identification of postburn erosion source areas.

Reducing particles in Lake Tahoe

To reduce the delivery of fine particles into Lake Tahoe, sources of these sediments and their means of transport must be identified. In previous studies, rainfall simulators were used to test for significant relationships between erosion and various site properties (such as soil type, slope, roughness and cover) and to evaluate the effectiveness of soil amendments and cover treatments. This study continued previous work; a similar rainfall simulator was used with surfactant and water to isolate the effects of soil water repellency on infiltration. Additionally, a method assessment was conducted comparing rainfall-simulator-generated results with those from an MDI.

The efficacy of surfactant to induce wetting was considerable. Post-treatment soil moisture differed between treatments by a factor of at least three on granitic soils, where the effects of repellency seemed more pronounced than on volcanic soils. At these granitic sites, continuous wetting was approximately 6 inches below the surface, whereas virtually no wetting occurred under repellent conditions. Of the 24 rainfall simulations conducted, all untreated-water plots produced runoff, which occurred on only two of 12 plots receiving surfactant. Both plots were on volcanic soils; however, the effects of hydrophobicity were still apparent since runoff-producing plots that received surfactant took 16 and four times longer than average to produce runoff at two volcanic sites. Surfactant was also used with the MDI to assess the effects of repellency on infiltration. The effects of surfactant on rainfall-simulator-measured infiltration rates were greater on the granitic soils (four to eight times that for water) that comprise some 82% of Tahoe Basin soils than on the volcanic soils (0.2 to 3 times that for water). Differences between infiltration rates measured with the rainfall simulator and MDI were attributed to the constant head supplied by the MDI, and removal of the litter layer prior to MDI measurements.

We observed the importance of litter, and especially the underlying, partially decomposed layer, as a regulator of infiltration. Postsimulation excavations revealed that surfactant-treated water was prone to pursue preferential flow paths, beginning at the discontinuity between the organic and mineral soil layers. While the MDI measurements showed that mineral soil was repellent, its strength and particularly persistence were much less than that of the organic layer. These results indicate that repellency may be responsible for some runoff generation in the Tahoe Basin, but extrapolations based on these plot-scale measurements would not be helpful without additional efforts. Future research directed at quantifying repellency under different site conditions is necessary, as well as the studies currently under way to establish the scaling between plot-scale measurements and tributary sediment loading into Lake Tahoe.

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RESEARCH ARTICLE

Survey examines the adoption of perceived best management practices for almond nutrition

by Sara E. Lopus, María Paz Santibáñez, Robert H. Beede, Roger A. Duncan, John Edstrom, Franz J. A. Niederholzer, Cary J. Trexler *and* Patrick H. Brown

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There are more than 6,000 almond growers in California and 615,000 bearing acres. *Above*, an almond orchard in bloom at Nickels Soil Laboratory in Colusa County.

Fertilizer use in California agriculture has been under recent scrutiny regarding its impacts on air, surface water and groundwater quality. In June 2007, we surveyed almond growers to assess their plant nutrition practices, identify opportunities for improvement, and target research and extension needs. The majority of respondents, particularly those with large almond acreages, used fertigation to apply nitrogen; applied nitrogen coincident with periods of maximal plant demand; and collected annual tissue samples for analysis. While the survey results suggested broad compliance with the best-available management practices and are likely to indicate good nutrient-use efficiency, they also suggested that growers are uncertain about current practices to monitor orchard nutrient status and would value additional information to enable greater precision in fertilization rates and timing.

Nitrogen (N) is a key mineral element for the global food supply (Hirel et al. 2007; Vitousek et al. 1997), and adding nitrogen fertilizer is a fundamental step in producing commercially viable crops. However, nitrogen that is not taken up by plants or retained in soil organic matter will “leak” from agricultural systems, contributing to environmental challenges such as greenhouse-gas emissions in the form of nitrous oxide (N_2O) (Velthof et al. 2009) and watershed pollution in the form of high nitrate (NO_3) concentrations in water (Domagalski et al. 2008).

In 2006, California legislators identified reducing greenhouse gases as a major goal and passed Assembly Bill 32, which mandates that by 2020, statewide emissions be reduced 25% from 1990 levels (CARB 2006). Industries utilizing nitrogen have attracted policymakers’ attention for their potential greenhouse-gas reductions, because a single unit of nitrous oxide gas is equivalent in potency to approximately 300 units of carbon dioxide (CO_2) gas (IPCC 1995). In 2004, the California Air Resources Board concluded, based on the limited data available, that agricultural soils were the largest source of nitrous oxide in California, accounting for 50% of the state’s total emissions, with 60% related to synthetic fertilizers (CARB 2006). Because of nitrous oxide’s global warming potential, even modest reductions can contribute meaningfully to lowering greenhouse-gas emissions by 2020.

Soil nitrate concentrations can increase significantly when applied and mineralized nitrogen levels exceed the plant’s nitrogen use. Nitrate in runoff from heavily fertilized agricultural land can reach rivers and streams, raising concerns about drinking-water quality and the eutrophication of water bodies (Fenn et al. 1998), in which high nutrient levels in an aquatic ecosystem lead to increased primary production (by algae, for example) and subsequent decreases in oxygen levels.

Burow et al. (1998) found that a high proportion of groundwater samples from beneath almond orchards exceeded the maximum contaminant level of nitrate (10 milligrams per liter [mg/L]) (EPA 2006), reflecting high levels of nitrogen applications. Almonds represent California’s fifth-largest agricultural commodity (in percentage of the state’s total farm receipts) (USDA ERS 2009), and the industry has grown to more than 6,000 almond growers and 615,000 bearing acres (ABC 2008). Nitrogen management in almonds has been the subject of much research, and a summary of conventional practice is presented in the UC *Almond Production Manual* (Micke 1996).

Adding nitrogen to soil increases the potential for both nitrous oxide generation and nitrate leaching. To minimize

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Because of nitrous oxide's global warming potential, even modest reductions can contribute meaningfully to lowering greenhouse-gas emissions by 2020.

this potential, management practices that reduce total nitrogen inputs, increase the utilization of applied nitrogen by crops, and enhance nitrogen stability in soil must be developed and adopted. Bruulsema et al. (2008) summarized the principles and practices underlying the development of fertilizer best-management practices for nitrogen. These include: (1) the use of soil or plant testing to define crop nutrient status and (2) application of the right amount of fertilizer coincident with the times of greatest crop demand, placed in locations and forms that maximize uptake potential and minimize losses.

In agricultural systems where explicit experimental data and fertilization guidelines are poorly developed, fertilization practices that approach these ideal characteristics represent the best-available management practice and are most likely to optimize nitrogen-use efficiency. Given the absence of specific nutrition management guidelines for almonds, we theorize that these principles can best be applied under current production constraints through: (1) fertigation to enable nitrogen placement in the zone of greatest root activity, (2) the application of nitrogen coincident with periods of greatest nutrient demand and (3) tissue sampling and analysis to monitor nutrient levels in trees.

In June 2007, we surveyed almond growers to assess their current nutrition practices, concerns and needs. This article focuses on comparisons between respondent practices and the set of theorized best-management practices. We also present general demographic traits for respondents who did not adhere to the perceived best practices, in order to inform extension efforts related to nutrient-use efficiency.

Survey design and analysis

We designed and distributed a survey with 37 multipart questions to collect data regarding grower demographics (18 questions), fertilization-use practices (11 questions), factors affecting fertilization decisions (two questions), priorities in education and research relating to plant nutrition (three questions) and the expected consequences of environmental regulation to the almond industry (three questions). The questions were informed by the results of three concurrent focus-group sessions held in 2006 at the Almond Industry Conference in Modesto, Calif. Each consisted of 10 to 14 growers, chemical consultants, farm advisors and/or representatives from the California Environmental Protection Agency, California Air Resources Board and Almond Board of California (Lopus et al. 2010).

The survey population comprised 1,800 almond growers from 18 California counties, whose names were randomly selected from a pesticide-use database of 3,060 growers. Although we also surveyed all organic almond growers ($n = 76$) registered with California Certified Organic Farmers, the results are not presented in this article. In accordance with standard protocol (Dillman 2007), postcards were mailed in April 2007 to draw growers' attention to the forthcoming survey, surveys were mailed in June 2007, and second copies of the survey were mailed in August 2007 to growers who had not yet responded. Growers were given the option of submiting the survey by mail or online. Surveys were coded to maintain the anonymity of respondents and to ensure that online respondents were members of the randomly selected sample.

To assess fertilizer nitrogen use in almond orchards, we compared current grower practices with our set of theoretical best-management practices derived from existing knowledge, focus groups, e-mail consultations with informed individuals in the industry and the concepts in Bruulsema et al. (2008). Although many practices not discussed here have been applied in other cropping systems and may aid in achieving enhanced nitrogen-use efficiency, none have been adequately validated in almonds. Therefore, for this investigation we focused on three currently available practices for which grower compliance is measurable: (1) using fertigation to apply some or all nitrogen fertilizer in orchards (where irrigation methods permit), (2) applying nitrogen fertilizer with perceived optimal seasonality and (3) using annual tissue sampling to monitor nutrient levels in trees.

Assessing nutrition practices

We identified fertigation, in which fertilizer is applied through an orchard's irrigation system, as a theorized best-management practice because it allows for multiple in-season applications, targeted timing and synchrony with irrigation, potentially reducing fertilizer use and optimizing efficiency.

Optimized application timing ensures that nitrogen is available to trees when they are actively taking up nutrients. Research suggests that the pattern of nutrient demand during a cropping cycle closely matches the rate of nutrient accumulation in the almond crop, once nutrient reserves in perennial tissues have been depleted (Weinbaum et

Jack Kelly Clark, UC Statewide IPM Program al. 1980, 1990). Under California conditions, nutrient uptake in almond trees commences following full leaf expansion in March or early April; increases during periods of rapid fruit development in late spring and summer; is maximal during nut filling and prior to full maturity; and declines once the fruit reaches full maturity, with minimal nutrient uptake occurring during leaf senescence or dormancy.

If growers are to make nutrients available to trees at optimal times, the most nutrient should be applied during summer, a smaller portion in spring and in autumn, and none in winter. For the seasonality analysis, we calculated each grower's deviation from this schedule of nutrient uptake. Scores ranged from 2 to 10, with 10 assigned to growers who applied with optimal seasonality and the lowest possible score of 2 assigned to those who applied 100% of nitrogen fertilizer in winter (see box, table 1).

In deciduous tree production, the primary tool for fertilizer decision-making is leaf sampling and analysis and comparison with established standards, called "critical values" (Brown and Uriu 1996). Critical values are the nutrient levels (present in almond tissues at a specific time of the cropping cycle each year) below which trees will begin to show deficiency symptoms. They represent the tipping point between a tree that is or is not deficient in a particular nutrient. When properly taken and analyzed, annual tissue samples provide growers with useful information about their trees' nutrient status and demand, allowing nitrogen applications to be adjusted accordingly.

Data was analyzed with chi-square analysis ($\alpha = 0.05$), and logistic regression was used for answers rated on a Likert scale. Response areas left blank and "I don't know" answers were excluded from the analysis. Data analysis was performed using JMP 7 statistical software (SAS 1989–2007).

Of the 1,800 growers that we mailed the survey to, 38 informed us that they no longer grow almonds and 529 completed the survey, for an overall response rate of 30.0% (529/1,762). Of the 529 respondents, seven grew some or all of their almonds organically, so we analyzed their responses separately; results

Calculation of seasonal score

In order to calculate seasonal scores, we awarded points to growers based on the percentage of nitrogen that they applied during each seasonal period: 0 points = 0%; 1 point = 1% to 30%; 2 points = 31% to 70%; 3 points = 71% to 99%; and 4 points = 100%.

Seasonal periods were defined as: winter, Nov. 1–Jan. 31; spring, Feb. 1–April 30; summer, May 1–July 31; fall, Aug. 1–Oct. 31.

The scores for each season were then subtracted from the optimal scores and subtracted from 10:

$$\text{Seasonal score} = 10 - |\text{spring score} - 1| - |\text{summer score} - 2| - |\text{fall score} - 1| - \text{winter score}$$

For example, grower A applies 20% of nitrogen in spring, 65% in summer, 15% in fall and 0% in winter, and receives a seasonal score of 10 (table 1). We classified seasonal scores of 7 or greater as "good" and seasonal scores of 6 or below as "poor."

TABLE 1. Seasonal scores assigned to three hypothetical growers, based upon deviation (+/–) of their seasonal fertilization schedule (red) from theorized "optimal" schedule (blue)*

		Spring	Summer	Fall	Winter	Dev. from optimal	Seasonal score (10 – dev.)
"Optimal" points		1	2	1	0		
Grower A	Applied (%)	20	65	15	0		
	Points	1	2	1	0		
		|1 – 1| = 0	|2 – 2| = 0	|1 – 1| = 0	|0 – 0| = 0	0	10
Grower B	Applied (%)	35	25	25	15		
	Points	2	1	1	1		
		|1 – 2| = 1	|2 – 1| = 1	|1 – 1| = 0	|0 – 1| = 1	3	7
Grower C	Applied (%)	50	0	0	50		
	Points	2	0	0	2		
		|1 – 2| = 1	|2 – 0| = 2	|1 – 0| = 1	|0 – 2| = 2	6	4

* Based on Weinbaum et al. 1980, 1990.

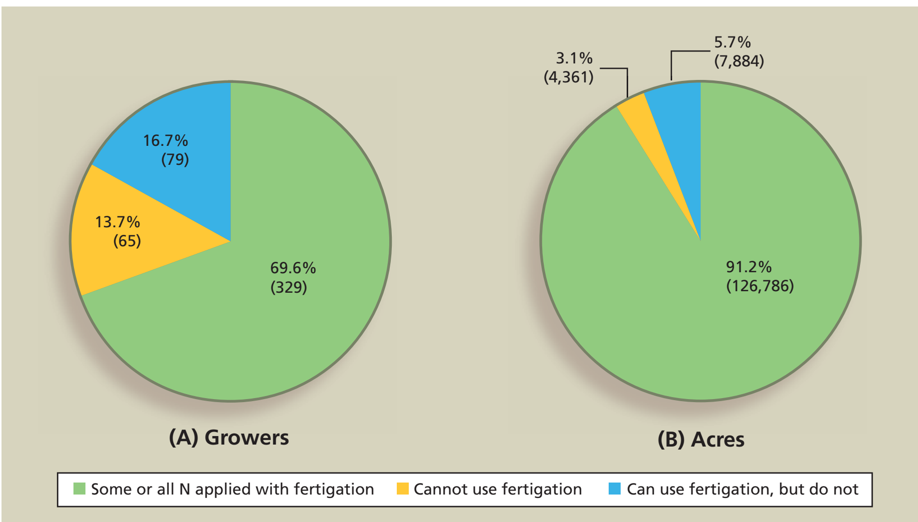

Fig. 1. (A) Growers and (B) acres with nitrogen fertilizer applied using fertigation. Those who cannot use fertigation irrigated entirely by flood or furrow.

TABLE 2. Growers and acres performing theorized best-management practices

	All growers	By generation growing almonds: First	≥ Second	*P* value	By acreage: < 20	20–249	≥ 250	*P* value
	% (number/n)				% (number/n)			
Apply nitrogen with fertigation*	80.6 (329/408)	81.3 (135/156)	72.4 (126/174)	0.051	61.2 (30/49)	63.8 (136/189)	94.1 (96/102)	< 0.001
High seasonal score	65.0 (294/452)	58.0 (130/224)	71.9 (161/224)	0.002	57.1 (48/84)	63.3 (167/264)	77.2 (61/79)	0.008
Collect tissue samples at least once annually	79.4 (396/499)	77.1 (195/253)	82.6 (200/242)	0.122	61.0 (64/105)	82.0 (232/283)	90.7 (98/108)	< 0.001

* If irrigation system permits. Number of responses (*n*) varied by question because blank and "I don't know" responses were excluded.

of the organic population are not presented in this article. Thirty of the 529 responses (5.7%) were submitted online.

By county, the respondents were representative of the whole population, as the selected recipients of each county were proportional to the whole population ($X^2 = 6.98$, $P = 0.935$).

Best application practices

Nitrogen fertigation. Most respondents (69.6%) (fig. 1A) applied any or all of their nitrogen fertilizer by fertigation. Of the remaining 30.4% who did not use fertigation, 45.1% (13.7% of all respondents) were unable to fertigate because they irrigated entirely by flooding or furrow and could not inject fertilizer into the irrigation system. More than half of the growers (54.9%) who did not use fertigation had the potential technical capacity to adopt the practice. A small portion (6.4%; five of 78) of these growers used fertigation to apply potassium and/or zinc fertilizer, but not nitrogen.

Among growers with the technical capacity for fertigation (excluding those who irrigated entirely by flood and/or furrow), there was no significant difference ($P = 0.051$) in likelihood to fertigate between first-generation and second-generation or greater growers (table 2).

Among all growers with the technical capacity to fertigate, there was a significant relationship between likelihood to fertigate and acreage ($P < 0.001$) (table 2). Growers with fewer than 20 acres were less likely to use fertigation to apply nitrogen (61.2%), while those with 250 or more acres were more likely to use fertigation (94.1%). Due to this trend, the proportion of acres managed by a grower who practiced fertigation was higher than the proportion who used the practice (fig. 1B). Growers who managed 91.2% of almond acreage in the survey used fertigation to apply any or all nitrogen fertilizer (fig. 1B), and the adoption of fertigation by growers who did not currently use the practice but had the capability was only possible on 5.7% of acreage.

TABLE 3. Importance of information or actions to meet potential environmental standards, rated from 1 ("not important") through 5 ("extremely important")

	Mean	SD	*n*
Information very or extremely important*			
Identifying fertilization practices that optimize yields	4.03	0.85	358
Identifying fertilization practices that minimize soil and water contamination	3.66	0.92	367
Conducting research to challenge new requirements	3.63	1.02	350
Information important, very or extremely important†			
Creating nutrient budgets that accurately reflect an orchard's fertilizer needs	3.47	0.85	357
Effectively regulating grower compliance	2.81	0.94	350

* Median score of 4. Number of responses (*n*) varied by question because blank and "I don't know" responses were excluded.
† Median score of 3. Number of responses (*n*) varied by question because blank and "I don't know" responses were excluded.

Seasonality. We classified seasonal scores of 7 or greater as "good" (65.0% of respondents; mean = 7.13, standard deviation [SD] = 1.61) and scores of 6 or below as "poor" (35.0%) (table 2). Poor seasonal scores corresponded to growers whose seasonal fertilization practices differed dramatically from the optimal schedule (Weinbaum et al. 1980, 1990) (see box, page 151).

The distribution of seasonal scores between first-generation growers and others was significantly different ($P = 0.002$), with only 58.0% of first-generation growers having good seasonal scores versus 71.9% or second-generation or greater growers (table 2).

The distribution of seasonal scores differed significantly with acreage ($P = 0.008$) (table 2). Growers with fewer than 20 acres were less likely to have good seasonal scores (57.1%) than growers with 250 or more acres (77.2%). Growers with poor seasonal scores managed only 23.5% of the acreage surveyed (28,021 of 199,422 acres).

Tissue sampling. Most respondents (79.4%) used tissue sampling on their orchards at least once per year, and very few (7.6%, 38 of 499) never used tissue sampling (table 2). Of growers who did not use tissue sampling at least once per year, 21.4% (22 of 103) collected tissue samples when problems were detected. Growers who collected tissue samples less than once per year cited the expense (31.9%, 22 of 69) and difficulty in interpreting and/or using results (15.9%, 11 of 69) as major reasons why they did not collect tissue samples more often.

There were no significant generational differences ($P = 0.122$) (table 2) between first-generation growers and other growers in the likelihood to use tissue sampling at least once annually.

The distribution of likelihood to collect tissue samples at least once per year differed significantly with acreage ($P < 0.001$) (table 2). Growers with fewer than 20 acres were less likely to collect tissue samples at least once annually (61.0%), while those with 250 or more acres were more likely (90.7%). Only 10.6% of acres were managed by growers who did not collect tissue samples at least once per year.

Grower attitudes. Although 61.3% of respondents stated that they were satisfied with their current nutrition management practices (315 of 514), only 29.5% (149 of 505) considered UC critical values (which dictate fertilization goals for particular nutrients) to be fully adequate to ensure maximal productivity. When rating the importance of five activities relating to potential environmental regulations, most growers identified three of the activities as very or extremely important (median rating of 4 or greater) (table 3), including identifying fertilization practices that optimize yields. From a list of 14 potential research topics, most growers selected eight topics as very or extremely useful (table 4), including fertilizer application timing.

Implications for outreach

The trends revealed by the survey will be useful to extension agents as they create outreach programs to reduce nitrogen loss and increase efficiency in almond production. First-generation almond growers, for example, were less likely to apply nitrogen with good seasonal timing (table 2), and almond growers with fewer than 20 acres were less likely to apply nitrogen with fertigation, apply nitrogen with good seasonal timing or collect annual tissue samples (table 2). It may therefore be effective to target first-generation and small almond growers with educational nutrition-management programs. The observation that small and/or first-generation growers are less likely to use the theorized best-nutrient practices may indicate that extension activities are not optimally tailored to these groups.

External factors such as the cost, availability and functionality of fertigation technologies for small growers may be significant constraints, suggesting that targeted financial incentives to develop or employ small-scale fertigation systems are needed to enhance the adoption of best nutrient practices. Since growers with large acreages are more likely to have adopted them, the perceived progressive practices of large growers dominate California almond acreage.

The practices investigated here represent our best current understanding of actions to achieve nitrogen-use efficiency (Bruulsema et al. 2008). Likewise, this survey did not attempt to identify whether growers fertigate properly, add appropriate amounts of nitrogen, or correctly use the results of tissue sample analyses to formulate their fertility programs. It therefore remains unclear if the use of best available practices is actually resulting in satisfactory efficacy of nitrogen use.

Even the most informed growers are uncertain about the practical applications of tissue analyses, since: (1) experimental trials examining the relationship between leaf tissue analysis and crop yield in almond are limited (Brown and Uriu 1996; Meyer 1996; Weinbaum et al. 1980, 1990); (2) no long-term experiments in mature trees have effectively demonstrated the use of leaf analysis to optimize fertilization regimes and nitrogen-use efficiency; and (3) it is difficult to obtain representative tissue samples in a perennial species due to substantial within-tree, between-tree and within-field variability (Lilleland and Brown 1943; Perica

TABLE 4. Usefulness of future UC research topics, from 1 ("not useful") through 5 ("extremely useful")*

	Mean	SD	*n*
Topic very or extremely useful*			
Fertilizer application timing	3.90	0.90	345
Leaf-sampling techniques that better reflect tree nutrient demand	3.83	0.95	352
Relationship between nutrition and disease	3.81	0.89	349
Accuracy of critical values to ensure they result in maximal yield	3.79	0.89	349
Tissue-sampling techniques that better reflect tree nutrient demand	3.76	1.01	339
Role and optimal use of foliar fertilizers	3.71	0.97	340
Relationship between fertilization and irrigation	3.65	0.99	353
Nutrient management in problem soils	3.57	1.11	337
Interactions between nutrients	3.55	0.93	340
Topic useful, very or extremely useful†			
Fertilization practices to optimize orchard establishment	3.46	0.95	340
Precision agriculture (site-specific fertilization)	3.20	1.06	339
Optimal use of fertigation systems	3.20	1.20	336
Effectiveness of nonfertilizer foliar and soil products	2.78	1.13	348
Remote sensing and automated nutrient status measurement	2.67	1.12	349

* Median score of 4. Number of responses (*n*) varied by question because blank and "I don't know" responses were excluded.
† Median score of 3. Number of responses (*n*) varied by question because blank and "I don't know" responses were excluded.

Jack Kelly Clark, UC Statewide IPM Program

Best management practices including fertigation, timed applications and leaf-tissue analysis can save growers money and minimize nutrient-laden runoff into surface waters. *Above*, furrow-irrigated orchards cannot use fertigation, which requires a drip irrigation system.

2001; Righetti et al. 1990; Sanchez and Righetti 1990).

In this paper, we addressed only three management practices believed to contribute to nitrogen-use efficiency; there are many other practices, however, that can theoretically contribute to nitrogen efficiency in the almond industry and for which research-based understanding is inadequate. These other practices include, but are not limited to: (1) soil sampling, (2) selecting proper nitrogen forms given seasonal timing and the crop stage, (3) determining nitrogen rates by tree age, potential yields and past yields and (4) balancing the leaf levels of other nutrients to gain the maximum benefits of applied nitrogen. These practices are not widely used in California's almond industry, so compliance was not investigated.

The creation of nitrous oxide and nitrate is unavoidable in agricultural settings and will occur on even the best-managed land. Almond productivity cannot be maintained in the absence of fertilization, so any nitrogen mitigation program must focus on increasing the efficiency with which applied nitrogen is used. The results of this survey illustrate that most almond growers, and the large majority of acreage, currently employ theorized best-fertilization practices, and the industry would value new information about a wide breadth of topics relating to nutrition management. While these results can be viewed as largely positive, they should be the basis for deploying new research and extension programs to develop integrated best management of nutrients in almonds and address the actions and research topics that growers identified as highly important.


Jack Kelly Clark, UC Statewide IPM Program

The survey found that most almond growers, managing the large majority of California acreage, currently employ best practices for nitrogen fertilization. *Above,* an orchard in Stanislaus County.

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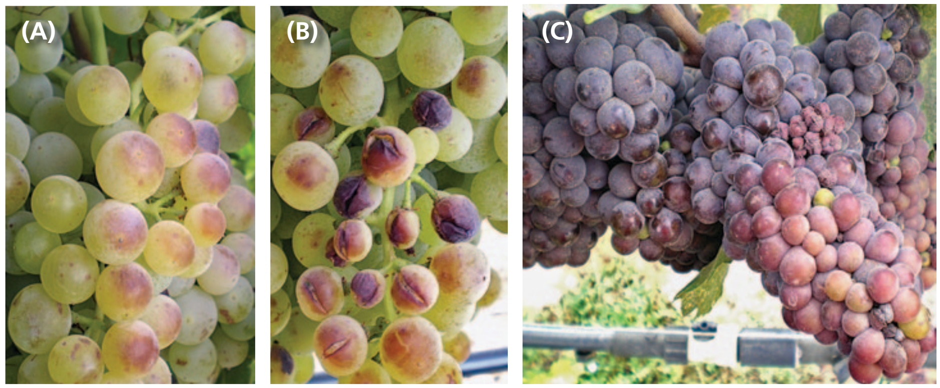
Distinctive symptoms differentiate four common types of berry shrivel disorder in grape

by Mark N. Krasnow, Mark A. Matthews, Rhonda J. Smith, Jason Benz, Ed Weber *and* Ken A. Shackel

Shriveled fruit in vineyards has several origins including sunburn, dehydration, bunchstem necrosis and the recently described sugar accumulation disorder. These disorders are often confused with one another, but they can easily be distinguished by the location or composition of shriveled fruit and the condition of the rachis (the stem structure of a cluster). Sunburn is typically exhibited only on berries that are exposed to direct sunlight, and bunchstem necrosis is typified by necrotic rachis tissue. Berries with sugar accumulation disorder exhibit low sugar concentration, whereas berries with late-season dehydration typically have above-normal sugar concentration. Berries with sugar accumulation disorder and bunchstem necrosis exhibit the sugar content when sugar accumulation ceases or stem necrosis occurs, respectively. In tests, berries with sugar accumulation disorder exhibited lower berry weight, pH and anthocyanins, as well as differences in many nitrogenous compounds compared to normally developing fruit. In one location, sugar accumulation disorder was expressed at the whole-vine level, but none of the commonly known pathogenic organisms were found.



A Burger grape cluster exhibits (A) slight browning due to sunburn and (B) more severe sunburn and cracking. (C) *Left*, A healthy Barbera cluster and, *right*, a sunburned cluster with poor coloration and raisining.

Shriveled berries on ripening clusters are not uncommon in California vineyards. They usually occur in only a small proportion of a vineyard's fruit (1% to 5%), but in particular vineyards and years, shriveling can affect more than half of the crop (M. Krasnow, unpublished observation). Most shrivel disorders make the fruit less desirable for winemaking, with subsequent yield and production losses. Before taking steps to reduce the incidence of fruit shriveling in vineyards, it is necessary to differentiate between shrivel disorders. We describe four common causes of fruit shriveling and detail compositional differences between normally developing fruit and that affected by sugar accumulation disorder (SAD).

Sunburn

Fruit exposed to direct sunlight for all or part of the day, especially in the heat of the afternoon, can be damaged by sunburn, which may be caused by high temperature, ultraviolet radiation or a combination of the two (Gindaba and Wand 2005). The physical appearance of sunburned fruit depends on the grape variety and stage of development — white grapes and red grapes exposed before pigment accumulation begins (veraison) develop brown discoloration, which varies depending on severity.Veraison and early post-veraison red varieties with sunburn often exhibit poor color development, and may remain pink for the remainder of the season. Post-veraison sunburn leads to fruit with less color and a shiny appearance. Sunburned berries often crack, presumably due to damaged epidermal tissues. Extreme sunburn leads to complete berry desiccation and the formation of raisins (raisining) in both red and white varieties.

Sunburn only affects berries that are directly exposed to sunlight. The nonexposed side of a sunburned cluster often develops normally. If a cluster is fully exposed to the sun on both sides, or if the rachis (the stem structure of a cluster) itself is damaged, then the cluster may be completely affected. Obvious signs of sunburn may only occur on the exposed portions of individual berries.

Sunburn can be avoided by reducing the fruit's exposure to direct sunlight, especially in the afternoon. While leaves are removed in the fruit zone in many growing regions to increase cluster exposure to indirect light, in north-south row orientations leaves are removed on the east side of the canopy to reduce direct exposure in the afternoon and the probability of sunburn. This practice does not completely eliminate the risk of sunburn, however, because morning sun can also cause damage.

Late-season dehydration

Natural dehydration is another type of shrivel that may affect berries late in ripening but prior to commercial harvest. These berries appear similar to fruit with bunchstem necrosis, but the rachis look green and healthy. For this type of shrivel, which is especially pronounced in Syrah (Shiraz), berries lose weight due to water loss, and sugars are concentrated (McCarthy 1999). Both increased transpiration (McCarthy and Coombe 1999) and decreased phloem (the sugar transport system in plants) influx (Rogiers et al. 2006) have been suggested as causes for late-season dehydration, but recent studies provide evidence that several varieties of grape berries remain hydraulically connected to the parent vine (Bondada et al. 2005; Chatelet et al. 2008) and therefore may lose water back to the parent plant late in ripening as well as to dry, ambient air (Keller et al. 2008; Tyerman et al. 2004).

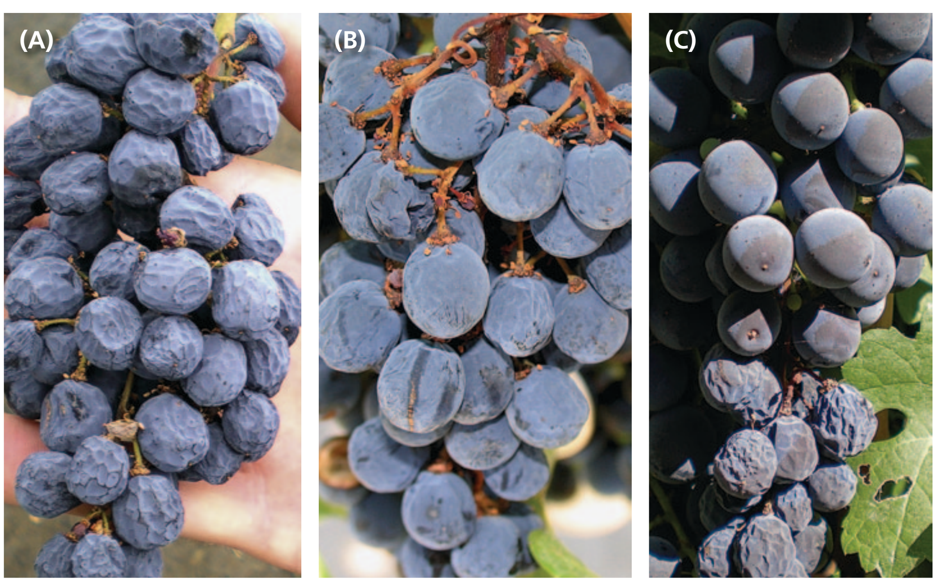
Bunchstem necrosis

Clusters affected by bunchstem necrosis are identified by necrotic (dead) rachis tissue, with shriveled berries distal to the necrotic tissue. The visible symptoms of bunchstem necrosis begin as small black spots on pedicels (branches of the rachis that attach to berries), and progress to the lateral stem structure and rachis (Christensen and Boggero 1985). Usually, necrosis symptoms are not noted until the rachis is affected. Bunchstem necrosis may affect an entire cluster as well as the wings and tips of otherwise healthy clusters ("wings" or "shoulders" are the parts of the cluster from the first branch of the rachis; "tips" refers to the grapes farthest from the stem within the cluster). It can occur in many varieties, but is especially prevalent in Cabernet Sauvignon on California's North Coast. It has been described in the literature in many different countries, with descriptive terms that include waterberry (California), bunchstem dieback (Australia), shanking (New Zealand), stiellähme (Germany), palo negro (Chile), desséchement de la rafle (France) and dessichimiento della rachide (Italy) (Christensen and Boggero 1985).

No specific cause of bunchstem necrosis has been identified, despite many years of research. In some cases, varietal differences in susceptibility have been correlated to xylem (water transport tissue) structure, specifically a reduction on the area of xylem distal to branch points in the peduncle (bunch stem) (During and Lang 1993). The incidence of bunchstem necrosis has also been correlated to various concentrations or ratios of mineral nutrients, including magnesium, calcium, potassium and nitrogen (Capps and Wolf 2000; Christensen and Boggero 1985; Cocucci et al. 1988; Morrison and Iodi 1990; Ureta et al. 1981). Work in Chile (Ruiz and Moyano 1998) and Australia (Holzapfel and Coombe 1998) has shown that the amino acid metabolite putrescine is associated with bunchstem necrosis. More light in the canopy can also reduce bunchstem necrosis (Perez-Harvey et al. 1987; Perez-Harvey and Gaete 1986).

Bunchstem necrosis can appear very early in fruit development (around bloom) or after veraison. The terms "inflorescence necrosis" and "early bunchstem necrosis" have been used to describe bunchstem necrosis around bloom (Gu et al. 1994; Jackson and Coombe 1988, 1995). The composition of such fruit varies depending on when during fruit development the rachis becomes necrotic. Presumably, the necrosis prevents both sugar and water transport to the berry. Hence, if the rachis becomes necrotic early in the ripening period before the berry has accumulated much sugar, fruit will have low Brix (Morrison and Iodi 1990; Ureta et al. 1981). (Brix is a unit of sugar concentration; a harvest Brix of about 24 to 28 is considered normal in California viticulture.) On the other hand, if the rachis becomes necrotic after the berries

Cabernet Sauvignon clusters display late-season dehydration shrivel.



Cabernet Sauvignon clusters display bunchstem necrosis. Clusters (A) and (B) are entirely affected, and cluster (C) is affected only at the tip.

have accumulated appreciable sugar, subsequent shriveling can concentrate the sugars. Bunchstem necrosis in Cabernet Sauvignon on the North Coast is usually the latter type. Fruit with bunchstem necrosis can have a Brix as high as 42 (unpublished data).

TABLE 1. Composition of sugar accumulation disorder (SAD) vs. normal fruit from three sites and two different cultivars, 2007

Sample	Fruit condition	Berry weight*	Brix	pH
		grams		
Napa Sauvignon blanc average	SAD	1.07	14.1	3.2
Napa Sauvignon blanc average	Normal	1.45	26.0	3.6
Napa Cabernet Sauvignon average	SAD	0.86	15.0	3.3
Napa Cabernet Sauvignon average	Normal	1.03	21.3	3.5
Sonoma Cabernet Sauvignon	SAD	0.73	15.5	3.2
Sonoma Cabernet Sauvignon	Normal	1.06	22.8	3.5
SAD average		0.90a	14.8a	3.26a
Normal average		1.15b	22.9b	3.51b

*Means of six to 40 samples. Different lowercase letters indicate significant differences by Dunnett's test at $P = 0.05$.

Sugar accumulation disorder

Another disorder with symptoms that occur during the ripening period has been called "berry shrivel"; we recently proposed that it be called "sugar accumulation disorder" (Krasnow et al. 2009). This disorder was first described in Emperor table grapes from California's San Joaquin Valley (Jensen 1970) and is characterized by poor coloration and low sugar accumulation. Sugar accumulation disorder has been found in a number of varieties and is present in many areas of California. In general, it affects only a small proportion of clusters in a vineyard, though in certain years and vineyards up to 50% of the fruit can be affected. Regardless of the variety or location, fruit affected by sugar accumulation disorder has lower pH, berry weight and Brix compared with normally developing fruit (tables 1 and 2). When multiple rachises and fruit with sugar accumulation disorder were tested for minerals, the only consistent difference from normally developing fruit or rachises was increased calcium in the rachis tissue (Krasnow et al. 2009).

To test the hypothesis that fruit exhibiting sugar accumulation disorder may have altered nitrogen metabolism, we measured the amounts of nitrogenous compounds at harvest in fruit with the disorder compared to normally developing fruit. The vines were located at the UC Oakville Experimental Vineyard in the Napa Valley. Samples were taken at harvest on Oct. 21, 2005. Berries with sugar accumulation disorder came from clusters on six vines that historically exhibited the disorder and showed symptoms in 2005 (table 3). Normally developing berries came from clusters on three nearby vines that had no history of sugar accumulation disorder and did not display symptoms at harvest. Two berries were sampled from each cluster and eight to 10 berries were pooled to ensure enough material for analysis. Berries were peeled, their seeds removed and flesh homogenized. One milliliter of the homogenate was used for the analysis of nitrogenous compounds.

Individual amino acids in three samples of berries with sugar accumulation disorder and normally developing berries were measured at the UC Davis Molecular Structure Facility (http://msf.ucdavis.edu/aaa.html). Briefly, juice samples were acidified with sulfosalicylic acid to precipitate any intact protein before analysis. Free amino acids were separated using a Li-citrate buffer system with ion exchange chromatography on a Hitachi L-8900 amino acid analyzer. Amino acids were quantified by a postcolumn ninhydrin-reaction detection system. Amino acid concentrations were quantified from peak areas using standard curves. Data was analyzed by ANOVA (SAS Institute, Cary, NC). Means comparisons were by Dunnett's test at $P = 0.01$.

Fruit with sugar accumulation disorder from the Oakville Experimental Vineyard had significant differences in many nitrogenous compounds compared to normally developing fruit (table 4). The concentrations of some nitrogenous compounds increased while others decreased, yet the overall amount of nitrogen per berry did not significantly differ. In addition to carbohydrate metabolism, nitrogen metabolism in fruit with sugar accumulation disorder was affected, although there was no net reduction in nitrogen import. The large increase in ammonium in fruit with sugar accumulation disorder suggests interference with transamination (a reaction involving the transfer of an amino group [$-NH_2$] between molecules) or ammonium assimilation processes (Monselise and Kost 1993).

Excess ammonium is toxic, and might account for the increased cell death observed in berries with sugar accumulation disorder compared to normally developing fruit (Krasnow et al. 2008). The reduction in phenylalanine in fruit with sugar accumulation disorder may explain its poor coloration

TABLE 2. Brix, pH and berry weight of Cabernet Sauvignon berries from Oakville Experimental Vineyard used to analyze nitrogenous compounds

Average	Brix ± SD	pH ± SD	Berry weight ± SD
			grams
Sugar accumulation disorder	17.1 ± 1.7a*	3.47 ± 0.06a	0.97 ± 0.08a
Normal	25.8 ± 0.7b	3.70 ± 0.02b	1.29 ± 0.14b

* Different letters indicate significant differences by Dunnett's test at $P = 0.05$.

TABLE 3. Compositional comparison of sugar accumulation disorder (SAD), bunchstem necrosis and normally developing fruit from Oakville Experimental Vineyard, Oct. 21, 2005

Sample	Berry weight*	Brix	pH	Sugar per berry
	grams			*grams*
SAD	1.06a	18.2a	3.52a	0.19a
Bunchstem necrosis	0.98a	24.3b	3.74b	0.23b
Normal	1.24a	24.8b	3.77b	0.31c

* Data are means of 16 samples for SAD, three for bunchstem necrosis and six for control. Means with different letters are significantly different by Dunnett's test at $P = 0.05$.

Cabernet Sauvignon | **Sauvignon blanc**




Cabernet Sauvignon and Sauvignon blanc grape clusters display sugar accumulation disorder.

(Krasnow et al. 2009), as phenylalanine is a necessary component for the biosynthesis of anthocyanins (red pigments in grapes). Likewise, an increase in the amino acid hydroxyproline may indicate a stress response. It remains unclear what changes in metabolism are leading to these observed differences in other nitrogenous compounds, but the fact that these differences exist suggests that both nitrogen and carbohydrate metabolism are affected by sugar accumulation disorder.

TABLE 4. Nitrogenous compounds from sugar accumulation disorder (SAD)–affected and normally developing Cabernet Sauvignon berries at Oakville Experimental Vineyard, 2005

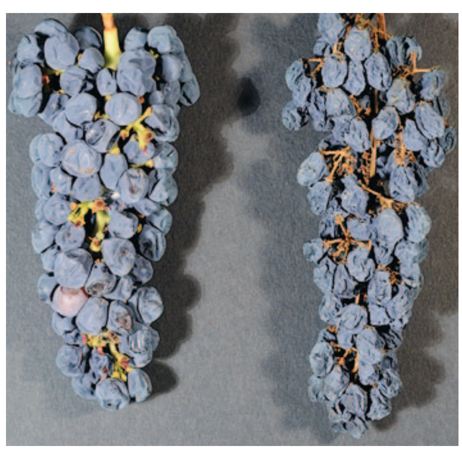
Compound	SAD	Normally developing	*P* value
	nanomoles/berry		
Compounds decreased			
Histidine	6.1	16.6	0.009
Leucine	20.0	53.4	0.044
Phenylalanine	3.4	22.7	0.017
Glycine	7.3	15.5	0.094
β-alanine	18.9	42.9	0.060
Isoleucine	19.8	47.6	0.055
Valine	31.1	77.9	0.048
Ornithine	None detected	1.6	NA*
Tyrosine	None detected	2.3	NA
Compounds increased†			
Aspartate	9.7	4.6	0.008
Alanine	30.9	11.2	0.002
Ammonium	356.0	168.2	0.031
Arginine	36.5	3.8	0.029
Hydroxyproline	32.3	18.9	0.010
Total nitrogen			
Nitrogen/berry (mg)	31.3	46.5	0.170

* NA = not applicable.

† None of the other nitrogen-containing compounds analyzed (threonine, serine, glutamine, sarcosine, glycine, cittruline, isoleucine, β-alanine, GABA, ethanolamine, hydroxylysine, lysine, 1-methylhistidine and proline) were significantly different between SAD and normally developing fruit.

Differentiating disorders

Sugar accumulation disorder and bunchstem necrosis are often confused with one another due to the similar appearance of affected fruit. With sugar accumulation disorder, the rachis appears outwardly healthy with no signs of necrosis. These two disorders can usually be differentiated by berry composition as well. As noted, berries affected by sugar accumulation disorder have lower Brix compared to normally developing fruit, whereas berries with bunchstem necrosis may have low to unusually high Brix depending on when in development the rachis becomes necrotic. The differences can often be large enough to distinguish by taste (M. Krasnow, personal observation).



Cabernet Sauvignon clusters with, *left*, sugar accumulation disorder (note the healthy rachis) and, *right*, bunchstem necrosis.

In fact, fruit with sugar accumulation disorder stops accumulating sugar several weeks before shriveling symptoms become visible (Krasnow et al. 2009). In contrast to the shrivel of bunchstem necrosis, which can appear any time after veraison, the shrivel symptoms of sugar accumulation disorder usually appear late in ripening, several weeks to just days prior to harvest. Given these distinguishing characteristics, we suggest that the terms "sugar accumulation disorder" and "bunchstem necrosis" be adopted instead of "berry shrivel" and "waterberry," which only describe fruit appearance/flavor.

Causes of sugar accumulation

Sugar accumulation disorder appears to be a vine phenomenon at some sites (i.e., Oakville Experimental Vineyard), as nonsymptomatic clusters on vines with sugar accumulation disorder clusters had sugar levels intermediate between control and symptomatic fruit (table 5) (Krasnow et al. 2009). Although some fruit on an affected vine at the Oakville Experimental Vineyard did not exhibit shrivel symptoms, this fruit nevertheless accumulated less sugar and displayed other metabolic symptoms of the disorder, indicating that the whole vine was affected and

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suggesting a possible pathogenic cause. However, tests based on polymerase chain reaction (PCR) carried out by UC Davis Foundation Plant Services (http://fpms.ucdavis.edu) on these vines were negative for phytoplasmas, closteroviruses (leafroll), fanleaf viruses, nepoviruses (arabis mosaic virus) and fleck complex viruses (tomato fleck virus) (Krasnow et al. 2009).

At other sites, sugar accumulation disorder appears to affect only specific clusters, and normal-appearing clusters on the same vine are similar to those of vines without the disorder (table 5). This data suggests that there may be more than one cause of sugar accumulation disorder. It is possible that the observed symptoms (i.e., shriveling, low pH and poor coloration in red varieties) are an indirect result of the lack of sugar accumulation, and experiments are currently under way to test this hypothesis. Future studies will focus on tests for a causal organism of sugar accumulation disorder at the Oakville Experimental Vineyard, and a more careful examination of the metabolism of fruit affected by this disorder compared to normally developing fruit.

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TABLE 5. Comparison of clusters on vines without sugar accumulation disorder (SAD), normal-appearing clusters from vines with SAD, and SAD clusters from Napa (2005) and Sonoma (2008)

Location	Condition	Juice pH*	Brix	Sugar per berry
				grams
Napa	Vines without SAD	3.71a	25.3a	0.350a
Napa	Normal-appearing clusters on vines with SAD	3.63a	22.0b	0.282b
Napa	SAD clusters	3.61a	19.2c	0.204c
Sonoma	Vines without SAD	3.45a	24.0a	0.218a
Sonoma	Normal-appearing clusters on vines with SAD	3.45a	23.0a	0.238a
Sonoma	SAD clusters	3.27b	18.2b	0.127b

*For Napa 2005 data, values are means of six samples from vines without SAD, six from normal-appearing clusters on vines with SAD and 16 for SAD. For Sonoma 2008 data, all values are means of 10 samples. Values from the same year and site with different letters are significantly different by Dunnett's test at $P = 0.05$.

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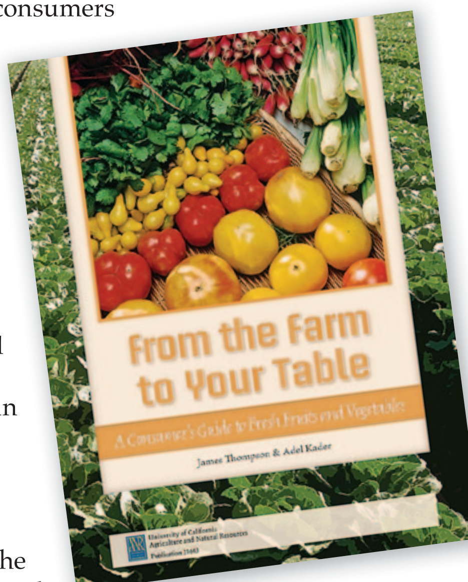

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