

# California Agriculture



Almond flowers, almond yields  
Groundwater nitrate as fertilizer  
Chaparral, biodiversity and fire  
Mapping cannabis cultivation  
The right ways to test soil nitrate



University of California  
Agriculture and Natural Resources

*California Agriculture* is a quarterly, peer-reviewed journal reporting research and reviews, published by University of California Agriculture and Natural Resources (ANR). The first issue appeared in 1946, making *California Agriculture* one of the oldest, continuously published, land-grant university research journals in the country. There are about 10,000 print subscribers.

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

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

**Indexing.** The journal is indexed by AGRICOLA, Current Contents (Thomson ISI's Agriculture, Biology and Environmental Sciences and the SCIE databases), Commonwealth Agricultural Bureau (CAB), EBSCO (Academic Search Complete), Gale (Academic One-File), Proquest and others, including open-access databases. It has high visibility on Google and Google Scholar searches. All peer-reviewed articles are posted to the ANR and California Digital Library eScholarship repositories. In the 2015 Thomson JCR, the journal's 5-year impact factor was 1.02.

**Authors and reviewers.** Authors are primarily but not exclusively from ANR; in the past 2 years, 25% were based at other UC or CSU campuses, in government agencies or at other universities and research institutions. In the same period, 39% of reviewers came from outside ANR.

**Rejection rate.** In the past 2 years, roughly 40% of submitted papers that have entered our peer-review process have been rejected. Roughly 50% of submissions are rejected by the editors without peer review due to a mismatch with the journal's scope or clear weaknesses in the research.

**Peer-review policies.** Manuscripts that pass the initial screening by the editors undergo double-blind, anonymous peer review. An associate editor evaluates the paper and then nominates two 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; see: [calag.ucanr.edu/submitarticles/](http://calag.ucanr.edu/submitarticles/).

**Letters.** The editorial staff welcomes letters, comments and suggestions. Please write to us at the

address below. Include your full name and address. Letters may be edited for space and clarity.

**Subscriptions.** These are free within the United States and \$24 per year abroad. Single copies are \$5 each. Go to: [calag.ucanr.edu/subscribe/](http://calag.ucanr.edu/subscribe/) or write us. International orders must include check or money order in U.S. funds, payable to UC Regents. Credit cards are accepted online.

**Permissions.** Material in *California Agriculture*, excluding photographs, is licensed under the Creative Commons CC BY-NC-ND 4.0 license. Please credit California Agriculture, University of California, citing volume, number and page numbers. Indicate ©[year] The Regents of the University of California.

To request permission to reprint a photograph published in *California Agriculture* in print or online, please complete the UC ANR Permissions Request Form (<http://ucanr.edu/survey/survey.cfm?surveynumber=5147>). In general, photos may be reprinted for non-commercial purposes.

## California Agriculture

Peer-reviewed research and news published by  
University of California Agriculture and Natural Resources

**VOLUME 71, NUMBER 2**

### Orders and Subscriptions:

1301 S. 46th St., Bldg. 478, Richmond, CA 94804-4600  
Phone: (510) 665-2163; Fax: (510) 665-3427; [calag@ucanr.edu](mailto:calag@ucanr.edu)

### Editorial:

2801 Second Street, Room 184; Davis, CA 95618-7779  
(530) 750-1223; [calag@ucanr.edu](mailto:calag@ucanr.edu)  
[calag.ucanr.edu](http://calag.ucanr.edu)

**Director of Publishing and Production:** Ann Senuta  
**Executive Editor:** Jim Downing  
**Managing Editor:** Deborah Thompson  
**Senior Editor:** Hazel White **Art Director:** Will Suckow  
**Senior Artist:** Kathreen Fontecha  
**Administrative Support:** Carol Lopez

### Associate Editors

**Animal, Avian, Aquaculture & Veterinary Sciences:**  
John Angelos, Maurice Pitesky

**Economics & Public Policy:** Rachael Goodhue, Mark Lubell,  
Kurt Schwabe

**Food & Nutrition:** Amy Block Joy, Lorrene Ritchie

**Human & Community Development:** Martin Smith

**Land, Air & Water Sciences:** Khaled Bali, Yufang Jin,  
Sanjai Parikh, Bryan Weare

**Natural Resources:** Richard B. Standiford, Elise Gornish

**Pest Management:** Kent Daane, Joseph DiTomaso,  
Neil McRoberts, James Stapleton

**Plant Sciences:** Kent Bradford, Kevin R. Day,  
Rachael F. Long

*California Agriculture* (ISSN 0008-0845, print, linking; ISSN 2160-8091, online) is published quarterly and mailed at periodicals postage paid at Richmond, CA, and additional mailing offices. Postmaster: Send change of address "Form 3579" to *California Agriculture* at the address above.

©2017 The Regents of the University of California



Editor's note: *California Agriculture* is printed on paper certified by the Forest Stewardship Council® as sourced from well-managed forests, with 10% recycled postconsumer waste and no elemental chlorine. See [www.fsc.org](http://www.fsc.org) for more information.



# Table of contents

## News and opinion

### Editorial

- 52 Glenda Humiston: California's working landscapes offer opportunities for economic growth**  
Building sustainable livelihoods around our farms, ranches and forests.

- 57 Hopland REC: After fire, the roles of rabbits and wildflowers**  
The dark ash left by a chaparral fire is rich in ammonium nitrogen; can the ecosystem absorb it before winter rains wash it away?

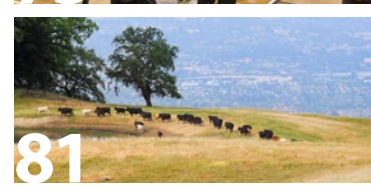
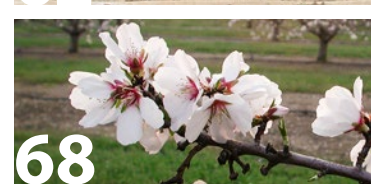
### Research news

- 53 How to study cannabis**  
Van Butsic is pioneering the study of how California's richest crop affects rural landscapes.
- 55 Hopland REC: Coexisting with chaparral**  
Long-term studies at Hopland REC find no simple answers for reducing fire risk while conserving biodiversity.

- 58 Apps for Ag winner launches community-building app in Davis**  
GivingGarden will connect neighbors through a produce-sharing service. It's superlocal, like NextDoor, but devoted solely to food and gardening.
- 59 Research highlights**  
Recent journal articles from the Agricultural Experiment Station campuses.

## Research and review articles

- 62 Field trials show the fertilizer value of nitrogen in irrigation water**  
*Cahn et al.*  
In Salinas Valley trials, lettuce and broccoli used irrigation water  $\text{NO}_3\text{-N}$  as efficiently as fertilizer N, across different  $\text{NO}_3\text{-N}$  concentrations and irrigation efficiencies.
- 68 Yield in almond is related more to the abundance of flowers than the relative number of flowers that set fruit**  
*Tombesi et al.*  
Maximizing healthy populations of productive spurs is key to optimizing yields in commercial almond orchards.
- 75 Lessons learned: How summer camps reduce risk factors of childhood obesity**  
*George et al.*  
Results suggest that youth in summer nutrition and fitness camps may lose more weight than those in non-nutrition-themed camps.
- 81 Using InVEST to assess ecosystem services on conserved properties in Sonoma County, CA**  
*Butsic et al.*  
A low-cost, spatially explicit method for documenting ecosystem services can help guide land conservation efforts.
- 90 Soil nitrate testing supports nitrogen management in irrigated annual crops**  
*Lazicki and Geisseler*  
Soil  $\text{NO}_3^-$  testing can help growers use N fertilizers efficiently.



**COVER:** A honeybee, *Apis mellifera*, collects pollen from an almond flower at Sloughside Farms in Yolo County. The golden bulb on the bee's hind leg is pollen packed into a specialized structure called a pollen basket, or corbicula. Photo by Will Suckow.

# California's working landscapes offer opportunities for economic growth

Glenda Humiston, Vice President, UC ANR

Working landscapes — croplands, rangelands, timberlands and more — are the basis of economic activity that support millions of Californians. Yet they are often under-appreciated for this economic contribution as well as the vital role they play in providing food, fiber, wildlife habitat, recreational venues, energy and valuable ecosystem services. Our working

landscapes represent an untapped economic potential that must be cultivated.

One goal within the recently adopted UC ANR strategic plan — “Building sustainable economies for working landscapes” — aims to improve that situation for the benefit of our various stakeholders. As goal owner, I will be personally leading an array of partners, along with various ANR personnel, in its implementation.

For over 100 years, UC ANR has been a source of information and expertise that has enabled innovation and economic

growth in rural communities. With a presence in every county in the state and a long history as a trusted partner — with private individuals and businesses, schools, community groups, local governments, nongovernmental organizations and state and federal agencies — UC ANR is uniquely positioned to be a catalyst for further economic development throughout California. Toward that goal, we will pursue several actions.

First, we will call attention to our institutional expertise in community economic development and seek out opportunities to leverage existing efforts and broaden our impacts. We'll be emphasizing UC Cooperative Extension (UCCE) programs that already support economic development and looking for new ways to catalyze economic development through the work UC ANR is doing with clients around the state. This represents a long-term prioritization that I believe will yield major benefits.

Second, partnerships. This is one of my big themes, and my work here at UC ANR and previously as the head of USDA Rural Development for California has shown me the power of connections between people, businesses and institutions. Partnerships can open up access to the resources needed to grow a business, create a team to

solve a problem, or help to resolve a long-standing conflict. Our research, extension and various programs offer valuable tools that can enhance those efforts. The [University Economic Development Association](#) showcases innovations and examples from around the nation that can be adapted for use in California.

Finally, we'll be working to raise awareness of the economic value of working landscapes. At venues like the California Economic Summit, an annual high-level meeting of leaders from around the state, we will carry the message that working landscapes and rural communities can be engines of innovation, job growth and sustainable prosperity.

What does building sustainable economies mean in practice? Economic opportunities can take many forms. What they have in common is using new ideas to meet a need.

For example, one area in which a number of UCCE personnel are working is in the development of what's known as values-based supply chains. Consumers increasingly differentiate among goods — from meat to vegetables to fabric to lumber — produced in a certain location or by a certain set of rules. That sort of differentiating information can have significant market value, but it may be lost in a supply chain that pools products from many sources. A values-based supply chain ensures that the information is passed down to the retail level, enabling producers to capture more value from what they grow or raise and opening up new markets for their goods.

We are also partnering with large-scale economic development organizations like [Central Valley AgPLUS](#), which in 2015 was designated by the U.S. Economic Development Administration as one of 12 Investing in Manufacturing Communities Partnerships in the nation. Central Valley AgPLUS focuses on creating new opportunities in food and beverage processing, with a holistic approach: workforce and training; supplier networks; research and innovation; infrastructure and site development; trade and international investment; and operational improvement and capital access — all areas in which the University of California has resources and knowledge to share.

One of the four aspirations in our mission statement is to help the people of California achieve “economic success in a global economy”. The initiatives identified in our new strategic plan will enhance UC ANR's role in developing sustainable economies throughout California and help to build bridges between our urban and rural sectors — a valuable contribution toward a vibrant California! [CA](#)



Glenda Humiston



# How to study cannabis

Van Butsic is pioneering the study of how California's richest crop affects rural landscapes.

Soon after Van Butsic arrived in California in 2013 to join UC Agriculture and Natural Resources, he noticed a pattern.

"Fire, water and weed are the three land-use issues that come up no matter who I talk to in this state," he said.

Fire and water were well-covered by UC and other researchers already. But cannabis looked to be an unexploited niche.

So Butsic, a UC Cooperative Extension (UCCE) assistant specialist in land systems science in the UC Berkeley Department of Environmental Science, Policy and Management, decided to build part of his research portfolio around understanding the scope, intensity and landscape impacts of cannabis cultivation in California (a research paper from another area of his research, ecosystem service valuation, appears on page 81 of this issue).

While the environmental impacts of cannabis production have drawn substantial media attention, and though it is by many estimates

the state's most valuable crop, data beyond anecdotes is scarce.

Butsic attacked the problem by visually analyzing satellite-based imagery, identifying remote plantations and greenhouses in Humboldt County and mapping them using GIS.

This approach required many hundreds of hours of manual inspection of satellite images, and one of the first challenges was figuring out how to do this labor-intensive work. It wasn't difficult to find UC Berkeley undergraduates interested in working for course credit. Nearly 25 students have now contributed to the project, and two (so far) have moved on to full-time GIS jobs after graduation. An anonymous nonprofit organization provided financial support for a part-time staff researcher and to purchase more recent high-resolution satellite data.

The team has built a GIS data layer for about half of Humboldt County's land area, identifying roughly 300,000 cannabis plants (equivalent to a wholesale value of perhaps \$150 million) based on 2012 imagery, with an updated estimate now in the works. The data layer enables a variety of analyses — from the zoning of the land used by cannabis growers (only about a quarter of the 1,429 grows identified were on land zoned for agriculture); to the slope of cannabis production plots, a factor influencing erosion (almost



UCCE Assistant Specialist Van Butsic uses satellite imagery to analyze the environmental impacts of cannabis production.



This series of satellite images shows the development of a greenhouse complex in a Humboldt County forest. Using satellite imagery in combination with GIS layers showing topography, watercourses, zoning and other variables, Butsic and his colleagues can characterize cannabis production sites in a variety of ways, such as average slope, proximity to streams, and whether they are located on land zoned for agriculture.





**Butsic and his colleagues identified approximately 4,400 grow sites in their research. Five percent of those, including the site pictured above, were within 100 meters of salmon streams.**

a quarter are on very steep ground, with slope exceeding 30%); to proximity to salmon streams (more than 200 grows were found within 100 meters of critical habitat for steelhead and chinook salmon) (Butsic and Brenner 2016).

Butsic estimates the absolute volume of water used to irrigate cannabis to be fairly modest — on the order of a few thousand acre-feet. But that figure probably understates the habitat impact of water diversions; water is withdrawn from small watersheds during summer months when water is scarce, and some creeks are known to have been completely dewatered.

The information is helping to inform local debates. Humboldt County recently adopted an ordinance requiring all new cannabis grows to be developed on

land zoned for agriculture (existing grows on nonagricultural land are grandfathered in). This policy raises concerns about rapid inflation of agricultural land, as cannabis growers bid up prices beyond what other farm or livestock operations can support. Butsic's work provides insights into the characteristics and geography of lands that are likely to be developed for cannabis production.

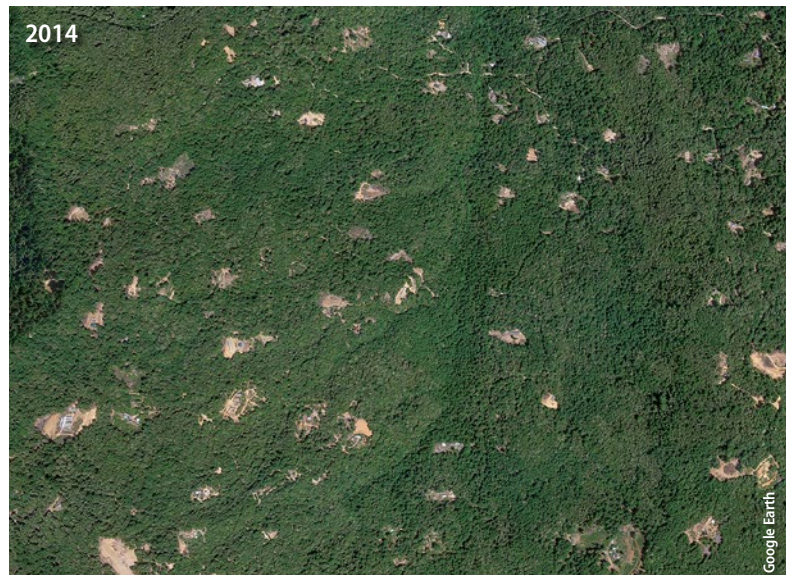
Related to this issue, Butsic and several Humboldt County-based UCCE academics — County Director Yana Valachovic, Area Fire Advisor Lenya Quinn-Davidson, and Livestock and Natural Resources Advisor Jeffery Stackhouse — are currently surveying Humboldt County landowners about cannabis-related land use issues.

Butsic's next steps include continued mapping of cannabis production in California, with Mendocino County to be completed by the end of 2017. Given the uncertainty around federal restrictions on cannabis production under the Trump administration, Butsic said it's difficult to predict what the most essential research questions surrounding cannabis will be. Nonetheless, "by continuing to document on the ground patterns of cannabis production, we will be in a position to answer those questions," he said. [CA](#)

—Jim Downing

## References

Butsic V, Brenner JC. 2016. Cannabis (*Cannabis sativa* or *C. indica*) agriculture and the environment: a systematic, spatially-explicit survey and potential impacts. *Environ Res Lett* 11(4). <https://doi.org/10.1088/1748-9326/11/4/044023>.



Forest fragmentation occurs when cannabis growers clear land and build roads to access their grow sites. The Butsic team's analysis indicates that 68% of grows were located more than 500 meters from developed roads.



# Coexisting with chaparral

Long-term studies at Hopland Research and Extension Center find no simple answers for reducing fire risk while conserving biodiversity.

**M**ore than half of California's 20 largest wildfires have involved chaparral ecosystems. The oily shrubs burn hot — up to 3,500°F, with flames that can reach 50 feet high.

Because chaparral is found in and around many of the state's largest population centers, chaparral systems include a great deal of what's known as wildland-urban interface. That makes chaparral a major focus of efforts to manage fire risk by reducing wildland fuels loads — typically through prescribed fire and mastication (mechanical chopping).

Chaparral is also one of California's most biodiverse ecosystem types, which sets another imperative for land managers: avoiding the degradation or loss of chaparral systems.

UC ANR's Hopland Research and Extension Center (HREC) in southern Mendocino County provides a unique experimental location to study the effects on chaparral systems of fuels reduction treatments. There's abundant chaparral on the 5,300-acre site, it's remote enough to make burning safe and practical, and researchers can conduct long-term studies; some data sets collected at HREC span more than 40 years.

Since 2001, Scott Stephens, a professor in the Department of Environmental Science, Policy and Management at UC Berkeley, and his collaborators have studied the ecosystem changes wrought by mastication treatments and more than 35 controlled fires at HREC. The fires have been managed by California Department of Forestry and Fire Protection (CAL FIRE) and REC staff.

In California's conifer forests, it's now well-established that fuels reduction treatments promote healthy ecosystem function — in part because those systems are adapted to frequent low-intensity fires that burn the underbrush and small trees.

But chaparral systems are different. They appear to be adapted to infrequent fire, recurring perhaps only every 50 or 100 years. The shrubs that define chaparral systems are slow to grow back, and that can allow nonnative grasses to establish.

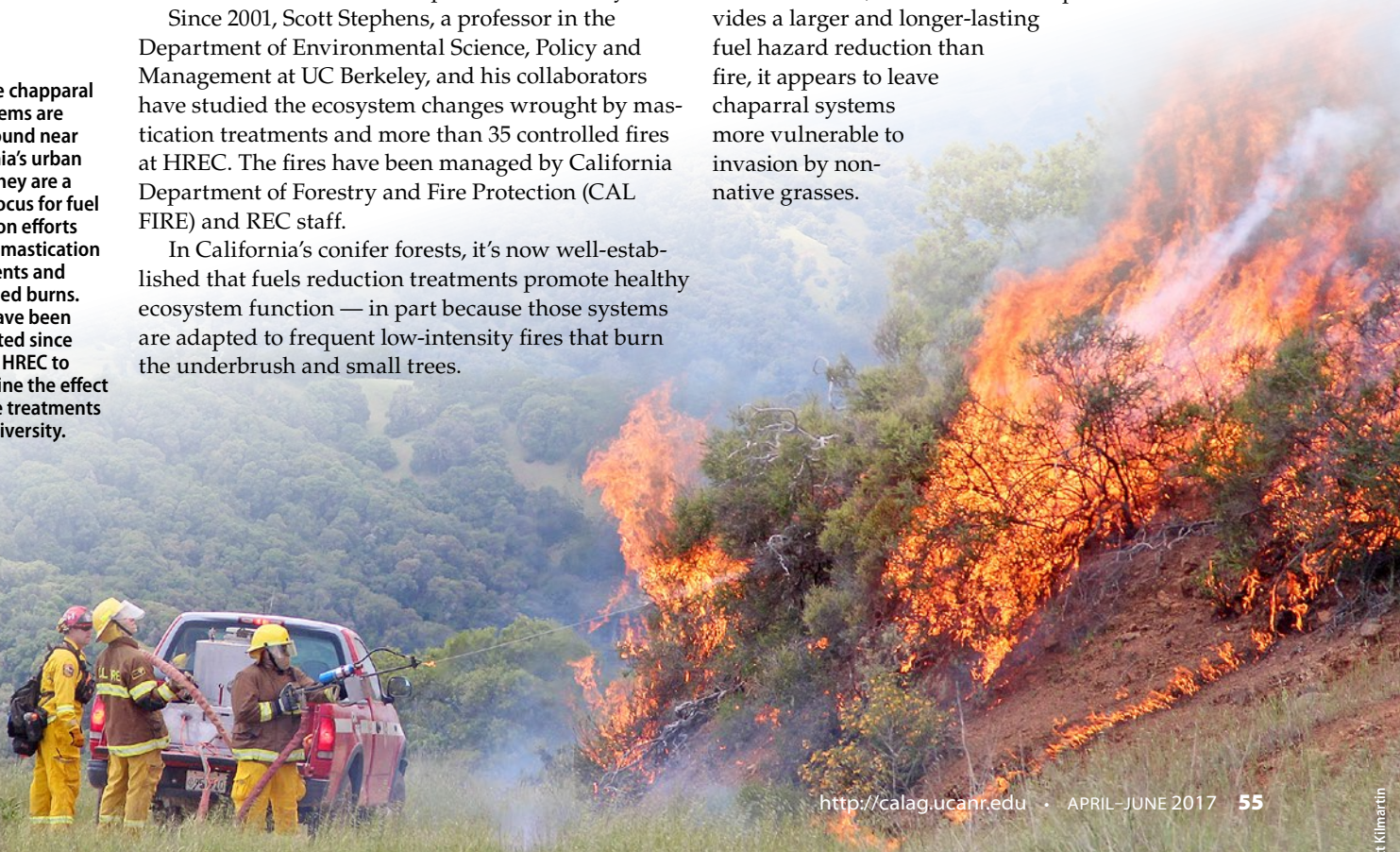
Nonnative grasses are a problem because their flammability is higher than that of native grasses, and much higher than that of chaparral shrubs (which are fairly resistant to ignition but burn very hot once lit). High flammability of vegetation increases the probability of frequent accidental wildfires. Ecologists consider nonnative grasses one of the gravest threats to the diversity of a chaparral ecosystem; they can eventually convert chaparral to permanent grassland.

"They're a giant red flag for the ecosystem," said Stephens.

Ongoing trials at HREC are comparing five treatments: fall, winter and spring prescribed fire, and fall and spring mastication. The findings illustrate the multiple considerations that must inform fuels management strategy — and that no strategy is a clear winner in all situations.

For instance, while mastication provides a larger and longer-lasting fuel hazard reduction than fire, it appears to leave chaparral systems more vulnerable to invasion by non-native grasses.

Because chaparral ecosystems are often found near California's urban areas, they are a major focus for fuel reduction efforts such as mastication treatments and controlled burns. Trials have been conducted since 2001 at HREC to determine the effect of these treatments on biodiversity.







Prescribed fire tends to reduce some native shrubs, such as buckbrush (*Ceanothus cuneatus*), which is an important deer browse.

Three years postfire, all of Stephens' plots contained more nonnative grasses than did the untreated plots, but nonnative grasses were much more prevalent in the masticated plots (Potts and Stephens 2009).

On the other hand, 10 years after treatment, the native shrub buckbrush, an important deer browse, had almost disappeared from all fire plots, while it was more prevalent in the masticated plots than in the untreated plots (Wilkin et al. 2015).

The fuels hazard reduction treatments themselves also have tradeoffs. Compared to mastication, prescribed fire is less costly and can be used on steep or rough terrain. But it also needs approval from air quality regulators, requires skill and coordination to manage safely, and can't be used during much of the dry season.

Based on recent findings, Stephens believes a fall prescribed fire may pose the lowest overall risk to the chaparral ecosystem. A vital part of the study remains — re-burning the fire plots to study the effects on the plant community of repeated fire treatments, which are necessary every 10 to 15 years to maintain a fire prevention program. [CA](#)

—Jim Downing

## References

- Potts JB, Stephens SL. 2009. Invasive and native plant responses to shrubland fuel reduction: Comparing prescribed fire, mastication, and treatment season. *Biol Conserv* 142:1657–64.
- Wilkin K, Ponisio LC, Fry DL, Tubbesing C, Potts J, Stephens S. 2015. Trade-offs of reducing chaparral fire hazards. Final Report Joint Fire Science Program Project 11-1-2-12. Berkeley, CA: UC Berkeley. [www.firescience.gov/projects/11-1-2-12/project/11-1-2-12\\_final\\_report.pdf](http://www.firescience.gov/projects/11-1-2-12/project/11-1-2-12_final_report.pdf).





# After fire, the roles of rabbits and wildflowers

The dark ash left by a chaparral fire is rich in ammonium nitrogen; can the ecosystem absorb it before winter rains wash it away?

Herbaceous annual plants can act as sponges for nitrogen.

Immediately after a chaparral fire, the ground is covered with a few millimeters of very dark ash that is rich in ammonium nitrogen, a form highly available to plants. The boon it promises to this generally nitrogen-limited ecosystem, however, can be short-lived. To help restore chaparral shrubs and a full recovery of the chaparral ecosystem, plants must take up this nitrogen quickly. Otherwise, it converts to nitrate nitrogen and at the onset of winter rains runs off or leaches to creeks, where it becomes a pollutant.

At Hopland Research and Extension Center (HREC), researcher Lindsey Hendricks-Franco, a doctoral candidate in integrative biology at UC Berkeley, is investigating the postfire nitrogen cycling roles played by ephemeral herbaceous plants such as whisperingbells (*Emmenanthe penduliflora*) and Brewer's redmaids (*Calandrinia breweri*) and by herbivores — black-tailed deer, rodents and rabbits. She suspects they play a significant role in retaining nitrogen in chaparral ecosystems, the most extensive ecosystem type in California.

"It's a race," Hendricks-Franco says. "From dormant seed banks, you get blankets of big leafy herbaceous annuals that are really important ammonium nitrogen sponges. And if those plants don't appear and grow quickly, the ash, and the nonabsorbed nitrogen, washes away."

Last year, Hendricks-Franco set fires at HREC in April and October, sampling for nitrogen before and after the fires. In mid-December, annuals were

sprouting, and the chaparral shrubs burned in the spring fire showed some new growth. But so much rain had fallen, ash was also washing away.

In late December, fences were up around some of the burned plots, to study the effect of excluding herbivores. In January, Hendricks-Franco was weeding the plots so that they contained four different plant groups: (1) all naturally occurring herbaceous plants, (2) only plants that aren't nitrogen fixers, (3) only nitrogen-fixing plants and (4) no herbaceous plants at all.

She hypothesizes that the first group will cycle nitrogen most vigorously, followed by the second, third and fourth, in that order. Additionally, she thinks herbivores will accelerate nitrogen cycling in some plots, because in high-nitrogen systems, they stimulate growth of fast-growing plants that can tolerate grazing. Nitrogen sampling during the next two years will reveal how well different plant communities retain nitrogen after fire, with and without herbivores, and the effect of fire season.

This work requires a trial in a natural setting such as HREC, which has mature chaparral that is accessible and can be burned safely. Until now, there had been no formal replicated fire trials with control plots to measure the effects of animal grazing on nitrogen cycling after chaparral fire. The study results will help guide land managers on what to do in the first few months after a fire — perhaps seeding native plants and introducing grazers — to encourage fast recovery of the chaparral and associated species. [calag.ucanr.edu](http://calag.ucanr.edu)

—Hazel White



Researcher Lindsey Hendricks-Franco hypothesizes that herbivores will accelerate nitrogen cycling in nitrogen-rich chaparral systems.

Whisperingbells (*Emmenanthe penduliflora*) may cycle the nitrogen in wildfire ash faster than nitrogen-fixing herbaceous plants.





# Apps for Ag winner launches community-building app in Davis

**GivingGarden will connect neighbors through a produce-sharing service. It's superlocal, like NextDoor, but devoted solely to food and gardening.**

**H**ow big is a microclimate or a neighborhood? Can gardeners improve their health and happiness by getting to know one another? Might they like to get involved in tracking Asian citrus psyllid, and can they help build a plant database that's more valuable locally than the *Sunset Western Garden Book*? Deema Tamimi, winner of last summer's UC ANR-sponsored Apps for Ag hackathon and the CEO and cofounder of GivingGarden Co. ([givinggarden.io](http://givinggarden.io)), is excited about what will happen when her startup launches its app in Davis in early summer. It's local, like Nextdoor but focused entirely on food.

Her GivingGarden app could help UC ANR and government agencies connect with gardeners about best practices for pest management and water use. Tamimi is interested in that. The app's biggest value, though, will likely not be as a one-way channel of expert information, but rather as an instigator of people getting to know neighbors, "connecting people to good food and to each other," says Tamimi. So GivingGarden is launching primarily as a produce-sharing service.

In her research, Tamimi discovered food sharing and bartering apps are gaining popularity in Australia and the U.K., and produce sharing is happening here on Nextdoor and Craigslist, but gets lost among crime reports and job listings. Users of GivingGarden will be able to contact one another on the app and post gardening photos, events and questions to neighbors.

At one point, Tamimi had hoped to launch with recommendations on what to grow, but that requires a huge dataset, which currently doesn't exist at the level of neighborhood microclimates. The U.S. Department of Agriculture and Sunset give plant recommendations for relatively large climate zones, but publish no local data for cities or neighborhoods. Tamimi sees crowd sourcing, via the app, as the best means to build that dataset.

Connectivity is the key to what gets generated by the app users and its success. The business plan includes expansion to other cities. To reach the app audience as she launches GivingGarden, Tamimi is

talking to growers, researchers, community gardeners, school gardeners, Master Gardener groups and writers, inviting them energetically to help build community and change.

The app has already changed Tamimi's life. At the hackathon last July, she planned to take a back seat but stepped up to pitch the project on the spur of the moment, the only woman to pitch an idea. The two men who joined her and her husband, Josh Livni, to build out a part of it that hackathon weekend became cofounders of GivingGarden. Scott Kirkland is head of mobile development; John Knoll is head of web and operations; Livni is head of data. Tamimi leads the company she started, a lifelong goal that she'd been sidelining for years as she worked in Silicon Valley. In the fall, Tamimi left her position as head of product and performance marketing at Flipboard and set up a second business, Caneberry, a consulting company in food and ag startups.

"A revolutionary idea could change food and agriculture," encourages AgStart, the nonprofit business incubator that organizes the Apps for Ag hackathon. Maybe it's Tamimi's. At the California State Fair last summer, the crowd and four influential judges, including Glenda Humiston, UC ANR vice president, and [Better Food Ventures](#) and [Mixing Bowl Hub](#) founder Rob Trice, got behind it. [CA](#)

—Hazel White



Deema Tamimi is CEO and co-founder of GivingGarden Co.



From left to right, Apps for Ag winners Scott Kirkland, Josh Livni, Deema Tamimi and John Knoll. This summer the team will launch the GivingGarden app, which will help users build a local plant database and share gardening advice and produce with their neighbors.



# Research highlights

Recently published articles from campus-based faculty and UC Cooperative Extension researchers at the Agricultural Experiment Station sites: UC Berkeley College of Natural Resources, UC Riverside College of Natural and Agricultural Sciences and UC Davis School of Veterinary Medicine and College of Agricultural and Environmental Sciences.



The insecticide fipronil is often used to prevent household infestations of Argentine ants (*Linepithema humile*), but runoff is a concern, particularly from driveways. UC Riverside researchers found that using other treatments in the driveway area can maintain efficacy while greatly reducing fipronil runoff.

## Household ant control with less pesticide runoff

Household infestations of Argentine ants, a common pest in California, are often treated with a band of the insecticide fipronil around the foundation of a house. Runoff of fipronil into urban waterways is a concern, with applications of the insecticide at the driveway-garage door interface a key source of such pollution.

Les Greenberg, a specialist in the UC Riverside Department of Entomology, and his colleagues tested ways to maintain the efficacy of ant treatments while reducing runoff. They applied fipronil around test houses but in the driveway area replaced the fipronil application with alternative treatments less likely to produce polluted runoff. A gel bait containing thiamethoxam (brand name Optigard) performed best, but only after 8 weeks. Avoiding spraying the driveway reduced fipronil runoff by two to three orders of magnitude.

Greenberg L, Rust MK, Wright SJ, Choe D-H. 2017. Argentine ant control around homes: Efficacy of treatments and urban runoff. *Int J Pest Manage*. <http://doi.org/10.1080/09670874.2016.1278085>.

## A better way to sample for pyrethroid pesticides in urban streams

Runoff of pyrethroids, widely used household insecticides, has led to contamination of urban waterways as

well as a need to accurately assess pyrethroid concentrations in waterways.

Current grab-sample methods provide only a snapshot of contamination levels. Further, sampling of pyrethroids is complicated because the compounds readily sorb to organic matter in water, while the free concentration is what determines toxicity.

Jay Gan, professor in the Department of Environmental Sciences at UC Riverside, and his colleagues report the development of an effective polyethylene film passive sampler that can be deployed in the field for a period of several days. Laboratory and field tests showed that the sampler accurately detected free concentrations of pyrethroids at concentrations as low as 1 part per trillion.

Xue J, Liao C, Wang J, Cryder Z, Xu T, Liu F, Gan J. 2017. Development of passive samplers for in situ measurement of pyrethroid insecticides in surface water. *Environ Pollut*. <http://doi.org/10.1016/j.envpol.2017.02.034>.

## Another reason why water quality in the Delta is so difficult to manage

Microbial contamination is a key indicator of water quality impairment, commonly assessed by sampling for fecal indicator bacteria (FIB).

A team of researchers in the laboratory of Rob Atwill, UC Cooperative Extension Director of Veterinary Medicine Extension and Director at the Western Institute for Food Safety and Security at the UC Davis School of Veterinary Medicine, sampled FIB monthly at 88 sites in the Sacramento-San Joaquin Delta for two years. They collected data on 53 variables that may influence bacterial concentrations, from water chemistry to recent rainfall totals to nearby land uses.

The results provide important baseline data on microbial contamination in the Delta. But a key message from the study is that it is very difficult to determine what causes high levels of FIB at a given time and place in a system as complex as the Delta, with its hundreds of channels and tidal influence. Ongoing and perhaps unending monitoring is needed, a challenge the researchers describe as Sisyphian.

Partyka ML, Bond RF, Chase JA, Atwill ER. 2017. Monitoring bacterial indicators of water quality in a tidally influenced delta: A Sisyphian pursuit. *Sci Total Environ* 578:346–56. <http://doi.org/10.1016/j.envpol.2017.02.034>.



## Early exposure to ambient wildfire smoke may impair lung function later in life

Human exposure to wildfire smoke in California is an increasing concern given the vulnerability of the state's forests to major fires and the likelihood that climate change will increase wildfire severity.

Professor Lisa Miller of the UC Davis School of Veterinary Medicine and her colleagues evaluated multiple measures of lung function and pulmonary immune response in a group of rhesus macaque monkeys in Yolo County that were exposed in infancy to the smoke from mountain wildfires that filled the Sacramento Valley in the summer of 2008. The monkeys were born and raised in large outdoor field cages and exposed to ambient smoke (as was anybody outdoors in the region at that time).

When they reached adolescence, the exposed monkeys exhibited compromised immune and lung function compared to a control group; the results suggest that human children may be similarly affected. Monkeys exposed as adults to the same ambient smoke episode did not show long-term lung impacts.

Black C, Gerriets JE, Fontaine JH, Harper RW, Kenyon NJ, Tablin F, Schelegle ES, Miller LA. 2017. Early life wildfire smoke exposure is associated with immune dysregulation and lung function decrements in adolescence. *Am J Resp Cell Mol Biol*. <http://doi.org/10.1165/rcmb.2016-0380OC>.

The Rim Fire near Yosemite National Park burned 400 square miles in 2013. Results from a UC Davis School of Veterinary Medicine study suggest that exposure to wildfire smoke during infancy may compromise lung function in adolescence.



## Air pollution in China reduces rice yields

Increasing surface ozone pollution in China, the world's largest producer and importer of rice, poses a threat to global food security.

UC Davis Professor of Agricultural and Resource Economics Colin Carter and his colleagues analyzed data on air quality and rice yields in 5 provinces over 3 years. They found that, for each day during panicle development, a doubling of surface ozone from 60 to 120 parts per billion or more is associated with a yield loss of approximately 1%.

Emissions of nitrogen oxides from cars, power plants and other sources are the root cause of surface ozone pollution.

The pollution-related yield losses in China may have international significance. Because only about 8% of the world's rice harvest is traded, global market prices are quite sensitive to changes in production.

Carter CA, Cui X, Ding A, Ghanem D, Jiang F, Yi F, Zhong F. 2017. Stage-specific, nonlinear surface ozone damage to rice production in china. *Sci Rep* 7:44224. <http://doi.org/10.1038/srep44224>.

## Current protected areas may be inadequate to preserve biodiversity as the climate changes

As the climate changes and habitats shift, so may the biodiversity conservation value of existing protected areas.

Max Moritz, UC Cooperative Extension (UCCE) specialist in UC Berkeley's Department of Environmental Science, Policy and Management, and his colleagues examined the potential effect of climate change on protected areas in the United States, Canada and Mexico.

They found that approximately 80% of protected areas in North America could experience high rates of climate change by the year 2100, which could lead to shifts in species abundance or distribution in those areas. Additional stressors like altered fire regimes and land development will compound the threats presented by climate change.

The majority of nearest climatic analogs for the protected areas were found to be in locations that are currently unprotected. Thus, to ensure the effectiveness of protected area networks, conservation plans will need to include areas outside those currently under protection.

Battlori E, Parisien M-A, Parks SA, Moritz MA, Miller C. 2017. Potential relocation of climatic environments suggests high rates of climate displacement within the North American protection network. *Glob Change Biol*. <http://doi.org/10.1111/gcb.13663>.





Good Land Organics farmer Jay Ruskey (left) and UC Davis researcher Juan Medrano (right) examine coffee cherries at Good Land Organics in Goleta, California, in 2016. Medrano and his team used samples from Ruskey's coffee trees to sequence the *Coffea arabica* genome.

Joe Proudman / UC Davis

## UC Davis researchers sequence genome for *Coffea arabica*

The [UC Davis Coffee Genome Project](#) — Juan Medrano, professor in the Department of Animal Science, Allen Van Deynze of the UC Davis Seed Biotechnology Center, Dario Cantu, associate professor in the Department of Viticulture and Enology, and postdoctoral researcher Amanda Hulse-Kemp — analyzed samples obtained from coffee trees grown on a farm in Goleta, north of Santa Barbara. The trees are the first commercial coffee plants to be grown in the continental United States.

The researchers report that the new genome sequence will be helpful in developing disease-resistant coffee varieties that can adapt to climate change, which threatens global coffee production in tropical regions.

Medrano JF, Van Deynze A, Cantu D, Hulse-Kemp A. 2017. The UC Davis *Coffea arabica* Genome Project. *Coffea arabica* UCDv 0.5. [https://phytozome.jgi.doe.gov/pz/portal.html#!info?alias=Org\\_Carabica\\_er](https://phytozome.jgi.doe.gov/pz/portal.html#!info?alias=Org_Carabica_er).

## Effect of food safety culture on individuals in the fresh produce sector

Concern over outbreaks of foodborne illness in the United States has resulted in increased scrutiny of food safety throughout the produce sector. In response, the industry has adopted “food safety culture”, a people-management strategy that aims to better protect consumers and businesses by changing employee values and behavior.

To determine the effect of these initiatives, a team of UC Berkeley researchers interviewed vegetable growers and produce buyers in California. Assistant UCCE Specialist Jennifer Sowerwine,

Associate UCCE Specialist Christy Getz and post-doctoral fellow Patrick Baur, all with the Department of Environmental Science, Policy and Management, found that the growing emphasis on food safety culture implicitly categorizes companies, employees and agricultural products as “good” and “bad,” which can create an atmosphere of fear and uncertainty.

These effects may have the most worrisome impact on vulnerable actors, including small-scale and minority farmers and workers. The researchers suggest that this model will not lead to a healthy food system, and may instead perpetuate a cycle of crisis and regulatory reform that puts the public at risk.

Baur P, Getz C, Sowerwine J. 2017. Contradictions, consequences and the human toll of food safety culture. *Agric Hum Values*. <http://doi.org/10.1007/s10460-017-9772-1>.

An assessment of “food safety culture”, a management strategy in the food industry for changing employee behavior, suggests that it has unintended negative effects.



USDA / Lance Cheung



# Field trials show the fertilizer value of nitrogen in irrigation water

by Michael Cahn, Richard Smith, Laura Murphy and Tim Hartz

*Increased regulatory activity designed to protect groundwater from degradation by nitrate-nitrogen ( $\text{NO}_3\text{-N}$ ) is focusing attention on the efficiency of agricultural use of nitrogen (N). One area drawing scrutiny is the way in which growers consider the  $\text{NO}_3\text{-N}$  concentration of irrigation water when determining N fertilizer rates. Four drip-irrigated field studies were conducted in the Salinas Valley evaluating the impact of irrigation water  $\text{NO}_3\text{-N}$  concentration and irrigation efficiency on the N uptake efficiency of lettuce and broccoli crops. Irrigation with water  $\text{NO}_3\text{-N}$  concentrations from 2 to 45 milligrams per liter were compared with periodic fertigation of N fertilizer. The effect of irrigation efficiency was determined by comparing an efficient (110% to 120% of crop evapotranspiration,  $\text{ET}_c$ ) and an inefficient (160% to 200% of  $\text{ET}_c$ ) irrigation treatment. Across these trials,  $\text{NO}_3\text{-N}$  from irrigation water was at least as efficiently used as fertilizer N; the uptake efficiency of irrigation water  $\text{NO}_3\text{-N}$  averaged approximately 80%, and it was not affected by  $\text{NO}_3\text{-N}$  concentration or irrigation efficiency.*

California agriculture faces increasing regulatory pressure to improve nitrogen (N) management to protect groundwater quality. Groundwater in agricultural regions, such as the Salinas Valley and the Tulare Lake Basin, has been adversely impacted by agricultural practices, with nitrate-N ( $\text{NO}_3\text{-N}$ ) in many wells exceeding the federal

drinking water standard of 10 mg/L (Harter et al. 2012). The threat to groundwater is particularly acute in the Salinas Valley, where the intensive production of vegetable crops has resulted in an estimated net loading (fertilizer N application – N removal with crop harvest) of > 100 lb/ac (> 112 kg/ha) of N annually (Rosenstock et al. 2014).

Levels of  $\text{NO}_3\text{-N}$  in irrigation wells in the Salinas Valley commonly range from 10 to 40 mg/L. Given the typical volume of irrigation water applied to vegetable fields,  $\text{NO}_3\text{-N}$  in irrigation water

could represent a substantial fraction of crop N requirements, provided that crops can efficiently use this N source. Indeed, the concept of “pump and fertilize” (substituting irrigation water  $\text{NO}_3\text{-N}$  for fertilizer N) has been suggested as a remediation technique to improve groundwater quality in agricultural regions (Harter et al. 2012).

Cooperative Extension publications from around the country (Bauder et al. 2011; DeLaune and Trostle 2012; Hopkins et al. 2007) agree that the fertilizer value of irrigation water  $\text{NO}_3\text{-N}$  can be significant, but they differ as to what fraction of water  $\text{NO}_3\text{-N}$  should be credited against the fertilizer N recommendation. There is a paucity of field data documenting the efficiency of crop utilization of irrigation water N. Francis and Schepers (1994) documented that corn could use irrigation water  $\text{NO}_3\text{-N}$ , but in their study N uptake efficiency from irrigation water was low, which they attributed to the timing of irrigation relative to crop N demand and the availability of N from other sources. Martin et al. (1982) suggested that uptake efficiency of irrigation water  $\text{NO}_3\text{-N}$  could actually be higher than from fertilizer N, but their conclusion was based on a computer simulation, not on field trials.

With this near total lack of relevant field data, California growers have legitimate concerns about the degree to

Online: <https://doi.org/10.3733/ca.2017a0010>

Inexpensive nitrate test strips allow on-farm estimation of irrigation water  $\text{NO}_3\text{-N}$  concentration. In Salinas Valley irrigation wells, levels of  $\text{NO}_3\text{-N}$  commonly range from 10 to 40 mg/L, which could supply a substantial portion of crop N requirements.





An injection system generated irrigation water with  $\text{NO}_3\text{-N}$  concentrations of 12, 25 and 45 mg/L.

which irrigation water  $\text{NO}_3\text{-N}$  can substitute for fertilizer N. Two questions commonly asked by growers are whether plants can effectively use N at the low concentrations common in irrigation water, and to what degree irrigation inefficiency reduces water  $\text{NO}_3\text{-N}$  availability. We undertook this study to document the agronomic value of irrigation water  $\text{NO}_3\text{-N}$  in the production of vegetable crops under field conditions representative of the Salinas Valley.

## Irrigation water $\text{NO}_3\text{-N}$ trials

Four field trials were conducted at the U.S. Department of Agriculture Agricultural Research Service (USDA-ARS) facility near Salinas between 2013 and 2015. The soil was a Chualar sandy loam. Before planting, fields were sprinkler-irrigated to leach residual soil  $\text{NO}_3\text{-N}$  so that all trials were conducted with low background soil N availability. The well water used for pre-plant leaching as well as for all in-season irrigation ranged between 2 and 4 mg/L  $\text{NO}_3\text{-N}$  over the course of this study. The experimental design for each trial was a randomized complete block, with four replications. Individual plots consisted of four beds, each 40 inches (1 meter) wide and 40 feet (12.2 meters) long, with all data collected from the middle two beds.

Crisphead lettuce ‘Telluride’ was seeded on May 16, 2013, in two rows per

bed and germinated using sprinklers. A soil anticrustant solution containing 17 lb/ac (19 kg/ha) of N was applied to all treatments at planting to improve germination. After plants were thinned to a final in-row spacing of approximately 12 inches (30 centimeters), drip tape was installed on top of the beds and the field was drip-irrigated for the rest of the season.

Crop growth and N uptake were compared across a range of treatments simulating different irrigation water  $\text{NO}_3\text{-N}$

concentrations during the drip-irrigated phase of the crop. The different  $\text{NO}_3\text{-N}$  concentrations were achieved by using water-powered proportional injectors to enrich all drip-applied water to 12, 25 or 45 mg/L  $\text{NO}_3\text{-N}$ . Injected  $\text{NO}_3\text{-N}$  was a blend of  $\text{Ca}(\text{NO}_3)_2$  and  $\text{NaNO}_3$  to maintain a cation balance similar to groundwater (Ca:Na milliequivalent ratio of 1.0). A water sample was collected from each treatment during each irrigation to confirm that the target  $\text{NO}_3\text{-N}$  concentrations were achieved. Additionally, an unfertilized control and a fertilized control treatment were included; both were irrigated using water containing only 2 mg/L  $\text{NO}_3\text{-N}$ . The fertilized control received five fertigations of ammonium nitrate solution (AN-20) totaling 150 lb/ac (168 kg/ha) of N. Also, all treatments were fertilized with potassium thiosulfate (KTS) in two fertigations of 30 lb/ac (34 kg/ha) of K each.

Each N treatment was evaluated at two levels of irrigation to observe the interaction between irrigation efficiency and crop uptake of irrigation water  $\text{NO}_3\text{-N}$ . The lower level of irrigation, 110% of crop evapotranspiration ( $\text{ET}_c$ ), was chosen to represent efficient management with minimal leaching. The higher level of irrigation, 160% of  $\text{ET}_c$ , was chosen to represent less efficient irrigation management; we have observed a number of Salinas Valley vegetable fields in which irrigation reached as high as 200% of  $\text{ET}_c$  (Smith et

## Calculating the N in irrigation water

Calculation of the amount of nitrogen in irrigation water requires knowledge of both the N concentration and the volume of water applied. Laboratory analysis for nitrate in water is commonly reported as milligrams per liter (mg/L) or parts per million (ppm); these units are numerically the same: 1 mg/L equals 1 ppm. Labs may report concentration either as nitrate ( $\text{NO}_3^-$ ) or nitrate-N ( $\text{NO}_3\text{-N}$ ); the conversion between the two is

$$\text{NO}_3^- \div 4.43 = \text{NO}_3\text{-N}$$

To convert  $\text{NO}_3\text{-N}$  concentration to mass of N applied, this equation can be used:

$$\text{mg/L NO}_3\text{-N} \times 0.227 = \text{lb of N/ac-in of water}$$

Nitrate is usually the only form of N present in irrigation water in an agronomically significant amount, so it is the only N form reported on the typical water test. However, recycled municipal wastewater, which is increasingly being used for irrigation in California, can contain more ammonium N ( $\text{NH}_4\text{-N}$ ) than  $\text{NO}_3\text{-N}$ , as well as some organic forms of N that become relatively quickly available in soil. Wastewater treatment plants routinely test for these other N sources in addition to  $\text{NO}_3\text{-N}$ , and this information is publicly available. One should consider all forms of N when estimating the amount of plant-available N in recycled water.



al. 2016). Applying 160% of  $ET_c$  generated an estimated leaching fraction of 37% (Cahn and Bali 2015).  $ET_c$  was estimated by multiplying reference evapotranspiration ( $ET_0$ ) values obtained from the CIMIS weather station located on the USDA-ARS facility by crop coefficients calculated by the method described by Johnson et al. (2016). Irrigation was applied twice weekly. Data on  $ET_c$  and irrigation volume are given in table 1. Precipitation was an insignificant factor, with < 0.2 inches (< 0.5 cm) received in any trial.

A second trial of the same structure was conducted in 2014. Broccoli ‘Patron’ was seeded on Aug. 18 in two rows per bed and germinated with sprinkler irrigation following an anticrustant application containing 23 lb/ac (26 kg/ha) of N. After crop establishment and bed cultivation, the trial was converted to surface drip irrigation. The irrigation levels evaluated were 110% and 190% of  $ET_c$ . The fertilized control treatment received three fertigations of AN-20 totaling 220 lb/ac (246 kg/ha) of N. All treatments were also fertigated with KTS in two applications of 25 lb/ac (28 kg/ha) of K.

Two trials were conducted in 2015 to directly compare the uptake efficiency of irrigation water  $NO_3-N$  to that of fertilizer N. In the spring trial, crisphead lettuce ‘Telluride’ was seeded and germinated as previously described. After converting the field to drip irrigation, four levels of fertigation (a seasonal total of 0, 20, 60

Year	Crop	$ET_c$	Irrigation applied		Leaching fraction (%)†	
			Low*	High	Low	High
2013	Lettuce	6.3	7.0	10.1	10	37
2014	Broccoli	6.0	6.8	11.5	12	48
2015	Lettuce	3.6	4.0	6.6	10	45
2015	Broccoli	8.5	10.2	16.8	17	49

\* Low = 110% to 120% of  $ET_c$ , high = 160% to 200% of  $ET_c$ .

† Calculated by the method of Cahn and Bali 2015.

and 150 lb/ac [0, 22, 67 and 168 kg/ha] of N from AN-20, applied in three equal fertigations) were compared at each of two irrigation levels (110% and 180% of  $ET_c$ ). In each irrigation treatment, three concentrations of irrigation water  $NO_3-N$  (14, 25 and 45 mg/L) without any AN-20 fertigation were also evaluated. In the fall trial, broccoli ‘Patron’ was grown. The treatments were similar to the lettuce trial, with the exception that the seasonal AN-20 fertigation levels were 0, 40, 80 and 200 lb/ac (0, 45, 90 and 224 kg/ha) of N. The irrigation levels evaluated were 120% and 200% of  $ET_c$ .

In all trials, plots were harvested when the highest fertilizer N rate treatment reached commercial maturity. Aboveground fresh and dry biomass and whole-plant N concentration were determined. From these data, crop N uptake was calculated. Uptake efficiency of irrigation water  $NO_3-N$  was calculated as the

increase in crop N uptake above the unfertilized control divided by the amount of  $NO_3-N$  in the applied water.

## Uptake efficiency of $NO_3-N$

Lettuce biomass and crop N uptake increased linearly with increasing irrigation water  $NO_3-N$  concentration in the 2013 trial (fig. 1). Across the  $NO_3-N$  enrichment levels, uptake efficiency of irrigation water  $NO_3-N$  was 85%, and it was similar between the levels of irrigation (which received 7.0 and 10.1 inches [18 and 26 centimeters] of drip irrigation in the 110% and 160%  $ET_c$  treatments, respectively). The amount of N applied in the 45 mg/L water treatment at 160% of  $ET_c$  (91 lb/ac, or 102 kg/ha) was sufficient to maximize crop productivity, producing fresh biomass equivalent to the biomass of the fertilized control receiving 150 lb/ac (168 kg/ha) of N from AN-20.



An on-site CIMIS weather station provided accurate evapotranspiration data. Each N treatment was evaluated at two levels of irrigation — 110% and 160% of  $ET_c$ .



Recycled municipal wastewater contains nitrate as well as other forms of plant-available nitrogen.



Results of the 2014 broccoli trial were similar, with crop biomass and N uptake increasing linearly with increasing irrigation water  $\text{NO}_3\text{-N}$  concentration (fig. 2). Uptake efficiency of irrigation water  $\text{NO}_3\text{-N}$  was again high (78%) across  $\text{NO}_3\text{-N}$  concentrations and irrigation levels. However, given the much higher N requirement of broccoli compared to lettuce, even the 45 mg/L  $\text{NO}_3\text{-N}$  water treatment was insufficient to maximize crop productivity.

The 2015 trials clearly demonstrated that irrigation water  $\text{NO}_3\text{-N}$  was at least as effectively used by the crop as fertilizer N. The regression lines in figures 3 and 4 indicate the crop response to fertigation with AN-20 at the two levels of irrigation; all regressions were highly significant ( $p < 0.001$ ). The fact that the irrigation water  $\text{NO}_3\text{-N}$  treatments generally placed above the fertilizer response line for their respective irrigation regimes suggested

*The 2015 trials clearly demonstrated that irrigation water  $\text{NO}_3\text{-N}$  was at least as effectively used by the crop as fertilizer N.*

that a higher N uptake efficiency was achieved with irrigation water  $\text{NO}_3\text{-N}$  than with N from fertigated AN-20. This was most pronounced in the broccoli trial (fig. 4), where the N uptake efficiency for fertilizer was substantially lower under the high irrigation level (200% of  $\text{ET}_c$ ).

Averaged across all field trials, the N uptake efficiency of irrigation water  $\text{NO}_3\text{-N}$  was remarkably high, averaging approximately 80% (fig. 5). Neither  $\text{NO}_3\text{-N}$  concentration nor irrigation level significantly influenced N uptake efficiency. It must be noted that the high N uptake

efficiency in these trials was attributable to the fact that residual soil  $\text{NO}_3\text{-N}$  in these fields had been deliberately minimized by heavy preplant leaching in order to maximize the uptake efficiency of both fertilizer N and water  $\text{NO}_3\text{-N}$ . In typical production fields, higher levels of residual soil  $\text{NO}_3\text{-N}$  are common, and N uptake efficiency of applied N, whether from irrigation water or fertilizer, would likely be lower.

## Calculating “fertilizer credits”

These field trials unequivocally demonstrated that vegetable crops can effectively use  $\text{NO}_3\text{-N}$  from irrigation water, even at relatively low concentration. The important question is how can growers safely estimate an appropriate fertilizer credit for irrigation water  $\text{NO}_3\text{-N}$ . In answering that question, it is important to distinguish between N uptake efficiency and a

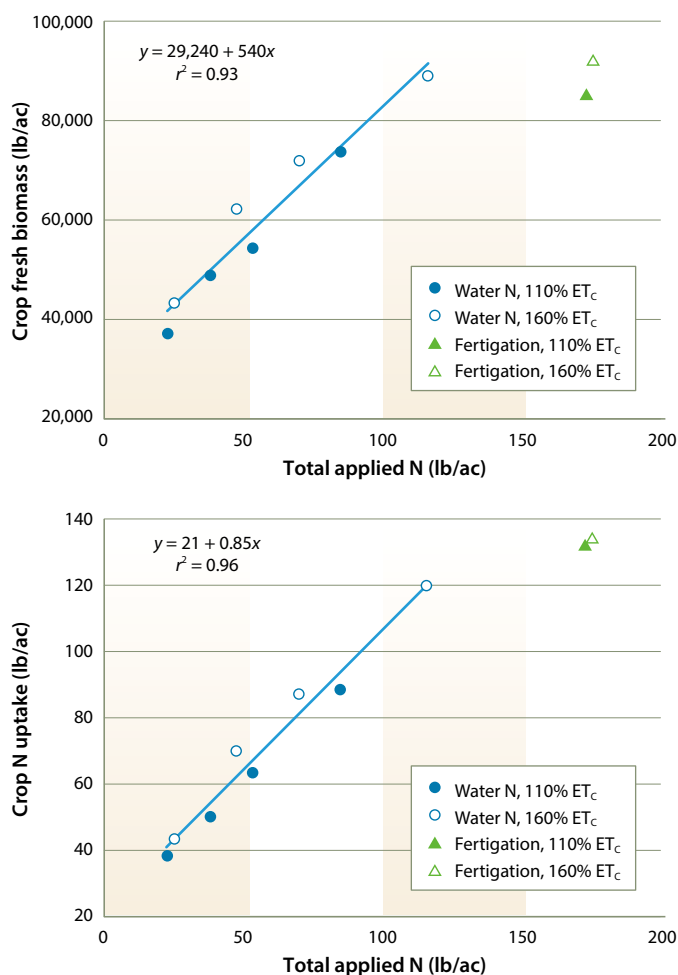


Fig. 1. Effect of irrigation water  $\text{NO}_3\text{-N}$  on lettuce biomass and aboveground N uptake, 2013 trial; water  $\text{NO}_3\text{-N}$  concentrations were 2, 12, 25 and 45 mg/L.

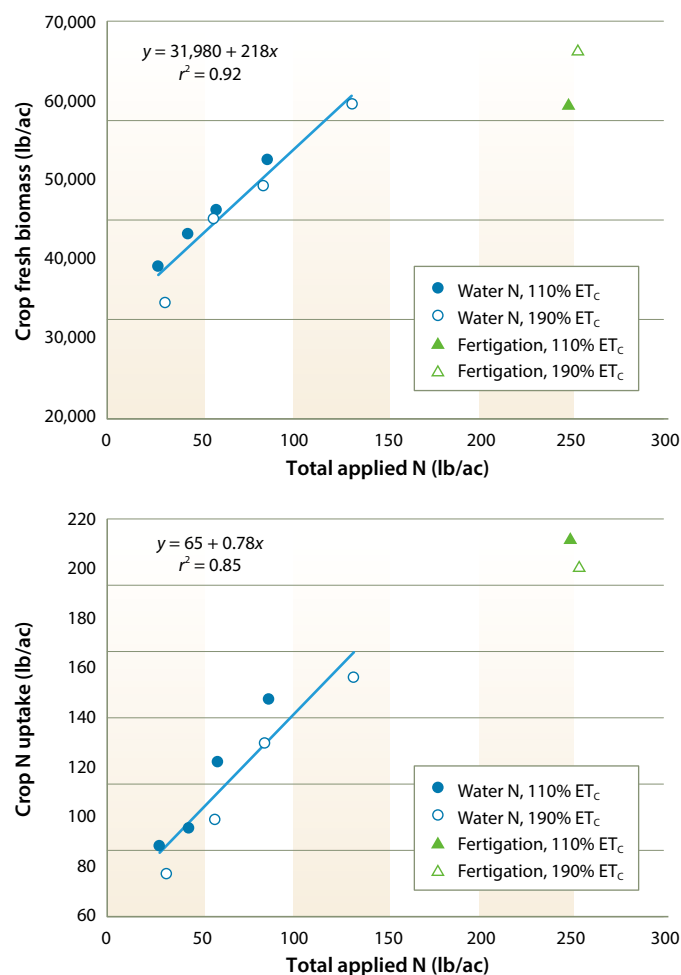


Fig. 2. Effect of irrigation water  $\text{NO}_3\text{-N}$  on broccoli biomass and aboveground N uptake, 2014 trial; water  $\text{NO}_3\text{-N}$  concentrations were 2, 12, 25 and 45 mg/L.



fertilizer credit. N uptake efficiency refers to the fraction of applied N taken up by the crop. N uptake efficiency from either fertilizer or irrigation water is affected by overall soil N availability (all sources,

including residual soil  $\text{NO}_3\text{-N}$  and soil N mineralization); as total N availability increases, N uptake efficiency from either fertilizer or irrigation water will decline. A fertilizer credit is the comparison of the

relative availability of N from irrigation water and from fertilizer N.

Several factors need to be considered in calculating a fertilizer credit. First, the stability of the irrigation water  $\text{NO}_3\text{-N}$  concentration over time is important. In general, surface water sources have reasonably low but stable  $\text{NO}_3\text{-N}$ , typically < 5 mg/L. Water districts usually have historical records that provide good estimates of  $\text{NO}_3\text{-N}$  concentration for the current season. Nitrate concentration in irrigation wells may be more variable, so periodic monitoring within a growing season may be appropriate. Growers who use several wells of differing  $\text{NO}_3\text{-N}$  concentration to irrigate a field would need to monitor the  $\text{NO}_3\text{-N}$  concentration of the blended water. This can be accomplished by collecting water in a covered bucket using a drip emitter connected to the irrigation main line; this sample can be tested using nitrate-sensitive colorimetric test strips.



Drip irrigation increases irrigation efficiency and simplifies the determination of the “fertilizer credit” for irrigation water  $\text{NO}_3\text{-N}$ .

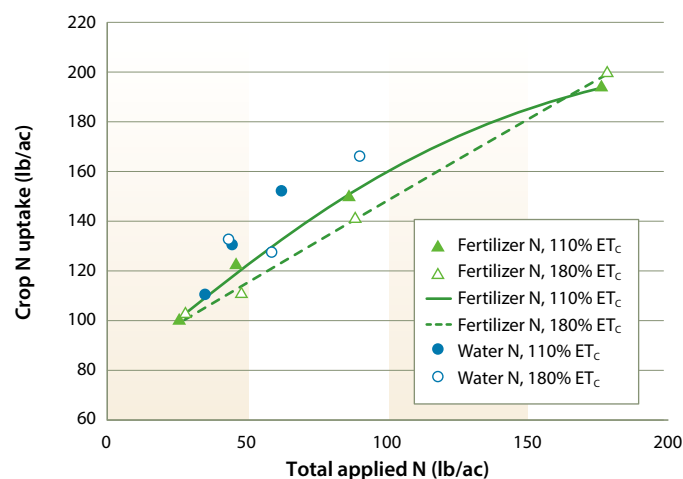
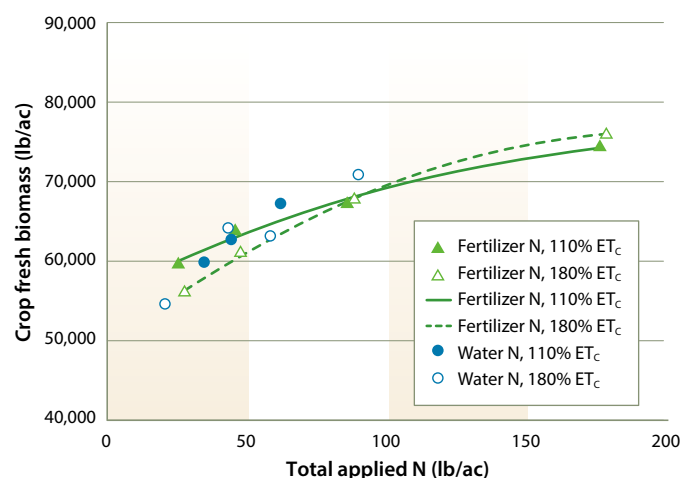


Fig. 3. Comparison of lettuce response to N fertilizer (solid and dashed lines) with crop response to irrigation water  $\text{NO}_3\text{-N}$ , 2015 trial; water  $\text{NO}_3\text{-N}$  concentrations were 14, 25 and 45 mg/L.

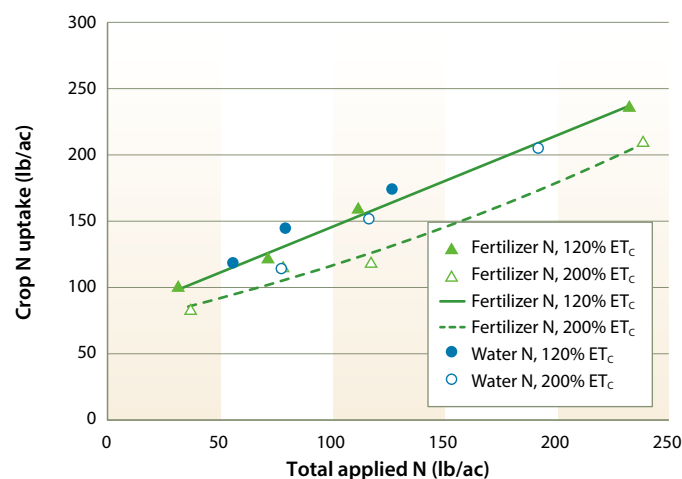
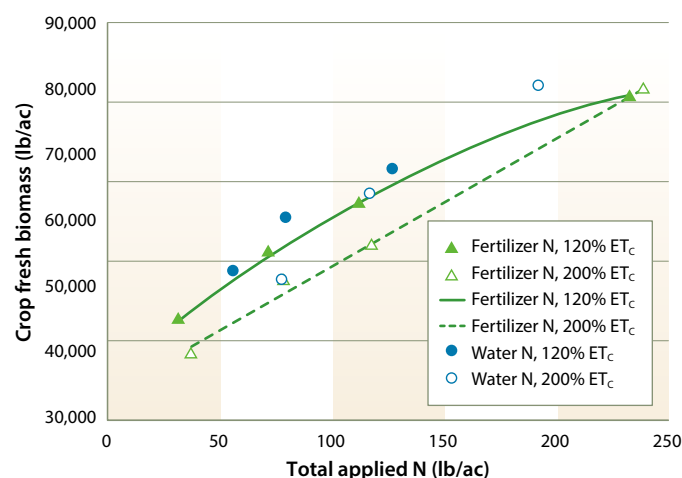
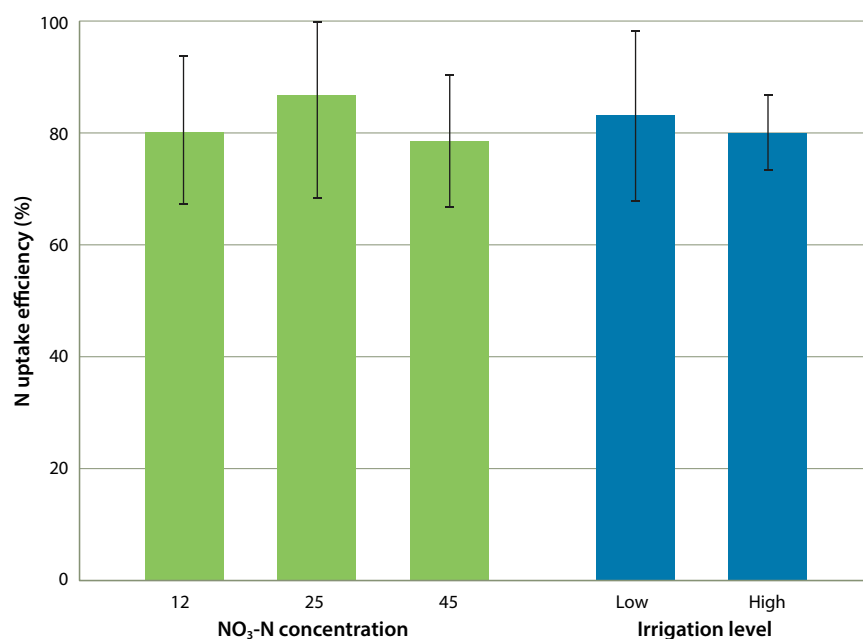


Fig. 4. Comparison of broccoli response to N fertilizer (solid and dashed lines) with crop response to irrigation water  $\text{NO}_3\text{-N}$ , 2015 trial; water  $\text{NO}_3\text{-N}$  concentrations were 14, 25 and 45 mg/L.



Second, it may be necessary to consider irrigation inefficiency when calculating a fertilizer credit, depending on the details of the irrigation management. In this study, drip irrigation was used, with frequent irrigation at relatively low volume, typically < 0.6 inches (1.5 centimeters) per application; even in the high irrigation treatment (160% to 200% of  $ET_c$ ), the volume of leachate from individual irrigations was small. Under these conditions, N uptake efficiency was similar in the high and low irrigation regimes, indicating that the crops were able to remove a substantial amount of  $NO_3$ -N even from the fraction of applied water that eventually leached. This phenomenon may relate to the residence time of applied water within the active root zone. With low volume leaching events, it may take several irrigation cycles before water moves below the root zone, giving the crop the opportunity to take up applied  $NO_3$ -N. In a fertigation trial with bell pepper, Scholberg et al. (2009) found that increasing fertilizer retention time from 1 to just 3 days quadrupled fertilizer N uptake efficiency.

Conversely, when irrigation management features large leaching events, particularly early in the season when crop N uptake is slow and before a substantial root system has developed, crop access to and use of irrigation water  $NO_3$ -N would be limited, and this should be considered in the fertilizer credit calculation. In the context of vegetable production, irrigation to germinate seeded crops or to establish transplants would be particularly vulnerable to inefficiency. It may be appropriate not to credit any of the irrigation water  $NO_3$ -N applied during crop establishment. Presidedress soil nitrate testing



**Fig. 5. Influence of irrigation water  $NO_3$ -N concentration (mg/L, across irrigation levels) and irrigation level (across water  $NO_3$ -N concentrations) on the mean N uptake efficiency of irrigation water  $NO_3$ -N across the four field trials. Bars represent the 95% confidence interval of the measurement.**

(PSNT, a valuable practice to evaluate N fertilizer requirements; Hartz 2003) would capture any N contribution from irrigation water still in the root zone following establishment. From that point forward, crediting 100% of irrigation water  $NO_3$ -N against the assumed fertilizer N requirement would be a reasonable practice if in-season irrigation were managed efficiently. Where in-season irrigation results in large leaching events, a smaller fertilizer credit could be justified. However, it should be acknowledged that large leaching events may similarly restrict crop recovery of fertilizer N.

These field trials documented that  $NO_3$ -N in irrigation water is effectively used by crops. Growers can confidently

adjust their fertilization practices to reflect the agronomic value of this N source. In doing so they will reduce the potential for N loading to groundwater. [CA](#)

*M. Cahn is UC Cooperative Extension (UCCE) Farm Advisor in Monterey County; R. Smith is UCCE Farm Advisor in Monterey County; L. Murphy is Staff Research Associate with UCCE in Monterey County; and T. Hartz is UCCE Specialist in the Department of Plant Sciences at UC Davis.*

*This project was funded by a grant from the California Department of Food and Agriculture's Fertilizer Research and Education Program (FREP) and the Fertilizer Inspection Advisory Board. We thank Sharon Benzen and David Lara of the USDA-ARS in Salinas, California, for assistance with the field trials.*

## References

- Bauder TA, Waskom RM, Sutherland PL, Davis JG. 2011. Irrigation Water Quality Criteria. Colorado State Univ. Fact Sheet 506.
- Cahn M, Bali K. 2015. Drought Tip: Managing Salts by Leaching. UC ANR Pub 8550. Oakland, CA. p 8. <http://anrcatalog.ucanr.edu/pdf/8550.pdf>.
- DeLaune P, Trostle C. 2012. Nitrates in Irrigation Water: An Asset for Crop Production. Texas A&M Publication E-619.
- Francis DD, Schepers JS. 1994. Nitrogen uptake efficiency in maize production using irrigation water high in nitrate. *Fert Res* 39:239–44.
- Harter T, Lund JR, Darby J, et al. 2012. Addressing Nitrate in California's Drinking Water with a Focus on Tulare Lake Basin and Salinas Valley Groundwater. Report for the State Water Resources Control Board to the Legislature. Center for Watershed Sciences, UC Davis, CA. 80 p. <http://groundwater.nitrates.ucdavis.edu>.
- Hartz TK. 2003. The assessment of soil and crop nutrient status in the development of efficient fertilizer recommendations. *Acta Hort* 627:231–40.
- Hopkins BG, Horneck DA, Stevens RG, et al. 2007. Managing Irrigation Water Quality for Crop Production in the Pacific Northwest. Publication PNW 597-E.
- Johnson L, Cahn M, Martin F, et al. 2016. Evapotranspiration-based irrigation scheduling of head lettuce and broccoli. *HortScience* 51(7):935–40.
- Martin DL, Watts DG, Mielke LN, et al. 1982. Evaluation of nitrogen and irrigation management for corn production using water high in nitrate. *Soil Sci Soc Am J* 46:1056–62.
- Rosenstock TS, Liptzin D, Dzurella K, et al. 2014. Agriculture's contribution to nitrate contamination of California groundwater. *J Environ Qual* 43:895–907.
- Scholberg JM, Zotarelli L, Tubbs RS, et al. 2009. Nitrogen uptake efficiency and growth of bell pepper in relation to time of exposure to fertilizer solution. *Commun Soil Sci Plan* 40:2111–31.
- Smith R, Cahn M, Hartz T, et al. 2016. Nitrogen dynamics of cole crop production: implications for fertility management and environmental protection. *HortScience* 51:1586–91.



# Yield in almond is related more to the abundance of flowers than the relative number of flowers that set fruit

by Sergio Tombesi, Bruce D. Lampinen, Samuel Metcalf and Theodore M. DeJong

*Almond tree yield is a function of the number of flowers on a tree and the percentage of flowers that set fruit. Almonds are borne on spurs (short proleptic shoots that can have both leaves and flowers). Almond tree spur dynamics research has documented that previous year spur leaf area is a predictive parameter for year-to-year spur survival, spur flowering and to a lesser extent spur fruiting, while previous year fruit bearing has a negative impact on subsequent year flowering. However, a question remained about whether yields are more dependent on flower numbers or relative fruit set of the flowers that are present. The aim of the present work was to compare the importance of flower abundance with that of relative fruit set in determining the productivity of a population of tagged spurs in almond trees over a 6-year period. Overall tree yield among years was more sensitive to total number of flowers on a tree rather than relative fruit set. These results emphasize the importance of maintaining large populations of healthy flowering spurs for sustained high production in almond orchards.*

**A**lmond is the most important tree nut crop in California in terms of acreage and production value (USDA NASS 2015). Grower attention has been focused on increasing orchard yields for decades (Kester and Griggs 1959) and research efforts have been aimed at improving almond orchard

productivity through the optimization of all variables involved in nut production. Fundamentally, almond tree yields are the product of the number of kernels produced per tree and kernel weights. Of these two factors, the number of kernels is the most important (Reidel et al. 2001) since kernel weight is generally not a

factor of paramount importance for growers (Spiegel-Roy and Weinbaum 1985).

The reproductive process in almond trees involves two years from flower bud induction to fruit set and fruit maturity. In this process the number of flowers borne and the number of flowers that set fruit determines the final kernel yield per tree. Fruit set in almond is strongly influenced by presence of pollinizer cultivars, insect pollinators and by climatic conditions affecting pollen viability, germination and pollinator activity (Corbet 1990; Dulberger et al. 1994; Eisikowitch et al. 1991; Gradziel and Weinbaum 1999; Hedhly et al. 2007; Kozłowski and Pallardy 2002; Ortega et al. 2007; Thorp 1996; Tombesi et al. 2010; Vasilakakis and Porlingis 1985; Weinbaum et al. 1984) in addition to general tree health.

In 1959, Kester and Griggs stated that “the question often arises as to whether or not the fruit set for specific almond orchards could be increased by using more bees and pollinizers to effect more complete cross pollination”. Mean relative

Online: <https://doi.org/10.3733/ca.2016a0024>

Published online November 16, 2016

Results from spur dynamic studies indicate that maximizing healthy populations of productive spurs is key to optimizing yields.



fruit set (i.e., percentage of flowers that set a fruit) in almond has been reported to be about 30% but there is large year-to-year variability that can make it range as low as 5% (Socias i Company 1994) and as high as 40% (Kester and Griggs 1959). These relatively low fruit set percentages offer a potential margin for almond crop improvement. Accordingly, almond orchards are planned and managed to improve relative fruit set by planting pollinizer rows on either side of the main cultivar rows to increase availability of compatible pollen (Dag et al. 2000). The use of bees in almond orchards during flowering increases the likelihood of movement of pollen among trees (Artz et al. 2013; Brittain et al. 2013). Enhancing tree nutrition has also been reported to increase fruit set rates (Nyomora et al. 1997, 1999). In spite of these efforts, relative fruit set is still variable and little improved since the early data reported in 1959 by Kester and Griggs.

## Almond spur dynamics

But, is fruit set the main limiting process for almond productivity? Another approach could be to increase the number of flowers per acre — but that approach demands more information on the eco-physiological basis that regulates flowering of almond spurs (short lateral shoots that are the main flowering and fruit bearing units in mature almond trees — see illustration). Individual spurs tend to alternate bear with only a small percentage of spurs flowering the year after bearing (Lampinen et al. 2011). The authors have observed tagged spurs in outer canopy-exposed positions to live at least 15 years.

To investigate this, an almond spur dynamics research project was initiated by Lampinen and colleagues in 2001. This study was designed to quantify the dynamics of spur renewal, fruitfulness and longevity and to determine how these dynamics are impacted by orchard management practices. Results from the study indicated that the number of flowers borne by individual spurs is a function of spur leaf area in the previous year and whether or not the spur bore a fruit in the previous year. Spurs that bore fruit in a given year rarely flowered or bore fruit in a subsequent year (Lampinen et al. 2011). Furthermore, spur mortality was much higher in spurs that had low



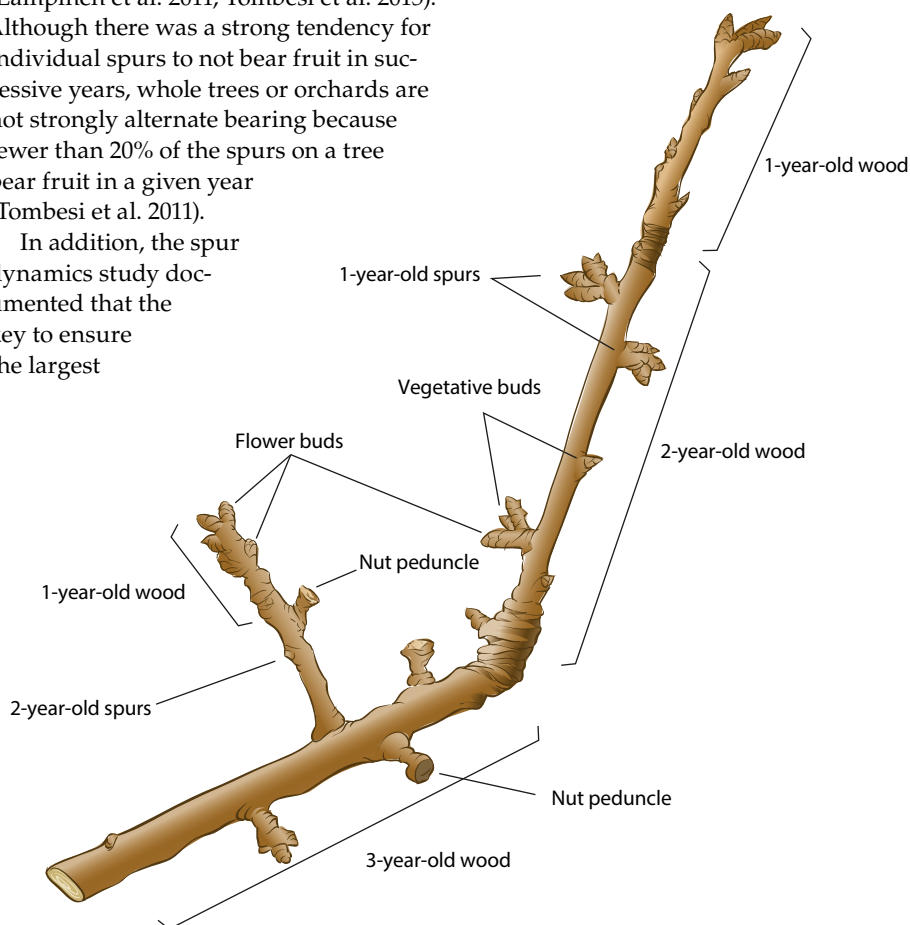
**An almond spur with a flower in full bloom. The number of flowers that set fruit determines the final kernel yield per tree.**

previous year spur leaf area (PYSLA) because fruit bearing competes with leaf growth and decreases the amount of source organ available on bearing spurs (Lampinen et al. 2011; Tombesi et al. 2015). Although there was a strong tendency for individual spurs to not bear fruit in successive years, whole trees or orchards are not strongly alternate bearing because fewer than 20% of the spurs on a tree bear fruit in a given year (Tombesi et al. 2011).

In addition, the spur dynamics study documented that the key to ensure the largest

flowering over an orchard's life is to have the largest number of spurs possible with the optimal leaf area for flowering. Proper irrigation during the previous year vegetative season and even after harvest can help to minimize spur death and has been reported to have a critical impact on subsequent bloom and fruit set (Esparza et al. 2001; Goldhamer and Smith 1995).

The almond spur dynamics study also provided information regarding the importance of PYSLA in determining subsequent spur flowering, fruit bearing and survival (Lampinen et al. 2011) as well as the fact that spur fruit bearing in turn, reduces spur leaf in the same year (Tombesi et al. 2015). Thus, spur flowering and fruiting in two sequential years is relatively rare (Tombesi et al. 2011). However, the total number of flowering spurs on a tree may be of limited significance if greater relative fruit set of the flowers can compensate for decreased flower numbers in the orchard. Thus, understanding



**Almond bearing habit. One- and 2-year-old spurs borne on 2- and 3-year-old wood, respectively.**



the relative impact of flower number and relative fruit set on almond tree yield in commercial orchards is essential for guiding efforts to improve orchard productivity and help growers determine the most profitable practices for almond crop management.

**A vegetative almond spur, top, and fruitful spur, bottom, marked with aluminum tags. Spurs are short lateral shoots that are the main flowering and fruit bearing units in almond trees.**



Bruce Lampinen



Bruce Lampinen

## Study of flowering and fruit set

To address this question we analyzed flowering and fruit set data recorded during the almond spur dynamics project. The study was conducted in a 145-acre orchard, planted in 1996, at 24 feet between and 21 feet within rows. The orchard planting consisted of rows of 'Nonpareil' (50%) alternating with pollinizer rows of 'Monterey' (25%), and 'Wood Colony' (25%). The orchard was located in Kern County on a sandy-loamy soil. Irrigation was carried out by microsprinklers and irrigation schedule was based on weekly measurement of midday stem water potential that was maintained between  $-0.7$  and  $-1.2$  MPa. Nitrogen was applied at 110 to 220 pounds per acre and leaf N content was between 1.95% and 2.45% over the period of the experiment. Bee hives were placed at a density of two to three hives per acre prior to bloom. During the experiment, weather conditions during the pollination period were not limiting for bee activity.

The orchard was divided into six equal-sized replicate blocks and 50 spurs were tagged in eight 'Nonpareil' trees within each of the six blocks. A total of 2,400 spurs were marked with aluminum tags in late March and early April 2001. Twelve spurs were selected on each of the northeast and northwest quadrants of individual trees and 13 spurs were selected on each of the southeast and southwest quadrants of the same trees. Tagged spurs were located at positions ranging from shaded (near the trunk) to exposed (on

the periphery) portions of the canopy at a height of 3 to 12 feet. During the first 4 years of the study, lost tags or dead spurs were replaced with spurs in close proximity with similar light exposure to the original tagged spurs.

The dynamics of annual growth, flowering, fruitfulness and spur mortality were quantified annually. For more detail see Lampinen et al. (2011). The number of flowers produced on each tagged spur was counted in the spring of each year from 2002 through 2007. Multiple year records of PYSLA (from an adjacent, similar spur as described earlier), previous year bearing, number of flowers in the current year and number of fruit in the current year were used to assess spur behavior in relation to PYSLA in spurs that bore no fruits in the previous year. These analyses involved data from 6,980 spurs spread over the 6 years.

Kernel yield of the individual trees with tagged spurs and the kernel yield of the orchard containing those trees were also recorded for 6 years (2002–2007).

Statistical analyses were carried out using ANOVA (Sigmaplot 8.0, SPSS Inc., Chicago, Illinois) to test the significance at  $P < 0.01$  of relationships between PYSLA and current year spur flower density (flowers per spur), current year spur fruit density (fruit per spur) and current year spur relative fruit set. The same test was also used to test the significance of the relationship between tree yield (expressed as kilograms of kernels per tree) and tree spur population relative fruit set (expressed as the relative fruit set recorded on the 50 spurs tagged on each





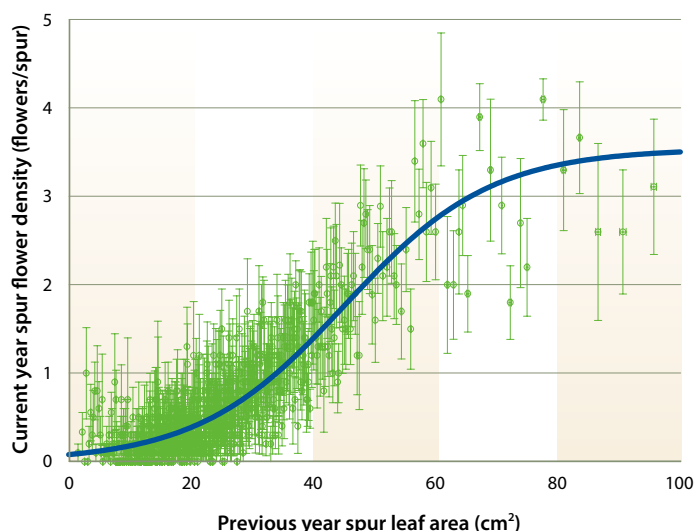


Fig. 1. Relationship between current year spur flower density and previous year spur leaf area on tagged spurs from 2002 to 2007 ( $R^2 = 0.76$ ,  $P < 0.0001$ ). Each point is the mean of 10 spurs  $\pm$  SE.

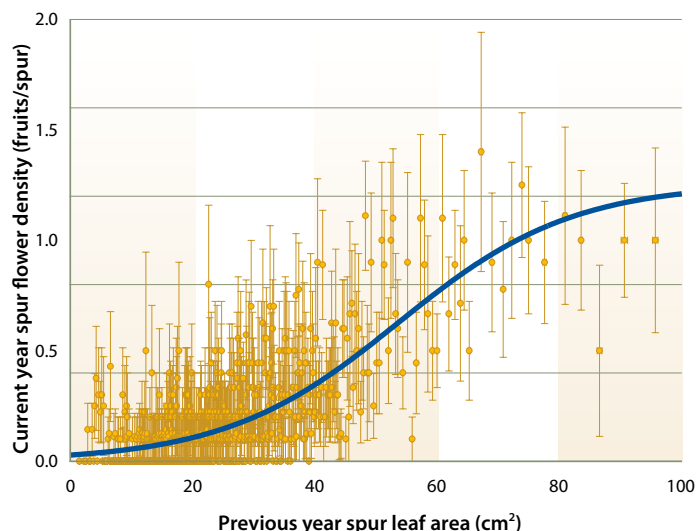


Fig. 2. Relationship between current year spur fruit density and previous year spur leaf area on tagged spurs from 2002 to 2007 ( $R^2 = 0.59$ ,  $P < 0.0001$ ). Each point is the mean of 10 spurs  $\pm$  SE.  $1 \text{ cm}^2 = 0.001 \text{ ft}^2$ .

tree) and spur flower density (expressed as the mean number of flowers per spur recorded on the 50 spurs tagged on each tree).

## Effects on yield

The number of flowers differentiated (formed) during the previous year is the first component of yield in fruit trees (Werner et al. 1988). In almond spurs, flower formation was closely related to spur leaf area in the previous year (PYSLA) (fig. 1). Thus, if the leaf area of each spur on a tree were known, the number of flowers that a tree would

bear in the following year could be estimated, and, if spur relative fruit set were constant, spur fruit bearing and yield of that tree could be predicted. However, although the relationship between spur fruit density and PYSLA was significant, it was weaker than the relationship between spur flowering and PYSLA (fig. 2). This was because fruit set was highly variable in almond across years. Relative fruit set varied from 19% to 36% (table 1).

These data apparently support the large effect of season, and particularly weather conditions, on the fruit set process. In almond, rainfall during the bloom period has been reported to affect

pollinator activity (Eisikowitch et al. 1991; Vicens and Bosch 2000) and to wash pollen off stigmas (Dulberger et al. 1994; Ortega et al. 2007). Anther dehiscence (shedding of pollen by the anther) also can be affected by rain (Corbet 1990) and high relative humidity (Gradziel and Weinbaum 1999; Kozłowski and Pallardy 2002). Temperature affects pollen germination, pollen tube growth (Vasilakakis and Porlingis 1985; Weinbaum et al. 1984), ovule degeneration (Hedhly et al. 2007; Postweiler et al. 1985) and pollinator activity in the field (Corbet et al. 1993; Thorp 1996; Vicens and Bosch 2000). Wind can also affect pollinator activity

TABLE 1. Number of flowers, fruits and relative fruit set rate of the spur population evaluated from 2002 to 2007

Year	Flowers	Fruits	Relative fruit set
2002	1,246	368	29.5%
2003	1,225	288	23.5%
2004	1,490	536	36.0%
2005	1,907	351	18.4%
2006	1,882	364	19.3%
2007	1,330	409	30.8%

Almond nuts and hulls at harvest time.



(Thorp 1996; Vicens and Bosch 2000). On the basis of this information, some have hypothesized that yield fluctuations can be explained mainly by variations in climatic factors (Dorfman et al. 1988). Actually, large relative fruit set variability also occurred among individual trees (fig. 3). This fluctuation could be a result of “on-trees” and “off-trees” (i.e., bearing more or less nuts than their average production) occurring in the same orchard and season (Tombesi et al. 2011). On the other hand, fluctuations of relative fruit set of spur populations in different trees exposed to the same climatic conditions suggest that climatic conditions are not the major factor influencing tree spur population fruit set.

In this experiment, at the spur level, there was no correlation between the PYSLA and relative fruit set in the current year (fig. 4). Thus, whereas previous year conditions are fundamental for flower formation on spurs (Lampinen et al. 2011), previous year leaf area did not appear to influence current year spur relative fruit set. Furthermore, spur fruiting was associated with reduced spur leaf area in the current season, suggesting that current year spur leaf area does not exert any influence on spur relative fruit set (Tombesi et al. 2015). In this experiment, the number of nuts borne by individual trees was significantly correlated with the number of nuts borne by the tagged spur populations in those trees (fig. 5). This suggests that our spur sample was relatively representative of the spur population of the trees. On a whole tree basis, tree yield was not correlated with mean relative fruit set measured on tree spur populations. Instead, tree yields appeared to be more closely correlated with flower density on the tagged spur population. Thus, while relative fruit set is obviously important, it was not the primary yield-limiting factor in this orchard situation, and increased relative fruit set when floral densities were low did not compensate for lower numbers of flowers (fig. 6).

There were significant correlations between spur flower density and tree yield over years (fig. 7); for individual years, the relationship was significant in 4 of the 6 years of our experiment (table 2). On the other hand, the relationship between tree relative fruit set and tree yield was not significant in any of the 6 years of the experiment. However, it should be noted

that the coefficients of determination ( $R^2$ ) were low due to the large number of points and the limited size of the spur sample compared with the total number of spurs borne by each tree; only 5.3% of the variability in tree yield can be explained by spur flower density.

These results support the validity of flower density as an important parameter in the evaluation of almond cultivars

(Kodad and Socias i Company 2008; Socias i Company et al. 1998). These data support the importance of total flower production for obtaining large crops.

## Maximizing productive spurs

As a result of these spur dynamics studies, it is clear that the key to optimizing yields in commercial almond orchards is to

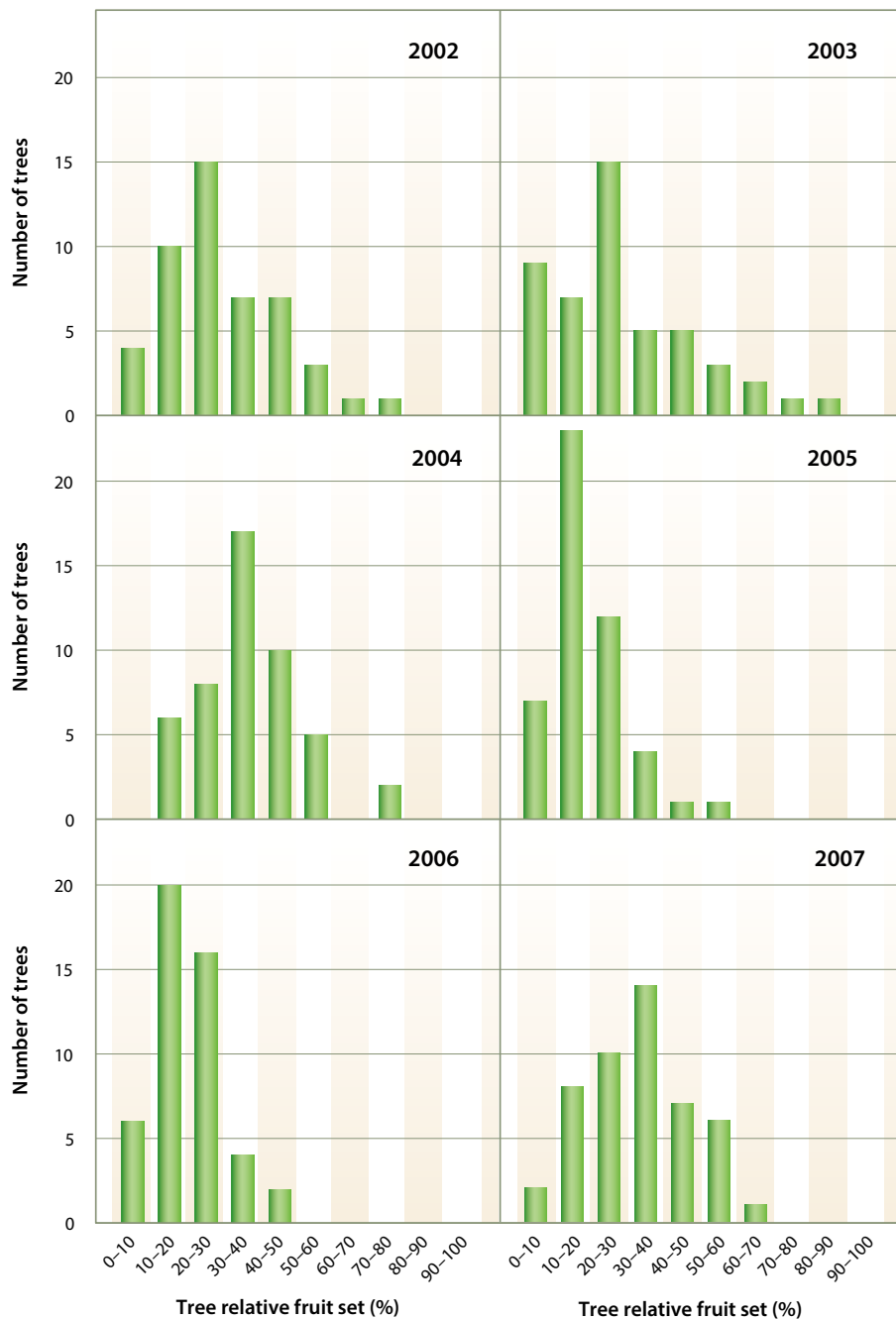


Fig. 3. Distributions of number of trees with different tree relative fruit sets from 2002 to 2007. Relative fruit set was recorded on 50 spurs per tree and was obtained as the number of fruit borne on all 50 spurs divided by the number of flowers borne on all the 50 spurs times 100.



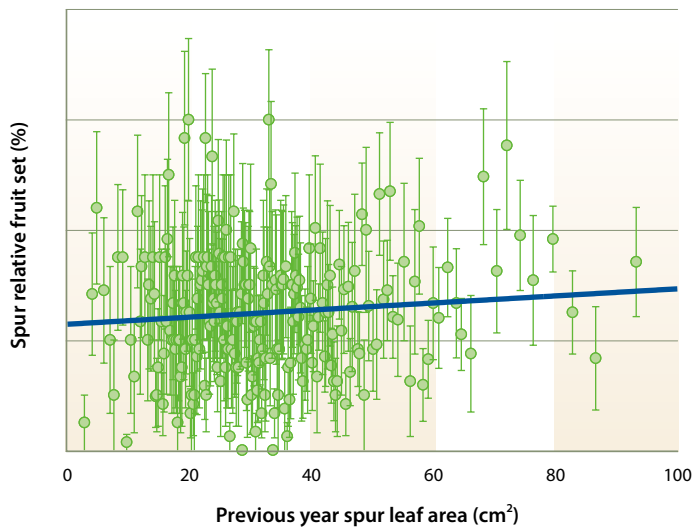


Fig. 4. Relationship between spur relative fruit set and previous year spur leaf area on tagged spurs from 2002 to 2007 ( $R^2 = 0.007$ ,  $P = 0.16$ ). Each point is the mean of 10 spurs  $\pm$  SE.  $1 \text{ cm}^2 = 0.001 \text{ ft}^2$ .

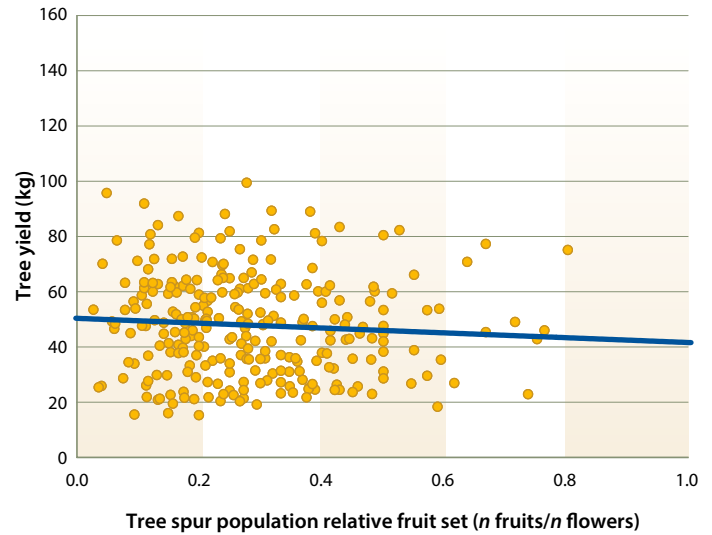


Fig. 6. Relationship between tree kernel yield and tree relative fruit set of the tagged spur population from 2002 to 2007 ( $R^2 = 0.005$ ,  $P = 0.23$ ).  $1 \text{ kg} = 2.2 \text{ lb}$ .

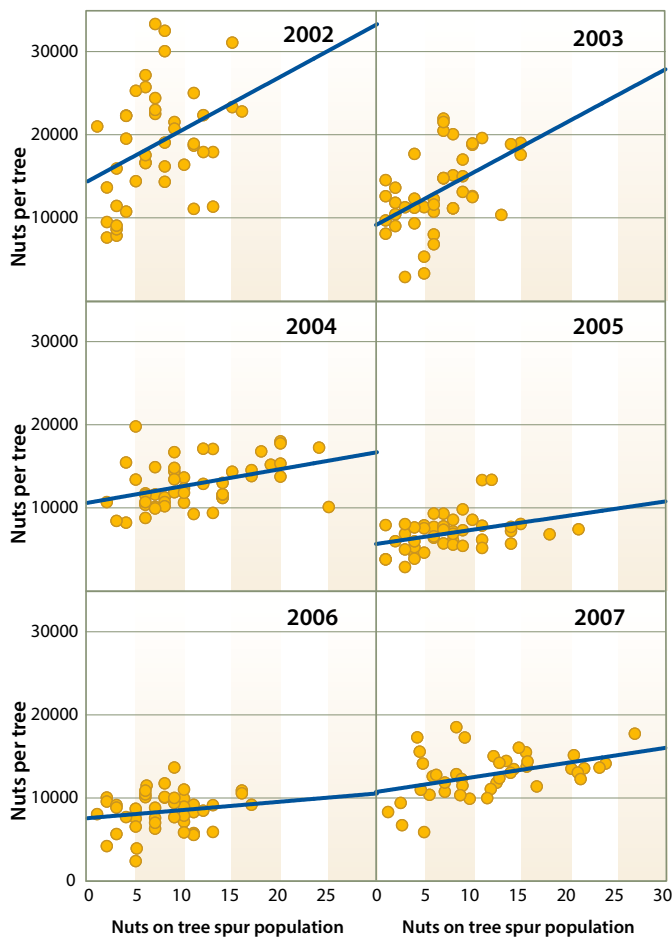


Fig. 5. Relationship between number of fruits per tree and number of nuts on a tree's tagged spur population in 2002 ( $R^2 = 0.14$ ,  $P < 0.05$ ), 2003 ( $R^2 = 0.25$ ,  $P < 0.01$ ), 2004 ( $R^2 = 0.16$ ,  $P < 0.01$ ), 2005 ( $R^2 = 0.13$ ,  $P < 0.05$ ), 2006 ( $R^2 = 0.028$ ,  $P = 0.26$ ) and 2007 ( $R^2 = 0.18$ ,  $P < 0.01$ ). Tree spur populations were composed of 50 spurs per tree.

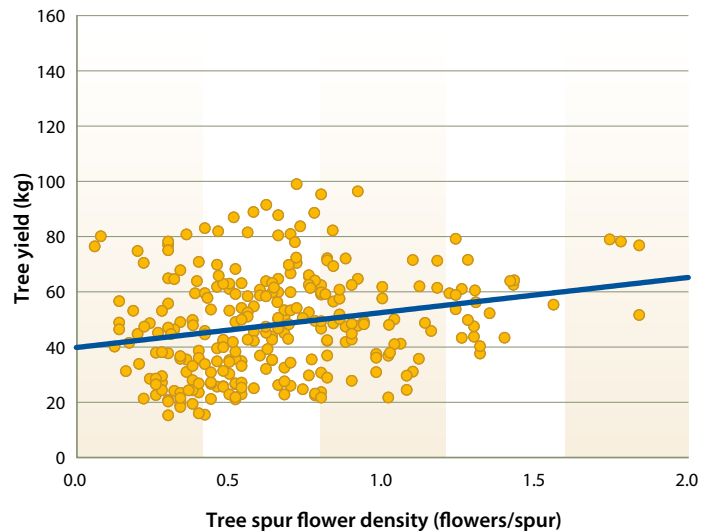


Fig. 7. Relationship between tree kernel yield and tree tagged spur flower density from 2002 to 2007. ( $R^2 = 0.053$ ,  $P < 0.0001$ ).  $1 \text{ kg} = 2.2 \text{ lb}$ .

TABLE 2. Coefficients of determination for relationships between tree yield, tree flower density and tree relative fruit set

Year	Flower density (flowers/spur)	Relative fruit set (%)	n
2002	0.164*	0.004	48
2003	0.101†	0.001	48
2004	0.02	0.001	48
2005	0.138*	0	48
2006	0.047	0.025	48
2007	0.164*	0.066	48
All years	0.053*	0.0052	288

\* Significant per  $P < 0.01$ .

† Significant per  $P < 0.05$  (t-test).

## Continued productivity is dependent on spur renewal that is achieved by ensuring that there is annual growth of as many existing spurs as possible and new shoots that provide sites for new spurs.

focus on maximizing healthy populations of productive spurs.

Some spur mortality is unavoidable and linked to insufficient spur leaf area associated with spur bearing and spur shading (Lampinen et al. 2011; Tombesi et al 2011; Tombesi et al. 2015). Thus, continued productivity is dependent on spur renewal that is achieved by ensuring that there is annual growth of as many existing spurs as possible and new shoots that provide sites for new spurs (Esparza et al. 2001). Health of spurs is also a function of total canopy light interception and good light distribution with the tree canopy (Lampinen et al. 2011). It is clearly important to select cultivars with the ability to produce large numbers of flowers

(Kodad and Socias i Company 2008) and have crop management practices (especially proper irrigation and fertilization) aimed at limiting abiotic stresses during the vegetative season (Esparza et al. 2001; Goldhamer and Smith 1995; Goldhamer and Viveros 2000).

In an experiment not potentially biased by experimental manipulation (i.e., deblossoming and hand pollination), these results support the assertion of Kester and Griggs (1959) that reductions in total number of flowers due to adverse orchard conditions are not likely to be compensated for by increased relative fruit set when adequate pollinizers and pollinators are present and can result in some measure of crop reduction. Such

was the case in this study since it was conducted in an orchard in which the 'Nonpareil' trees were flanked by two pollinizer cultivars selected for bloom overlap with 'Nonpareil' and relatively high populations of bee pollinators were placed in the orchard each year to facilitate pollination. Had such factors not been present in the orchard during bloom, it is likely that relative fruit set would have varied even more among years and measured tree yields would have been more dependent on variations in relative fruit set. [CA](#)

*S. Tombesi is Assistant Professor in the Department of Sustainable Crop Production at Catholic University of the Sacred Heart, Piacenza, Italy; B.D. Lampinen is UC Cooperative Extension Specialist in the Department of Plant Sciences at UC Davis; S. Metcalf is Staff Research Associate in the Department of Plant Sciences at UC Davis; T.M. DeJong is Professor in the Department of Plant Sciences at UC Davis.*

## References

- Artz DR, Allan MJ, Wardell GI, Pitts-Singer TL. 2013. Nesting site density and distribution affects *Osmia lignaria* (Hymenoptera: Megachilidae) reproductive success and almond yield in a commercial orchard. *Insect Cons Div* 6:715–24. doi: 10.1111/icad.12026.
- Brittain C, Williams N, Kremen C, Klein AM. 2013. Synergistic effects of non-Apis bees and honey bees for pollination services. *Proc Royal Soc B* 280:20122767.
- Corbet SA. 1990. Pollination and the weather. *Isr J Bot* 39:13–30.
- Corbet SA, Fussell M, Ake R, et al. 1993. Temperature and the pollinating activity of social bees. *Ecol Entomol* 18:17–30.
- Dag A, Weinbaum SA, Thorp RW, Eisikowitch D. 2000. Pollen dispensers (inserts) increase fruit set and yield in almonds under some commercial conditions. *J Apicult Res* 39:117–23.
- Dorfman J, Dorfman M, Heien D. 1988. Causes of almond yield variations. *Calif Agr* 42:27–8.
- Dulberger R, Smith MB, Bawa KS. 1994. The stigmatic orifice in cassia, senna and chamaecrista (caesalpinaceae)-morphological variation, function during pollination, and possible adaptive significance. *Am J Bot* 81:1390–6.
- Eisikowitch D, Gat Z, Karni O, et al. 1991. Almond blooming under adverse conditions. A compromise between various forces. *Proceedings Plant-Animal Interaction in Mediterranean-Type Ecosystems*. Crete, Greece, Medecos VI:234–40.
- Esparza G, DeJong TM, Weinbaum SA, Klein I. 2001. Effects of irrigation deprivation during the harvest period on yield determinants in mature almond trees. *Tree Physiol* 21:1073–9.
- Goldhamer DA, Smith T. 1995. Single season drought irrigation strategies influence almond production. *Calif Agr* 49:19–22.
- Goldhamer DA, Viveros M. 2000. Effects of preharvest irrigation cut-off duration and post-harvest water deprivation on almond tree performance. *Irrig Sci* 19:125–31.
- Gradziel TM, Weinbaum SA. 1999. High relative humidity reduces dehiscence in apricot, peach, and almond. *HortSci* 34:322–5.
- Hedhly A, Hormaza JL, Herrero M. 2007. Warm temperatures at bloom reduce fruit set in sweet cherry. *J App Bot Food Qual* 81:158–64.
- Kester DE, Griggs WH. 1959. Fruit setting in the Almond: the effect of Cross-pollinating various percentages of flower. *Proc Am Soc Hort Sci* 74: 206–13.
- Kodad O, Socias i Company R. 2008. Significance of flower bud density for cultivar evaluation in almond. *HortSci* 43:1753–8.
- Kozłowski TT, Pallardy SG. 2002. Acclimation and adaptive responses of woody plants to environmental stresses. *Bot Rev* 68:270–334.
- Lampinen BD, Tombesi S, Metcalf S, DeJong TM. 2011. Spur behaviour in almond trees: relationships between previous year spur leaf area, fruit bearing and mortality. *Tree Physiol* 31:700–6.
- Nyomora AMS, Brown PH, Krueger W. 1999. Rate and time of boron application increase almond productivity and tissue boron concentration. *HortSci* 34:242–5.
- Nyomora AMS, Brown PH, Freeman M. 1997. Fall foliar applied boron increases tissue boron concentration and nut set of almond. *J Amer Soc Hort Sci* 122:405–10.
- Ortega E, Dicenta F, Egea J. 2007. Rain effect on pollen-stigma adhesion and fertilization in almond. *Sci Hortic* 112:345–8.
- Postweiler K, Stösser R, Anvari SF. 1985. The effect of different temperatures on the viability of ovules in cherries. *Sci Hortic* 25:235–9.
- Reidel EJ, Brown PH, Duncan RA, Weinbaum SA. 2001. Almond productivity as related to tissue potassium. *Better Crops* 85:21–3.
- Socias i Company R, Alonso JM, Gómez Aparisi J. 2008. Fruit set and productivity in almond as related to self-compatibility, flower morphology and bud density. *J Hortic Sci Biotech* 79:754–8.
- Socias i Company R, Espada JL, Felipe AJ. 1994. The effect of orchard design on almond fruit set. *HortTech* 4: 377–9.
- Socias i Company R, Felipe AJ, Gomez Aparisi J, et al. 1998. The ideotype concept in almond. *Acta Hortic* 470:51–6.
- Spiegel-Roy P, Weinbaum SA. 1985. Increasing productivity in sweet almond using selected clones of bitter almond. *Euphytica* 34:213–7.
- Thorp RW. 1996. Bee management for pollination. In: W.C. Micke (ed.). *Almond Production Manual*. University of California, Oakland. p 132–8.
- Tombesi S, Lampinen BD, Metcalf S, DeJong TM. 2015. Spur fruit set is negatively related with current year spur leaf area in almond. *HortSci* 50:322–5.
- Tombesi S, Lampinen BD, Metcalf S, DeJong TM. 2011. Relationship between spur- and orchard-level fruit bearing in almond (*Prunus dulcis*). *Tree Physiol* 31:1413–21.
- Tombesi S, Scalia R, Connell J, et al. 2010. Fruit development in almond is influenced by early spring temperatures in California. *J Hortic Sci Biotech* 85:317–22.
- [USDA NASS] US Department of Agriculture and National Agricultural Statistics Service. 2015. *Noncitrus Fruits and Nuts*. California agricultural statistics. Crop year 2014. Preliminary survey. 79 p.
- Vasilakakis M, Porlingis IC. 1985. Effect of temperature on pollen germination, pollen-tube growth, effective pollination period, and fruit-set of pear. *HortSci* 20:733–5.
- Vicens N, Bosch J. 2000. Weather-dependent pollinator activity in apple orchard, with special reference to *Osmia cornuta* and *Apis mellifera* (Hymenoptera: Megachilidae and Apidae). *Environ Entomol* 29:413–20.
- Weinbaum SA, Parfitt DE, Polito VS. 1984. Differential cold sensitivity of pollen germination in two *Prunus* species. *Euphytica* 33:419–26.
- Werner DJ, Mowrey BD, Chaparro JX. 1988. Variability in flower bud number among peach and nectarine clones. *HortSci* 23:578–80.



# Lessons learned: How summer camps reduce risk factors of childhood obesity

by Gretchen L. George, Lucia L. Kaiser and Constance Schneider

*The purpose of this article is to present findings related to parent- and youth-reported outcomes from a nutrition- and fitness-themed summer camp targeting low-income families and to identify lessons learned in the implementation, evaluation and sustainability of a summer program. The Healthy Lifestyle Fitness Camp, offered through UC Cooperative Extension (UCCE), was a summer camp program for low-income youth at high risk for obesity. From 2009 to 2012, UCCE nutrition staff in Fresno County collaborated with the camp staff to provide a 6-week nutrition education program to the campers and their parents. Anthropometry and dietary data were collected from youth. Data about food preferences and availability were collected from youth and parents. As reported by parents in pre- to immediately post-camp surveys, Healthy Lifestyle Fitness campers consumed fruits and vegetables promoted at camp more often, relative to a comparison group of youth in a nearby non-nutrition themed camp. Summer programs may be an effective tool in the reduction of childhood obesity risk factors if implemented appropriately into the community and through the utilization of supportive partnerships such as UCCE and local parks and recreation departments.*

School-based programs have been successful in improving nutrition knowledge, food preferences, dietary intake and body weight outcomes

in youth (Healthy Study Group et al. 2010; Scherr et al. 2013). However, youth can relapse to inactive, less healthy lifestyles over summer vacations when the days

have less structure and access to school and summer food program meal service is limited (Hopkins and Gunther 2015; Tovar et al. 2010). Especially among overweight or obese African-American and Latino youth, body mass index (BMI) gains are greater over summer vacations compared to the school year (Downey and Boughton 2007; von Hippel et al. 2007).

Among youth 2 to 19 years of age, prevalence of overweight and obesity is highest among boys and girls who are Hispanic (38.9%) and non-Hispanic African-American (35.2%) and lowest in non-Hispanic white (28.5%) and Asian (19.5%) youth (Ogden et al. 2014). Obese youth are more likely than non-obese youth to be exposed to bullying and to suffer from psychosocial problems (Maggio et al. 2014); they also have increased rates of school absenteeism (Pan et al. 2013). Four European longitudinal studies found that childhood obesity persisting into adulthood increases risk of type 2 diabetes, hypertension, elevated blood lipids and atherosclerosis (Juonala

Online: <https://doi.org/10.3733/ca.2016a0025>

Published online December 15, 2016

Participation in a summer camp that focused on nutrition education and fitness resulted in weight loss and a decreased waist-to-height ratio.





et al. 2011). However, obese youth who achieve a healthier weight in late childhood into adulthood have the same level of risk as individuals who have never been obese.

Furthermore, programs to address prevention and the multiple needs of low-income youth are urgently needed, especially during the summer. Attention has focused on evidence that socioeconomically disadvantaged youth “fall behind” academically over the summer, compared to their more affluent peers (Alexander et al. 2007). In considering options to reduce academic disparities, it is critical to find solutions that promote positive youth development, including health and physical development, as well as social skills. Summer enrichment programs, tailored to meet the needs of high-risk youth, can be a strategy to reduce disparities.

From 2009 to 2012, UC Cooperative Extension nutrition staff in Fresno collaborated with their community partners to provide a 6-week nutrition education and healthy lifestyle program for youth from low-income families (those eligible for the Supplemental Nutrition Assistance Program) in a summer fitness camp

setting. In this community, a disproportionate share of the low-income population is African-American or Latino, two groups that also have some of the highest rates of childhood obesity.

The purpose of this article is to present and interpret findings related to parent- and youth-reported outcomes from this nutrition- and fitness-themed summer camp and to identify lessons learned in the implementation, evaluation and sustainability of a summer program.

## How the fitness camp evolved

In 2008, Fresno’s parks and recreation department piloted a fitness summer camp for the first time. Based on positive feedback from families, city staff reached out to UCCE in 2009 for assistance in adding a robust nutrition education component to the summer camp for youth at high risk for obesity and their families. Together, they developed the Healthy Lifestyle Fitness Camp (HLFC), a 6-week summer day camp focusing on nutrition education and fitness. This was a no-cost program for families who resided in low socioeconomic areas of Fresno, were eligible for

CalFresh (CDSS 2016) and had overweight or obese youth ages 9 to 14 years old. As determined by a doctor on physical examination, all youth accepted into the study were either overweight or obese based on BMI z-scores or had a family history of obesity or diabetes.

By 2009, the goal of the camp program was to promote a healthy lifestyle according to the Dietary Guidelines for Americans (USDA and DHHS 2005, 2010) using UCCE nutrition programs, city staff and external exercise programs (e.g., Zumba). Nutrition educators from the UC CalFresh program provided two nutrition classes a week to the campers and one nutrition class weekly to their parents for the duration of the camp. For the campers, UCCE staff selected the *EatFit* curriculum, which has demonstrated effectiveness in improving dietary and physical activity behaviors among middle school youth in California (Horowitz et al. 2004). The nutrition classes, offered twice a week for 3 hours each time, targeted messages about eating more fruits and vegetables, decreasing sugar-sweetened beverages, eating healthier types of fats (i.e., plant-based fats) and increasing moderate to vigorous physical activity. All classes included a lesson, a hands-on activity and a food demonstration with taste testing of fruits and vegetables. To ensure youth engagement, three educators worked with groups of 18 campers. The camp also provided 3 hours daily of moderate or high intensity physical activities, such as group sports, fitness workouts and a weekly field trip.

Parents received nutrition education and a physical activity component in a weekly class, based on *Eating Smart Being Active*. This nutrition curriculum has demonstrated effectiveness in low-income families (Baker and McGirr 2012). Key obesity prevention messages were the same for parents and youth. The 6-week parent education culminated in a cook-off event where parents submitted their favorite family recipes for nutritional modification and then prepared it for all the families to taste.

***Participation in the HLFC summer camp, compared to the other camp, resulted in significant pre-post decreases in body weight and waist-to-height ratio after adjusting for baseline anthropometric measurements.***



Youth in the Healthy Lifestyle Fitness Camp participated in 3 hours of physical activities, 4 days a week, for 6 weeks.



In addition to nutrition classes and physical activities, the Healthy Lifestyle Fitness Camp offered weekly field trips featuring Yosemite hikes, visits to San Francisco and Santa Cruz, and bike rides.

Though the camp continued to receive encouraging and constructive feedback from the participants, a more formal evaluation was lacking. Generating evidence on the effectiveness of the HLFC program was needed to ensure continued community and external support.

## Designing an evaluation

In 2010, a nutrition specialist (LLK) and graduate student (GLG) from UC Davis joined the UCCE team and its community partners to design an evaluation study of the HLFC program with useful and practical indicators and tools. The community partners did not think it was feasible to assign youth randomly to intervention or control groups. Therefore, the UCCE team chose a quasi-experimental approach in which HLFC campers would be compared to similar youth who had been placed on the HLFC waitlist but subsequently enrolled in another day camp not focused on nutrition or fitness.

The evaluation tools included surveys for both HLFC and non-HLFC campers and parents. The Parent Nutrition Survey (PNS) was a 41-question survey (in English and Spanish, which was translated into Spanish and then translated back into English to ensure accuracy of meaning). The parent or caregiver completed the survey before (pre) and immediately after (post) the 6-week camp program. The survey contained questions about household demographic characteristics, youth food intake frequency (matched to the 11 fruits and vegetables tasted during HLFC), home food environment and support, and family health history and concerns. This survey was previously validated in multi-ethnic samples of youth, but was not validated in our study sample. Results from the PNS (Cutler et al. 2010) indicated that home food environment and support variables correlated with dietary patterns of youth. The other evaluation tool used was My Food Preference (MFP), a 17-question survey for youth to complete pre- and post-camp. The MFP survey was validated through Kaiser

et al. (2012) and contained questions about the youth's preference for the same 11 fruits and vegetables and perception of the home food environment. The UC Davis Institutional Review Board (IRB) approved the protocol for the study.

A pilot study among HLFC campers (no comparison group) was conducted in 2010 to test the feasibility of collecting these surveys and anthropometric measurements (height, weight and waist circumference) (Kaiser et al. 2012). Upon discussion with UC CalFresh staff, minor edits were made in the wording of questions to improve relevancy to the HLFC population. Based on the pre-post changes in waist-to-height ratio, which is a sensitive indicator of abdominal fat accumulation and metabolic risk (Kuba et al. 2013), the team determined a sample size of 20 per group would be sufficient (using a 0.05 alpha, 0.20 beta, 0.02 delta for waist-to-height ratio).

In 2011 and 2012, the HLFC staff recruited campers through local radio bulletins and school site and after-school program visits. Prior to each camp year, the graduate student conducted a one-day training with the UCCE staff to measure height, weight and waist circumference for this evaluation study, based on methodology used in National Health and Nutrition Examination Survey (CDC 2011). Staff also learned human subjects procedures to administer surveys to parents and youth and reviewed how the nutrition curriculum activities aligned with

social cognitive theory. The staff was previously trained in using *EatFit* and *Eating Smart Being Active* curricula.

The comparison group consisted of youth who had been placed on a waitlist for HLFC but were not enrolled due to the need to maintain the required camper:counselor ratio (10:1). This group attended Fun Camp, another local summer camp consisting of games, crafts and other activities not focused on nutrition and physical activity.

HLFC orientation occurred 2 weeks prior to the start of camp. After the orientation, the graduate student explained the evaluation study. Parents and youth read and signed the IRB consent and assent forms. If not interested in the evaluation study, campers still were allowed to participate in camp. All parents and campers chose to participate ( $n = 126$ ). Parents signed informed consent forms. All youth received assent letters, and those who were 12 years or older signed consent forms.

## Evaluation study challenges

Conducting an evaluation study in a community of youth and their families poses many challenges, including recruitment of participants; collecting and matching data for youth and parents; and especially, follow-up 2 months after the end of the intervention. Combining the summers of 2011 and 2012, the HLFC group consisted of 126 youth and the comparison group





had 29 youth. Immediately at the end of camp (post), there were 111 HLFC and 23 comparison youth among whom anthropometric measures were recorded. At the 2-month follow-up, when only dietary, activity and anthropometric data were collected, 45 HLFC and 14 comparison youth remained. Two-month attrition was largely due to communication difficulties

(e.g., undelivered emails and disconnected phones).

Since it was not possible to assign youth randomly to HLFC or comparison groups, differences between groups were apparent at baseline (table 1). Compared to the HLFC campers, the comparison youth had lower baseline weights, waist circumferences, waist-to-height ratios and

BMI z-scores but still met study inclusion criteria,  $\geq 85$ th BMI-for-age percentile. Though the youth lived in the same neighborhood, ethnicity also differed: the comparison group was primarily African-American and the HLFC group was primarily Latino. The groups did not differ in gender, language spoken at home, child's birth country, parent education, income, employment status or participation in food assistance programs, though other unmeasured differences may exist.

## Camp outcomes

Due to the challenges of recruiting and retaining youth through a 2-month post camp follow-up, the repeated measures analysis of variance procedures controlled for ethnicity and baseline anthropometric values and used an intent-to-treat approach, assuming that youth who dropped out would have returned to baseline measurement values. As reported elsewhere (George et al. 2016), participation in the HLFC summer camp, compared to the other camp, resulted in significant pre-post decreases in body weight and waist-to-height ratio after adjusting for baseline anthropometric measurements. Though waist-to-height ratio reductions were maintained at the 2-month follow-up, these findings should be interpreted with caution due to attrition and small sample size.

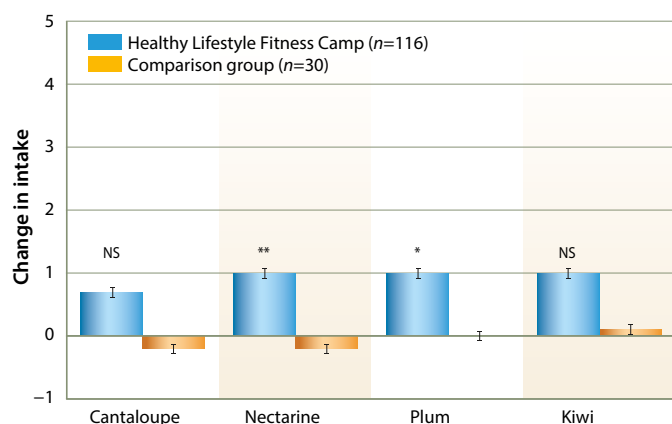
At baseline (pre), youth and their parents ( $n = 126$  dyads) independently assessed their home food environment in the MFP (all completed in English) and PNS surveys (13, or 10%, were completed in Spanish), respectively. Based on Spearman's correlation, agreement between youth and parent dyads was stronger for availability of fruits and vegetables ( $r = +0.33$ ,  $p = 0.0001$ ) than for the availability of snack foods, including chips and sodas ( $r = +0.11$ , NS). Since the youth were 9 years and older, hours of contact between parent and child may be fewer for this age group than for younger children and may explain the discrepancy in their perceptions on availability of snack foods that might be consumed outside of shared mealtimes.

There was a weak but significant relationship between parents' report of their children's frequency of consumption and youth food preferences for the same 11 fruits and vegetables (figs. 1

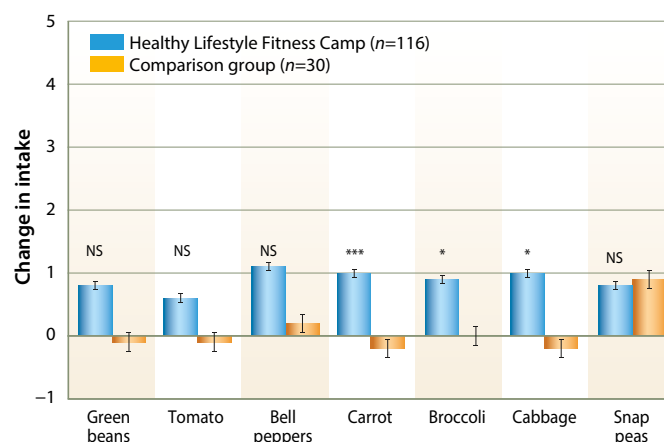
**TABLE 1. Baseline anthropometric and demographic characteristics of youth in HLFC intervention and comparison group youth**

	Intervention mean $\pm$ SD ( $n = 126$ )	Comparison mean $\pm$ SD ( $n = 29$ )
Age (years)	11.9 (1.5)	11.2 (1.6)
Weight (kg)**	74.2 (20.4)	59.7 (14.9)
Waist circumference (cm)**	97.9 (14.2)	82.3 (10.1)
Waist-to-height ratio**	0.64 (0.079)	0.54 (0.045)
BMI z-score**	2.02 (0.49)	1.51 (0.42)
Age of parent (years)	40.5 (7.8)	42.1 (9.4)
Household size	5 (2)	6 (2)
	Intervention $n$ (%)	Comparison $n$ (%)
Male gender (of youth)	62 (49)	14 (48)
Youth ethnicity**		
White, non-Hispanic	16 (13)	1 (4)
Latino	74 (59)	6 (21)
African-American, non-Hispanic	36 (29)	22 (76)
Mostly English spoken at home	121 (96)	29 (100)
Youth birthplace (United States)	100 (79)	25 (86)
Parent education		
Less than high school	35 (28)	5 (17)
High school to 2-year college	75 (60)	20 (69)
4-year college or higher	16 (13)	4 (14)
Parent income		
< \$500–\$1,500 per month	32 (25)	9 (31)
\$1,501–\$3,000 per month	51 (41)	12 (41)
\$3,001 or more per month	30 (24)	0 (0)
Declined to state	13 (10)	8 (19)
Parent employment		
Employed (full, part, homemaker)	17 (14)	6 (20)
Unemployed (student, out of work, unable)	37 (29)	15 (51)
Refused to answer*	72 (57)	9 (28)
Participation in food assistance programs		
1 program participation	74 (60)	17 (59)
2 program participation	33 (27)	9 (31)
3 or more program participation	16 (13)	3 (10)
None	0	0
Refused to answer	3	0

The t-test was used to compare for continuous variables and chi-square. For categorical variables \*  $p < 0.01$ ; \*\*  $p < 0.001$ .



**Fig. 1. Fruit consumption changes between HLFC and comparison group youth (post-pre).** Post-pre is difference, based on 0 = never to 5 = daily. Wilcoxon rank sum test: \*  $p = 0.02$  (note: mean change for comparison group was 0); \*\*  $p = 0.01$ ; NS = not significant. Error bars with SEs.



**Fig. 2. Vegetable consumption changes between HLFC and comparison group youth (post-pre).** Post-pre is difference, based on 0 = never to 5 = daily. Wilcoxon rank sum test: \*  $p < 0.03$ , \*\*\*  $p < 0.0001$ ; NS = not significant. Note: for broccoli, mean change in the comparison group was 0. Error bars with SEs.

and 2) ( $r = +0.19$ ,  $p = 0.01$ ). Especially for fruit, child preference was relatively high but home consumption was infrequent (data not shown), which could potentially be due to limited availability of fruit at home.

At baseline (pre), no differences between the two groups were observed in the frequency of consuming 11 fruit and vegetable items, except for green beans, which were consumed less often in HLFC youth (data not shown). By end of camp (post), parents of HLFC youth reported greater change than comparison parents in their child's frequency of consuming several fruits and vegetables (figs. 1 and 2). Controlling for ethnicity and baseline waist-to-height ratio, parent-reported change in their child's total consumption of the 11 fruits and vegetables was greater in HLFC than comparison group youth ( $p = 0.001$ , table 2). Change in youth preferences for fruits and vegetables did not differ among the groups (data not shown), but most of the youth from both groups liked the items (or were neutral, "it is ok") at baseline. Lack of statistical power could also be a reason that no significant change in youth preferences were observed, as these variables were not used in our power analysis.

There were no significant post-pre changes in the parent-reported availability of soda and chips in the home (table 2). However, the availability of fruits and vegetables at home tended to be greater among parents in the comparison group than in the intervention group (after adjusting for ethnicity and baseline

waist-to-height ratio,  $p = 0.05$ , table 2). The sample size was too small to explore whether other group differences (besides ethnicity and waist-to-height ratio) might explain this result.

Additionally, both PNS and MFP were not validated in our study but were previously validated in a similar population. This is a potential limitation to true interpretation of the results. However, taken together, these results may suggest that HLFC youth, compared to controls, began eating more of the fruits and vegetables that were already available at home and/or that parents might have substituted purchases to buy specific

foods their children requested after camp food tastings.

## Lessons for program managers

This study yields insights for program managers in planning evaluations for programs with youth and parent components. Program managers should ensure the tools correctly work with the study population. While using validated tools is a good start, additional time is often needed to test existing tools with the study population and make modifications as needed. This testing and modification

**TABLE 2. Immediately post camp–pre changes in home environment and total fruit and vegetables subscales, as reported by the parents of HLFC intervention ( $n = 126$ ) and the comparison group ( $n = 29$ )**

	Pre-camp mean $\pm$ (SD)	Post-camp mean $\pm$ (SD)	Post-pre camp mean	Unadjusted $p$ -value*	Adjusted for ethnicity and baseline WHtR $p$ -value†
<b>Youth frequency of fruit and vegetable consumption‡</b>					
Intervention	19.89 (11.1)	28.2 (10.6)	8.28		
Comparison	27.07 (14.2)	28.9 (14.5)	1.66	0.01	0.001
<b>Healthy home food environment = fruits and vegetables are available§</b>					
Intervention	7.9 (1.8)	8.4 (1.8)	0.4		
Comparison	8.2 (1.8)	9.1 (1.2)	0.83	0.04	0.05
<b>Unhealthy home food environment = soda and salty snacks are available§</b>					
Intervention	6.9 (1.9)	5.5 (1.9)	–1.3		
Comparison	6.1 (2.0)	5.8 (2.1)	–0.4	0.04	0.07

\* ANOVA.

† ANOVA, adjusted for child ethnicity and baseline weight-to-height ratio (WHtR).

‡ Variable is a sum of consumption frequency for 11 fruits and vegetables, including cantaloupe, nectarine, plum, kiwi, green beans, tomato, bell pepper, carrot, broccoli and cabbage. Responses for each item were: 5 = daily or almost daily, 4 = 2–3 times a week, 3 = once a week, 2 = 2–3 times a month, 1 = once a month, 0 = never. Range 0–55 points.

§ Variable is a sum of two items with Likert scale response: 5 = strongly agree, 4 = agree, 3 = neutral, 2 = disagree, 1 = strongly disagree. Range 1–10 points.



is likely to be especially important when working in languages other than English.

In delivering family-centered programs, having a very attractive youth component may be helpful in keeping parents engaged. For example, in post-camp focus groups, parents commented that their children were having fun, learning about healthy habits and making friends, which may have been a motivating factor for parent attendance at the parent nutrition classes. This made obtaining pre-post surveys from parents easier.

Often the biggest challenge in evaluation is designing a comparable control group. Thus, getting sufficient demographic data is essential to control for baseline differences. Additionally, it is important to analyze data as intent-to-treat to avoid any attrition-related confounding factors. Finally, well-designed evaluation studies cost money and not all expenses are allowable on USDA nutrition program grants. By leveraging program delivery funds with other funds from UC

Davis, community partners and external sources, the evaluation was doable.

Program managers should pay attention to fidelity issues and plan for sustainability. First, they need to select agencies and partners who are committed to delivering all the critical components of nutrition and fitness, establishing agreements and maintaining good communication throughout the study to parallel health messages. Second, training (and retraining) staff is essential to ensure that delivery consistently promotes behavior change. All who interact with the youth and their parents need staff development to maintain their enthusiasm and commitment to the program and behavior change messages. Since a summer camp has the potential to meet multiple needs — physical, academic and social — program managers and partners should focus on developing plans for camp reunions with families and other get-togethers after summer is over. These events may be crucial in building the support network for

youth to maintain healthier lifestyles and friendships into the school year.

This research suggests two recommendations for summer programming. First, Cooperative Extension, in partnership with local park and recreation departments, can provide summer enrichment programs to low-income students. In California, extension-designed nutrition curricula are aligned with state academic standards, so children can develop their math and science skills, while learning nutrition (Horowitz et al. 2004). Second, summer programs should focus on teaching nutrition and physical activity as part of an overall healthy lifestyle according to the Dietary Guidelines. [CA](#)

*G.L. George is Assistant Professor in the Nutrition and Dietetics, Consumer and Family Studies/Dietetics Department at San Francisco State University; L.L. Kaiser is UC Cooperative Extension Nutrition Specialist in the Department of Nutrition at UC Davis (retired); C. Schneider is Director, Youth, Families and Communities, UC Agriculture and Natural Resources (retired).*

## References

- Alexander K, Entwisle D, Olson L. 2007. Lasting consequences of the summer learning gap. *Am Sociol Rev* 72(2):167–80.
- Baker S, McGirr K. 2012. *Eating Smart Being Active*. Edition 2. Fort Collins, Colorado: Colorado State University.
- [CDSS] California Department of Social Services. 2016. CalFresh eligibility and insurance requirements. [www.calfresh.ca.gov/Pg841.htm](http://www.calfresh.ca.gov/Pg841.htm) (accessed February 2016).
- [CDC] Centers for Disease Control. 2011. National health and nutrition examination survey anthropometry procedures. [www.cdc.gov/nchs/nhanes/nhanes3/anthropometric\\_videos.htm](http://www.cdc.gov/nchs/nhanes/nhanes3/anthropometric_videos.htm) (accessed October 2015).
- Cutler G, Flood A, Hannan P, Neumark-Sztainer D. 2011. Multiple sociodemographic and socioenvironmental characteristics are correlated with major patterns of dietary intake in adolescents. *J Am Diet Assoc* 111(2):230–40. doi:10.1016/j.jada.2010.10.052.
- Downey D, Boughton H. 2007. Childhood body mass index gain during the summer versus during the school year. *New Dir Youth Dev* 114:33–43. doi:10.1002/yd.211
- George G, Schneider C, Kaiser L. 2016. Healthy Lifestyle Fitness Camp: A summer approach to prevent obesity in low-income youth. *J Nutr Educ Behav* 48(3): 208–12.e1.
- HEALTHY Study Group, Foster G, Linder B, et al. 2010. A school-based intervention for diabetes risk reduction. *N Engl J Med* 363(5):443–53. doi:10.1056/NEJMoa1001933
- Horowitz M, Shilts M, Townsend MS. 2004. EatFit: A goal oriented intervention that challenges adolescents to improve their eating and fitness choices. *J Nutr Educ Behav* 36(1):43–4.
- Hopkins LC, Gunther C. 2015. A historical review of changes in nutrition standards of USDA child meal programs relative to research finding on the nutritional adequacy of program meals and the diet and nutritional health of participants: Implications for future research and the summer food service program. *Nutrients* 7(12):10145–67. doi:10.3390/nu7125523
- Juonala M, Magnussen C, Berenson G, et al. 2011. Childhood adiposity, adult adiposity, and cardiovascular risk factors. *N Engl J Med* 365(20):1876–85. doi:10.1056/NEJMoa1010112.
- Kaiser L, Schneider C, Mendoza C, et al. 2012. Development and use of an evaluation tool for taste-testing activities by school-aged children. *J Acad Nutr Diet* 112(12):2028–34. doi:10.1016/j.jand.2012.07.006
- Kuba V, Leone C, Damiani D. 2013. Is waist-to-height ratio a useful indicator of cardio-metabolic risk in 6-10-year-old children? *BMC Pediatr* 13:91. doi:10.1186/1471-2431-13-91.
- Maggio A, Martin X, Saunders Gasser C, et al. 2014. Medical and non-medical complications among children and adolescents with excessive body weight. *BMC Pediatr* 14:232. doi:10.1186/1471-2431-14-232.
- Ogden C, Carroll M, Kit B, Flegal K. 2014. Prevalence of childhood and adult obesity in the United States, 2011–2012. *JAMA* 311(8):806–14.
- Pan L, Sherry B, Park S, Blanck H. 2013. The association of obesity and school absenteeism attributed to illness or injury among adolescents in the United States, 2009. *J Adolesc Health* 52(1):64–9. doi:10.1016/j.jadohealth.2012.04.003.
- Scherr R, Cox R, Feenstra G, Zidenberg-Cherr S. 2013. Integrating local agriculture into nutrition programs can benefit children's health. *Calif Agr* 67(1):30–7. doi:10.3733/ca.v067n01p30.
- Tovar A, Lividini K, Economos C, Foltz S, et al. 2010. School's out: What are urban children doing? The summer activity study of Somerville youth (SASSY). *BMC Pediatr* 10:16. doi:10.1186/1471-2431-10-16.
- [USDA and DHHS] US Department of Agriculture and US Department of Health and Human Services. 2005. *Dietary Guidelines for Americans, 2005*, 6th ed. <http://health.gov/dietaryguidelines/dga2005/document/> (accessed January 2016).
- USDA and DHHS. 2010. *Dietary Guidelines for Americans, 2010*. 7th ed. <http://health.gov/dietaryguidelines/dga2010/dietaryguidelines2010.pdf> (accessed October 2015).
- von Hippel P, Powell B, Downey D, Rowland NJ. 2007. The effect of school on overweight in childhood: Gain in BMI during the school year and during summer vacation. *Am J Pub Health* 97(4):696–702.



Sara Hamilton



# Using InVEST to assess ecosystem services on conserved properties in Sonoma County, CA

by Van Butsic, Matthew Shapero, Diana Moanga and Stephanie Larson

*Purchases of private land for conservation are common in California and represent an alternative to regulatory land-use policies for constraining land use. The retention or enhancement of ecosystem services may be a benefit of land conservation, but that has been difficult to document. The InVEST toolset provides a practical, low-cost approach to quantifying ecosystem services. Using the toolset, we investigated the provision of ecosystem services in Sonoma County, California, and addressed three related questions. First, do lands protected by the Sonoma County Agricultural Preservation and Open Space District (a publicly funded land conservation program) have higher values for four ecosystem services — carbon storage, sediment retention, nutrient retention and water yield — than other properties? Second, how do the correlations among these services differ across protected versus non-protected properties? Third, what are the strengths and weaknesses of using the InVEST toolset to quantify ecosystem services at the county scale? We found that District lands have higher service values for carbon storage, sediment retention and water yield than adjacent properties and properties that have been developed to more intensive uses in the last 10 years. Correlations among the ecosystem services differed greatly across land-use categories, and these differences were driven by a combination of soil, slope and land use. While InVEST provided a low-cost, clearly documented way to evaluate ecosystem services at the county scale, there is no ready way to validate the results.*

Ecosystem services, sometimes called “nature’s services,” are broadly defined as the ecosystem functions that benefit people (Daily 1997; Turner and Daily 2008). They are commonly grouped into four categories: supporting, provisioning, regulating and cultural services. Supporting services, such as nutrient recycling and soil formation, allow other ecosystem services to function. Provisioning services include food, raw materials, water and energy. Regulating services, such as carbon sequestration and water purification, regulate ecosystem processes. And cultural services, such as recreational opportunities, contribute to our quality of life. While the economic value of ecosystem services is often debated (Naidoo et al. 2008; Rockström et al. 2009), there is little doubt that the services are essential to human life (Daily 1997).

Online: <https://doi.org/10.3733/ca.2017a0008>



The purchase of conservation easements on agricultural land is one approach to preventing residential development on working landscapes. The authors present a low-cost tool for assessing ecosystem service values across large areas, a step toward quantifying the benefits of land conservation.



*A key challenge for scientists and policymakers is to quantify the values of ecosystem services so that those values, which may be found in both wild and agricultural lands, can be fully accounted for in land-use decisions.*

Often, however, ecosystem services are not taken into account when land use and policy decisions are made (Gómez-Baggethun et al. 2010) — either because the services are difficult to quantify or because they are not thought of as benefits until they are lost (Daily et al. 2009). Loss of ecosystem services can lead to sub-optimal landscapes for humans, plants and animals (Nelson et al. 2009). A key challenge for scientists and policymakers is to quantify the values of ecosystem services so that those values, which may be found in both wild and agricultural lands, can be fully accounted for in land-use decisions.

In California, the conversion of land to more intensive uses such as housing threatens the supply and delivery of ecosystem services (Cameron et al. 2014). Since 1984, over 1.4 million acres has been converted from agricultural to other uses, 78% of that to urban development (California Department of Conservation 2011). Various land-use policies exist to manage these conversions, including regulatory zoning and general plans adopted by local governments (Bowers and Daniels 1997). Their effectiveness varies, with policies showing promise in some locations but not others (Butsic et al. 2011; Pogodzinski and Sass 1994).

An alternative to regulatory approaches to land use policy is the purchase, either in fee title or through conservation easements, of private land for conservation (Fishburn et al. 2009; Sundberg 2006). Such transactions may involve local government agencies, private entities such as land trusts or a combination. This approach is common in California, with over 1 million acres conserved by land trusts as of 2010 (Land Trust Alliance 2011). Land conservation may help maintain ecosystem services by preventing conversion of natural and low intensity agricultural land to more intensive uses such as urban, residential or industrial development or large-scale agriculture (Rissman and Merenlender 2008).

In 1990, Sonoma County residents created the Sonoma County Agricultural Preservation and Open Space District (District) to permanently protect the greenbelts, scenic viewsheds, farms and ranches, and natural areas of the county. Living on the northern edge of the rapidly urbanizing Bay Area, and facing the loss of the natural and agricultural landscapes that define the county's rural character, the voters of Sonoma County recognized the need for proactive local funding for agricultural and open space protection. Voters approved a ballot measure that

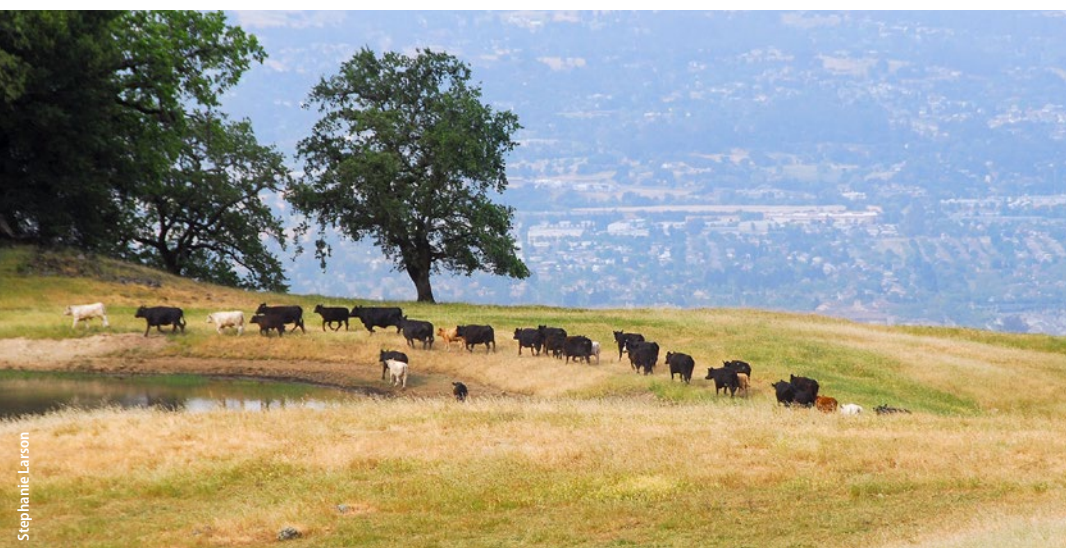
created the District and instituted a quarter-cent sales tax to fund District operations. The District is now one of the oldest and largest land conservation programs in California; over 100,000 acres has been protected through purchases of land and conservation easements over the last 25 years. Many of the purchased properties are likely to have high ecosystem service values (Ferranto et al. 2011; Plieninger et al. 2012), although these values have not been quantified.

Quantifying ecosystem services can be difficult (Eigenbrod et al. 2010). Models built to assess the biophysical parameters that constitute ecosystem services — such as carbon storage and sediment retention — often require large amounts of spatially explicit data that is not readily available. This issue has limited the application of the ecosystem services concept as a tool to quantify the benefits of land conservation programs, and to help the programs plan for the future (Daily et al. 2009).

Recent advances in modeling techniques, however, in particular the InVEST modular toolset developed by the Natural Capital Project (Sharp et al. 2015), promise to simplify the process of quantifying ecosystem services. The InVEST toolset is designed to run using the many free, large-scale datasets that are available for most California land types, and it can be run on standard personal computers. InVEST can assess the value of 18 different ecosystem services, including carbon sequestration, water yield, nutrient retention, and recreation and tourism. This tool may open the door for widespread quantification of ecosystem services across California.

To quantify the ecosystem services provided by conserved lands in Sonoma County, we used InVEST to estimate carbon storage, sediment retention, nutrient retention (nitrogen and phosphorus) and water yield. We chose these four ecosystem services because of their importance and because they can be degraded by land-use conversions. Carbon sequestration is being monetized in the California carbon markets, and methods to evaluate carbon storage are needed statewide. Land conversions to more developed uses

**The study assessed four ecosystem services provided by Sonoma County landscapes: carbon storage, sediment retention, nutrient retention and water yield.**



generally reduce carbon on the landscape. Sediment and nutrient retention impact water quality, which is important for human needs and also ecosystem needs; conversions of vegetation often result in poorer water quality. In the current era of drought, water yield from California landscapes is a topic of public concern, as every drop of water becomes more valuable. Land-use conversions can impact the amount of groundwater recharge or loss through runoff.

We quantified the ecosystem services for all of Sonoma County and then summarized the results across three types of land: (1) land purchased by the District, (2) land adjacent to District lands and (3) land that has been converted to developed uses in the last 15 years. While we did not do an economic valuation of each ecosystem service, the values we present here could serve as the foundation for such an analysis.

This process allowed us to test three hypotheses:

1. Do lands conserved by the District have higher ecosystem service values (carbon storage, sediment retention, nitrogen and phosphorus retention, and water yield) than lands adjacent to them or to developed land?
2. How are the ecosystem services correlated across land-use categories? Do high values for one service tend to be associated with low values for another?
3. What are the strengths and weaknesses of using the InVEST toolset at the county scale?

## Study area

Sonoma County, located on the north-western edge of the Bay Area, is comprised of roughly 1 million acres of farmland, rangeland, forest, cities and suburbs. It produces some of California's finest wines and cheeses, and its farms and ranches account for roughly 50% of the county's acreage. Forest covers approximately 41% of the county and has a modest impact on the economy (USDA 2016). Urban and suburban development and water constitutes the remaining 9% of the land area. Population has doubled over the last 30 years to nearly half a million people; during that time, over 10% of the best agricultural land (land classified as "Prime Farmland" by California's

Farmland Mapping and Monitoring Program) has been converted to more intensive uses, and this trend is likely to continue in the near future.

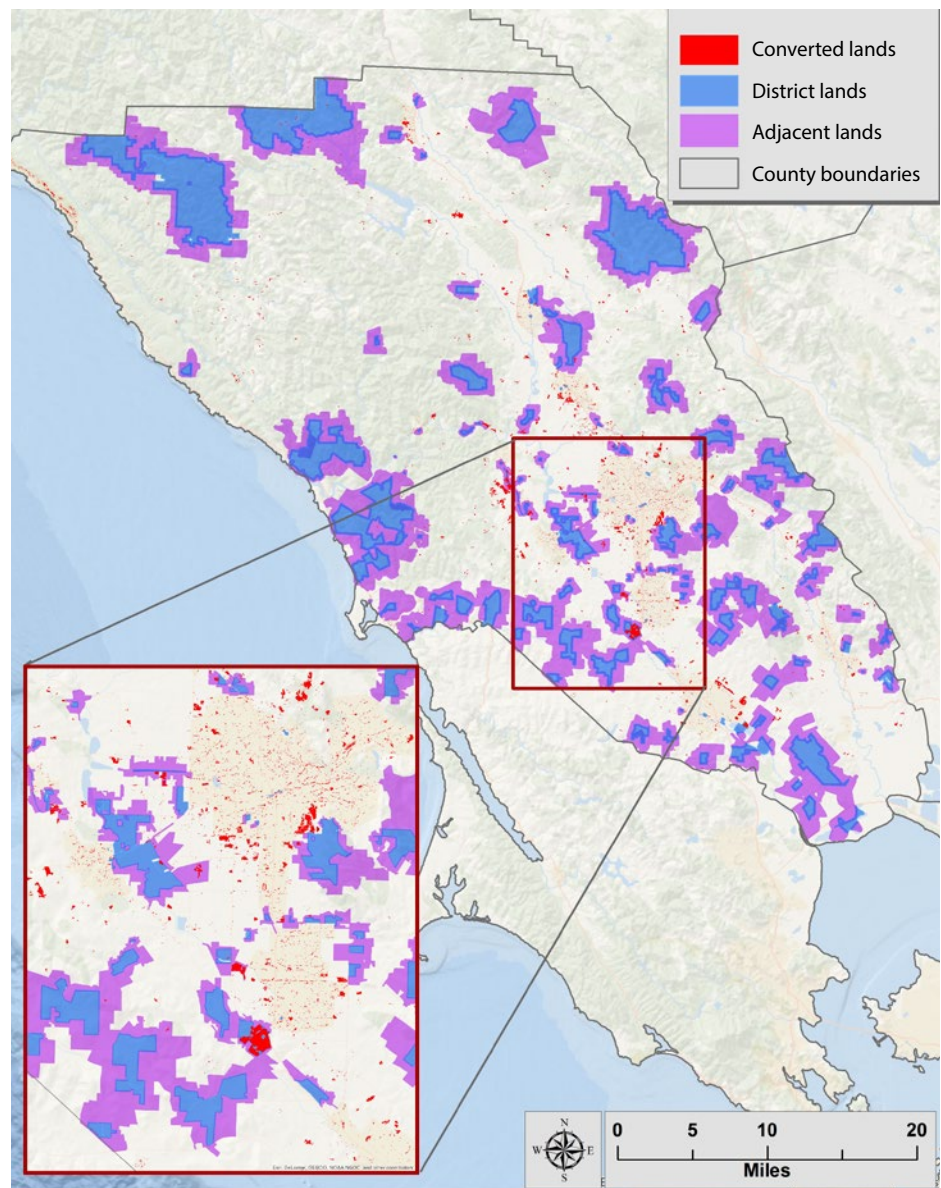
## Land typology

We classified the landscape of Sonoma County into three land typologies:

- District lands
- Land adjacent to District land
- Converted lands, lands converted from rangelands or woodlands to development (urban or residential) since 2001.

We classified as District lands all properties that had been acquired by the District since its founding, including parcels that were then managed by agencies other than the District. Lands adjacent to District lands were identified as those that shared a border with District properties, using the "Select" tool in ArcMap (fig. 1). These properties were identified using the Sonoma County parcel data layer provided by the county.

We believe adjacent lands provide useful points of comparison with district lands. Since they are necessarily in the same geographic area, they would be expected to have similar biophysical



**Fig. 1.** The study compared the average ecosystem service values of: parcels converted to developed uses in the past 15 years ("Converted land"); parcels conserved by the Sonoma County Agricultural Preservation and Open Space District ("District land"); parcels bordering District lands ("Adjacent lands"); and county lands as a whole.



features. Likewise, we found mean elevation and slope to be similar between the two types of parcels. District lands had a slope of 16.08 degrees (SD 9.96 degrees) and an elevation of 256.73 meters (SD 168.82 meters); adjacent lands had a slope of 13.85 degrees (SD 9.77 degrees) and an elevation of 222.63 meters (SD 184.61 meters). That said, we do not suppose that adjacent lands are a perfect control. Often, protected lands differ from non-protected lands (Joppa et al. 2008), and we did not attempt to control for these differences by statistical means.

To identify converted lands, we identified change pixels using the 2001-2011 National Land Cover Dataset (NLCD) change product. We identified all non-urban pixels that had converted to developed uses between the years 2001 and 2011. We then identified these pixels on the 2010 LANDFIRE database, the primary vegetation database used in our study.

All data was converted to 30-meter pixels. Using the methods described above, we calculated the total acreage of Sonoma County as 1,060,766 acres; total District holdings as 105,925 acres; adjacent lands to existing District land as 123,600 acres; and converted lands as 7,056 acres.

## Evaluating ecosystem services using InVEST

InVEST is a modular, open-source, free toolset in which tabular and spatial data are combined with stand-alone biophysical models to quantify, visualize and compare the delivery of key ecosystem services. While each module is different, most InVEST modules require a base land cover layer, a digital elevation model (DEM) and tabular data that set model parameters for the biophysical models. Outputs describe ecosystem services in terms of their biophysical values and their spatial location (for example, kilograms of carbon stored in a given 30-meter pixel). Full technical descriptions of each module can be found in the module user's guide (table 1). Our description of the models closely follows these guides.

### InVEST module 1: Carbon storage

The InVEST module uses land cover maps and data on stocks in four carbon pools (aboveground biomass, belowground biomass, soil, and dead organic matter) to

estimate the amount of carbon currently stored in a landscape. The estimation of total carbon storage is the sum of all carbon pools for each land cover type. The InVEST result is an estimate of carbon stocks for each pixel on the landscape.

For our model, we use estimates developed by the Nature Conservancy and the District of aboveground carbon associated with LANDFIRE land cover types in Sonoma County (USDA 2013). We used this local dataset as we considered it more accurate than more broad scale carbon estimates, such as estimates published by the Intergovernmental Panel on Climate Change (IPCC). For the belowground carbon pools, the LANDFIRE dataset for Sonoma County includes over 100 land cover types, but documented carbon estimates exist for only seven of these (Pachauri and Meyer 2014). We approximated belowground carbon for the other land cover types by assigning values to these from similar land cover types. Admittedly, this is a source of uncertainty in our results. Another source of uncertainty: we applied an average value for each vegetation type for belowground carbon; therefore, our maps of carbon storage may be inaccurate if there is variation within a land cover type, for instance due to vegetation age. Complete technical details of the model are available from the InVEST user's guide, [bit.ly/InvestCS](http://bit.ly/InvestCS).

### InVEST module 2: Sediment delivery ratio

The InVEST sediment delivery model maps overland sediment generation and delivery. Sediment dynamics at the

catchment scale are mainly determined by climate (in particular, rain intensity), soil properties, topography, vegetation and anthropogenic factors such as agricultural activities. Sediment sources include overland erosion (soil particles detached and transported by rain and overland flow), gullies (channels that concentrate flow), bank erosion and mass erosion (or landslides).

The sediment delivery module works at the scale of the 30-meter DEM. For each cell, the model first computes the amount of eroded sediment. Eroded sediment was calculated as the annual soil loss, using the Universal Soil Loss Equation (USLE). Data inputs to this equation include rainfall erosivity, soil erodability, slope length gradient factor, crop length factor (specific coefficients accounting for how various crops impact sediment delivery) and support practice factor (impact of alternative conservation practices). Next, the sediment delivery ratio (SDR), which is the proportion of soil loss reaching the catchment outlet, was calculated. The outputs from the sediment model included the sediment load delivered to the stream at an annual time scale, as well as the amount of sediment eroded in the catchment and retained by vegetation and topographic features.

The main limitation of this model was the reliance on the USLE. While this equation is widely used to calculate erodibility, it does not capture all types of erosion and therefore some delivered sediment may not be quantified. Full technical details of this model can be found in the InVEST users' guide, [bit.ly/InvestSDR](http://bit.ly/InvestSDR).

TABLE 1. Data requirements and source information used as inputs in the InVEST modules

<b>Carbon</b>	LANDFIRE vegetation map ( <a href="http://www.landfire.gov/vegetation.php">www.landfire.gov/vegetation.php</a> ) for above-ground carbon pools. Belowground carbon pools used IPCC 2006 values ( <a href="http://bit.ly/ipcc_carbon">bit.ly/ipcc_carbon</a> ).
<b>Sediment delivery ratio</b>	LANDFIRE vegetation map re-classified to seven Anderson categories. 30-m digital elevation model provided by SCAPOSD. Rainfall erosivity index (R) calculated using NRCS soil viewer extension ( <a href="http://bit.ly/nrcs_sdv">bit.ly/nrcs_sdv</a> ) and Statsgo2 ( <a href="http://bit.ly/nrcs_Statsgo2">bit.ly/nrcs_Statsgo2</a> ) soil data. Soil erodibility (K) calculated using NRCS soil data viewer extension and Statsgo2 soil data. Watersheds are from the Watershed Boundary Dataset ( <a href="http://nhd.usgs.gov/wbd.html">nhd.usgs.gov/wbd.html</a> ).
<b>Nutrient retention and water yield</b>	LANDFIRE vegetation map (link above). 30-m digital elevation model provided by SCAPOSD. Watershed Boundary Dataset ( <a href="http://nhd.usgs.gov/wbd.html">nhd.usgs.gov/wbd.html</a> ). Root restricting layer depth calculated using NRCS soil viewer extension ( <a href="http://bit.ly/nrcs_sdv">bit.ly/nrcs_sdv</a> ) and Statsgo2 ( <a href="http://bit.ly/nrcs_Statsgo2">bit.ly/nrcs_Statsgo2</a> ) soil data. Precipitation calculated using NRCS soil viewer extension and Statsgo2 soil data. Plant-available water content calculated using NRCS soil viewer extension and Statsgo2 soil data. Average annual potential evapotranspiration from ArcGIS Modis toolbox 900M grid ( <a href="http://bit.ly/Modis900M">bit.ly/Modis900M</a> ). Biophysical table values were taken from Drake 2005.

### InVEST module 3: Nutrient retention

The InVEST Water Purification Nutrient Retention model calculates the amount of nutrient retained on every pixel and sums nutrient export and retention per watershed. The pixel-scale calculations allowed us to represent the heterogeneity of key driving factors in nutrient retention, such as soil type, precipitation and vegetation type.

The model works in three parts. First, annual runoff from each pixel is calculated using the InVEST water yield model. The second phase determines the quantity of nutrient retained by each pixel on the landscape. The model estimates how much pollutant is exported from each pixel based on export coefficients from the user inputs. Export coefficients are annual averages of pollutant fluxes derived from various field studies that measure export from pixels within the United States.

The model was developed for watersheds and landscapes dominated by saturation excess runoff hydrology. The model does not address any chemical or biological interactions that may occur from the point of loading to the point of interest besides filtration by terrestrial vegetation. In reality, pollutants may degrade over time and distance through interactions with the air, water, other pollutants, bacteria or other actors. Full technical details of the model can be found in the InVEST user's guide, [bit.ly/InvestNR](http://bit.ly/InvestNR).

### InVEST module 4: Water yield

InVEST maps and models the annual average water yield from a landscape, defined as the amount of water running off the landscape. The model runs on a gridded map, estimating the quantity of water for each subwatershed in the area of interest. First, it determines the amount of water running off each pixel as the precipitation less the fraction of the water that undergoes evapotranspiration. The model does not differentiate between surface, subsurface and baseflow, but assumes that all water yields from a pixel reach the point of interest via one of these pathways. This model then sums and averages water yield to the subwatershed level. The pixel-scale calculations allow us to represent the heterogeneity of key driving factors in water yield, such as soil type, precipitation and vegetation type. However, the theory we are using



The type of vegetation cover influences the value of all four of the ecosystem services assessed in the study.

as the foundation of this set of models was developed at the subwatershed to watershed scale. We are only confident in the interpretation of these models at the subwatershed scale, so all outputs were summed and/or averaged to the subwatershed scale. Technical details of the water yield model can be found online at [bit.ly/InvestWY](http://bit.ly/InvestWY).

### Combining and comparing services

To understand the spatial distribution of the ecosystem services, we mapped the values of each (figs. 2A–E). We also developed a map of “hotspots” — areas that have high values for most or all services assessed (fig. 3) — using the following method. First, we rescaled the pixel level ecosystem services by dividing each pixel value by the maximum value for that service. This created a scaled raster for each service with a maximum value of 1. We then added the raster values from all services to create a map in which the maximum value of each pixel was 5. That is, if a pixel had the maximum value for all five services, it would have a value of 5.

To compare the potential trade-offs among ecosystem service values within different land types — that is, the positive or negative correlations — we created spider graphs (fig. 4). These graphs show the scaled value for the mean of each service for each land typology. For example, if District lands had the highest mean carbon per acre, on the spider graph District land would receive a 1.0. If adjacent lands

had a mean carbon value of 60% of the District lands, they would be represented by a 0.6 on the spider graph, and so forth.

### Model results

#### Carbon storage

Our models estimate carbon storage in Sonoma County at 205,496,048 Mg (fig. 2A). About 10.5% of carbon storage occurs on District lands, and District lands have the highest mean carbon storage levels, with an average of 49 Mg per pixel compared to 45 Mg for the county and 16.54 Mg for converted lands. The per-pixel level of carbon storage is primarily driven by vegetation type, and hence follows a gradient: developed land uses have lowest carbon storage levels, and forested areas with high biomass have the highest levels (table 1, fig. 2A).

#### Sediment retention

The sediment retention index is a comparison of the potential for soil loss from a given pixel without vegetation versus with current vegetation (fig. 2B). High values indicate that more soil loss is prevented due to vegetation. District lands rank high; the vegetation on these lands does a good job of retaining sediment, especially considering the high potential that these areas have for sediment export given their high average slope. County lands and adjacent lands rank lower, but both are far ahead of converted lands (table 2).

The sediment retention model produced six results, one of which we report here. We computed the potential soil loss



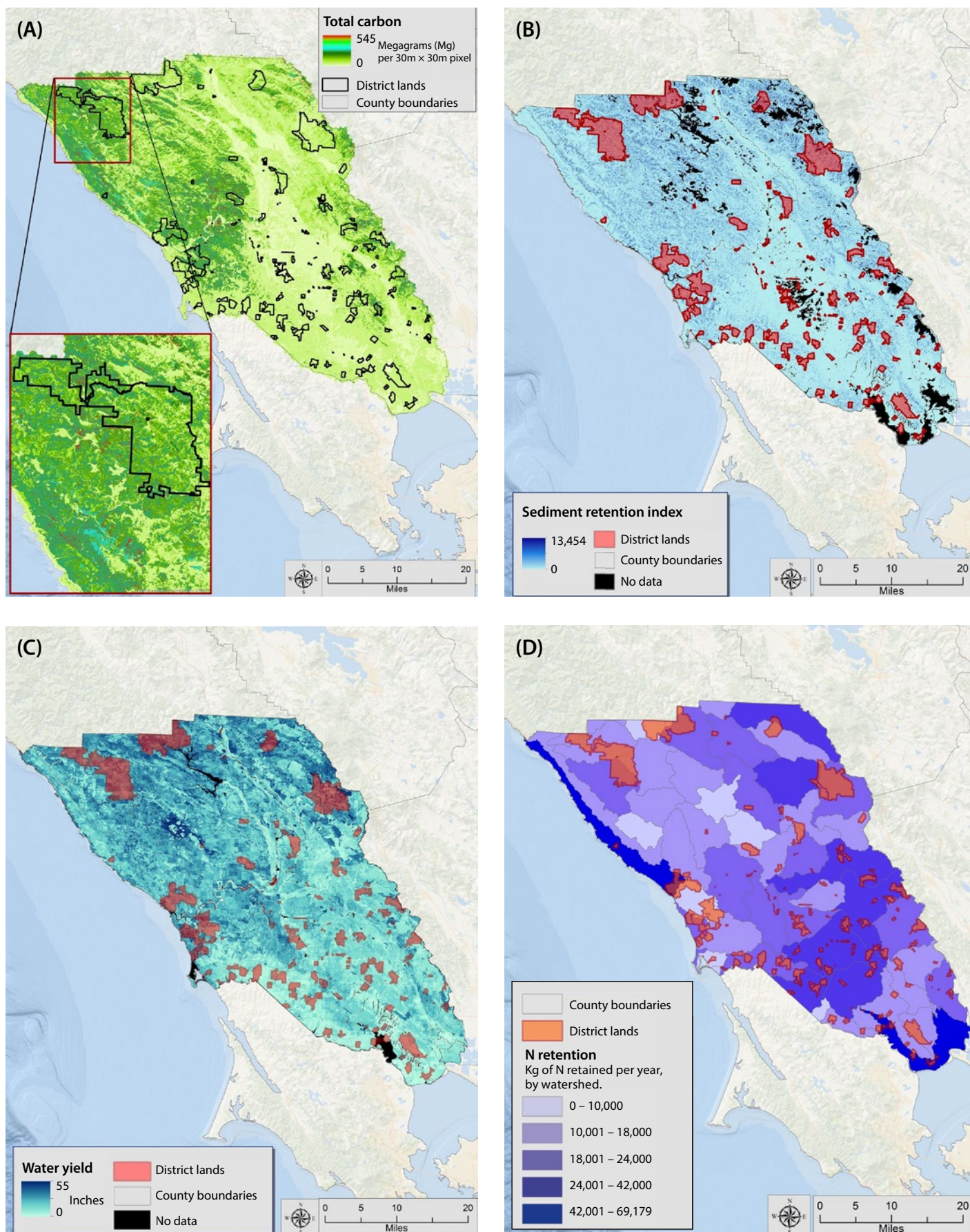


Fig. 2. Map of (A) total carbon storage, (B) sediment retention index, (C) water yield and (D) nitrogen retention.



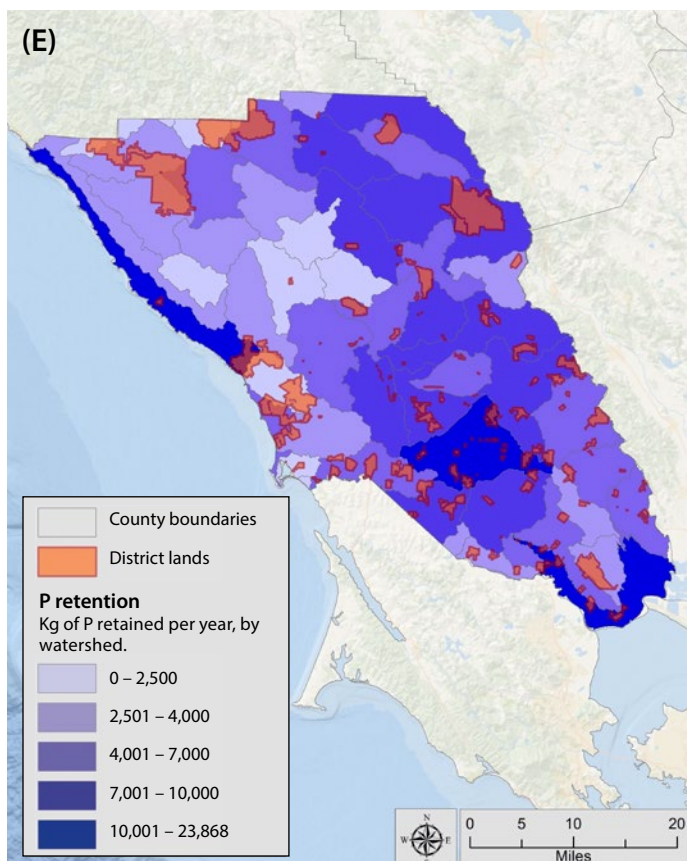


Fig. 2. Map of (E) phosphorus retention.

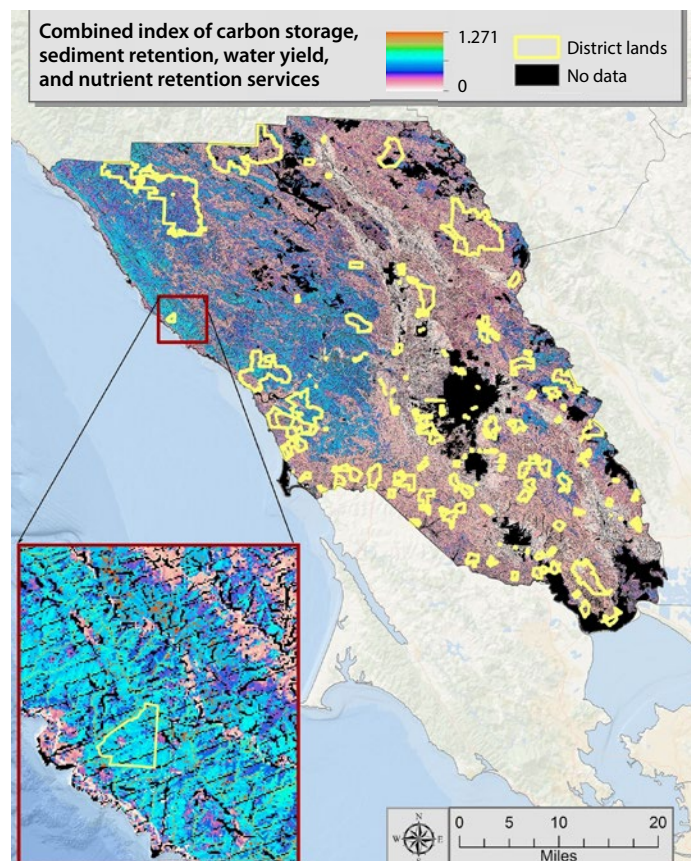


Fig. 3. Combined index of the ecosystem service values shown in Fig. 2 A-E.

per pixel, calculated with the current land cover, indicating the potential for soil loss from each land typology. District lands are vulnerable to soil loss; partially due to steep gradient lands, whereas converted lands have low potential for erosion; primarily because many of the conversions take place in areas that are relatively flat (table 2).

### Nutrient retention

Converted lands retained the most phosphorous, on a per-unit basis (fig. 2D). As with sediment retention, converted lands have low potential to export nitrogen and phosphorous, due to their generally flat topography (table 2). At the watershed scale, we see maximum retention in the low-lying areas around San Pablo Bay, in the southern portion of the county. Nitrogen retention follows a very similar pattern with highest retention rates near San Pablo Bay.

### Water yield

District properties had the highest per-cell water yield, followed by the county and converted lands (fig. 2C).

Interestingly, District lands had an almost 15% higher water yield than the parcels adjacent to them. Per-pixel water yield follows both a rainfall and vegetation gradient across the county (table 2). Maximum water yield occurs in steeper areas in the northern half of the county.

### Combined services index

The map of the combined ecosystem services index (fig. 3) shows that District lands tend to have relatively high values (table 2). It also shows that most parcels were not able to supply high levels of all ecosystem services. For the services analyzed, lands in the forested northwest of the county tend to have the highest combined ecosystem service values and the district has focused significant effort on purchasing these lands. The spider diagrams reveal that County and District lands rank relatively high in all ecosystem services. Converted lands rank lowest in carbon sequestration and sediment retention properties, as would be expected. The spider graphs illustrate how no one type of parcel provides the highest level each ecosystem services. This indicates that

there are trade-offs between conserving different services.

## Utility of the InVEST toolkit

Land is often conserved with the idea that conservation will protect ecosystem services, although these services are rarely quantified. Our analysis found that District lands provide higher levels of the ecosystem services studied, based on a composite index, than lands adjacent to District lands, converted lands and county lands overall. However, because we did not do a counterfactual analysis, we cannot say whether the District's land and easement purchases are responsible for these higher values. If the District purchased lands that would not have developed even in the absence of conservation, the impact of District purchases may be modest; though it is also possible that the lands would have been managed differently if they had not been purchased.

The map of ecosystem service hotspots highlights areas in the county with high composite ecosystem service values. District purchases in these areas may



result in high ecosystem service conservation. While the bulk of hotspots are in forested areas in the northern part of the county, there are high-value pockets throughout the county, indicating that the District may be able to choose from a suite of high ecosystem service parcels.

Our results are dependent on the suite of ecosystem services we selected. In our case, carbon storage and sediment retention are highest in forested areas, and therefore, our analysis values this vegetation type most highly. If other ecosystem services were selected, for example food

production or pollination services, the results might have been different. For results such as these to be useful for policy purposes, one must be sure that the ecosystem services evaluated fit the priorities of the communities in question.

From a methodological perspective, InVEST was a useful tool, capable of quantifying ecosystem services across broad scales, and making use of public datasets that are freely available for most or all of the state.

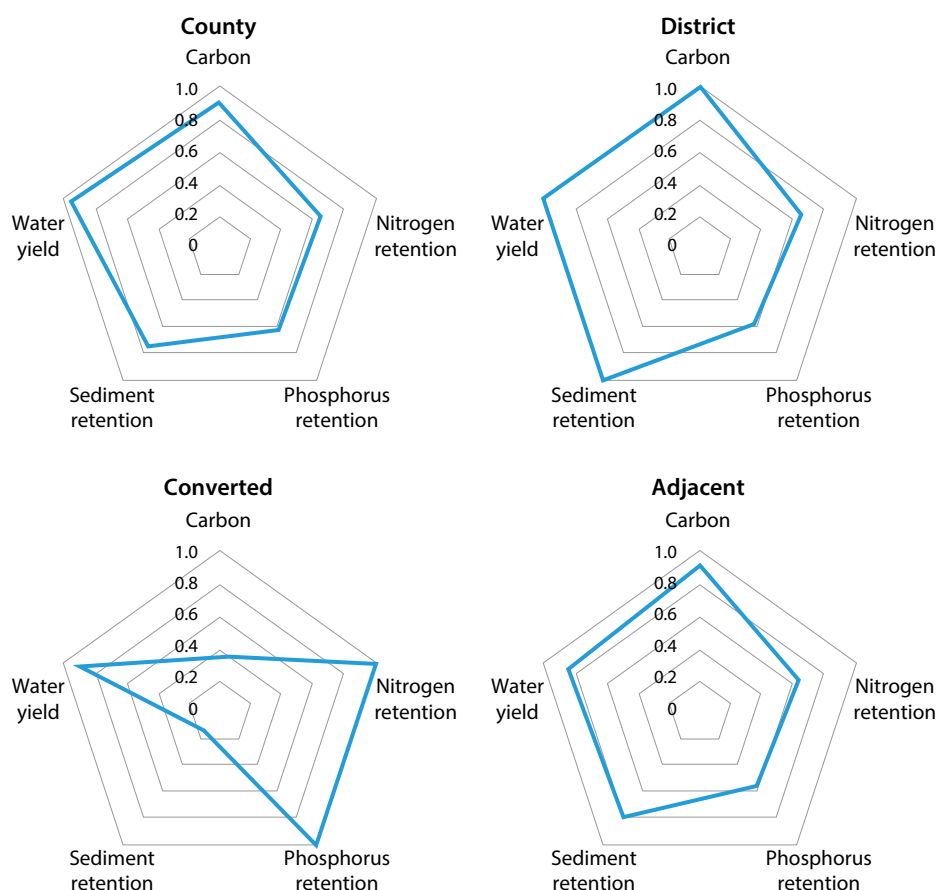
There was no way to directly validate our results. Other ecosystem service quantification efforts in Sonoma County that we are aware of, such as the aboveground carbon estimates produced by the District and The Nature Conservancy, were used as inputs in our analysis, and therefore could not be used for validation purposes. Linking external validation to InVEST estimates would be a useful extension of our research. However, this would require alternative models that also predict these services. With the possible exception of some alternative carbon sequestration models (Gonzalez et al. 2015), such models do not exist.

However, given that we are most interested in using InVEST for management actions which will rely on comparing ecosystem services within the same study area, we suspect that the relative values produced by InVEST will be useful to managers. Although the actual ecosystem service values may suffer from some inaccuracy, we suspect that the relative values of parcels within our study area may be similar. In this way, even if ecosystem services estimates are not completely accurate, they still may be useful for comparing competing sites in our study area.

An obvious extension of this work would be calculating the economic value of the ecosystem services. This could be accomplished by a host of methods, including benefits transfer, hedonic models or contingent valuation. In addition, quantifying the impacts of District land and easement purchases on ecosystem services would be interesting. We know of some landowners who have used District payments to purchase more land for agricultural use, thus providing a potential double benefit of district purchases. Quantifying how common this type of action is would give a more complete view

TABLE 2. Summary of model results

Total carbon (metric tons per 30-m x 30-m pixel)				
	Max	Mean	Standard deviation	Total(1000 Mg)
County	545.03	45.00	45.28	205,000.39
District	545.03	49.43	43.43	21,596.48
Adjacent	545.03	44.25	41.93	26,110.96
Converted	259.53	16.54	14.91	526.31
Sediment Retention Index				
	Max	Mean	Standard deviation	
County	12,389.17	13.88	50.67	
District	3,984.52	16.27	52.92	
Adjacent	5,645.87	15.10	49.53	
Converted	1,548.32	9.13	25.00	
Phosphorous retention (kg/pixel/year)				
	Max	Mean	Standard deviation	Total(kg/year)
County	1,514.10	0.05	0.76	274,544.50
District	15.61	0.05	0.15	24,525.20
Adjacent	76.75	0.05	0.21	33,110.39
Converted	21.61	0.087	0.36	3,099.44
Nitrogen retention (kg/pixel/year)				
	Max	Mean	Standard deviation	Total (kg/year)
County	4,344.08	0.18	2.24	930,811.01
District	35.29	0.18	0.44	93,081.29
Adjacent	132.52	0.18	0.57	120,887.50
Converted	58.03	0.23	1.03	8,520.08
Water yield				
	Max (inches of water on a given pixel)	Mean (inches of water on a given pixel)	Standard deviation	Total (acre-feet, across all pixels in category)
County	55.12	16.36	9.84	1,361,999
District	53.81	17.15	10.32	137,821
Adjacent	54.72	14.74	10.15	158,089
Converted	49.87	15.40	8.74	8,999
Combined index (dimensionless index with range 0-5; see fig. 3)				
	Max	Mean	Standard deviation	
County	1.27	0.11	0.09	
District	1.17	0.12	0.09	
Adjacent	1.14	0.11	0.08	
Converted	1.01	0.06	0.06	



**Fig. 4. Spider diagrams show the trade-offs among ecosystem service values across the four land categories studied.**

of the total benefits generated by District land conservation expenditures.

Protecting ecosystem services while communities grow will remain a challenge across California. Purchases of private land for public use will likely continue to be a popular nonregulatory method for constraining land use. Choosing the best sites to purchase will likely be a continued area of debate. Consistent quantification of ecosystem services can help communities make better land-use decisions. Given the difficulty of assessing ecosystem values, InVEST may prove to be a useful toolset for this purpose. [CA](#)

*V. Butsic is Assistant UC Cooperative Extension Specialist in the Department of Environmental Science, Policy and Management at UC Berkeley; M. Shapero is Academic Specialist in the Department of Environmental Science, Policy and Management at UC Berkeley; D. Moanga is a graduate student in the Department of Environmental Science, Policy and Management at UC Berkeley; and S. Larson is UC Cooperative Extension Livestock Range Management Advisor and County Director in Sonoma County. We thank Sonoma County Agricultural Preservation and Open Space District for financial and technical support.*

## References

- Bowers D, Daniels T. 1997. *Holding Our Ground: Protecting America's Farms and Farmland*. 1st ed. Island Press.
- Butsic V, Lewis DJ, Ludwig L. 2011. An econometric analysis of land development with endogenous zoning. *Land Econ* 87(3):412–32. doi:10.3368/le.87.3.412.
- California Department of Conservation. 2011. 2006–2008 California Farmland Conversion Report.
- Cameron D, Richard CD, Marty J, Holland RF. 2014. Whither the rangeland?: Protection and conversion in California's rangeland ecosystems. *PLOS ONE* 9(8):e103468. doi:10.1371/journal.pone.0103468.
- Daily GC. 1997. *Nature's Services: Societal Dependence on Natural Ecosystems*. Washington, DC: Island Press.
- Daily GC, Polasky S, Goldstein J, et al. 2009. Ecosystem services in decision making: Time to deliver. *Front Ecol Environ* 7(1):21–8. doi:10.1890/080025.
- Drake BE. 2005. Estimating increased erosion and sediment delivery caused by wildfires. Team project report. CE394K GIS in Water Resources. University of Texas.
- Eigenbrod F, Armsworth PR, Anderson BJ, et al. 2010. The impact of proxy-based methods on mapping the distribution of ecosystem services. *J Appl Ecol* 47(2):377–85. doi:10.1111/j.1365-2664.2010.01777.x.
- Ferranto S, Huntsinger L, Getz C, et al. 2011. Forest and rangeland owners value land for natural amenities and as financial investment. *Calif Agr* 65(4):184–91. doi:10.3733/ca.v065n04p184.
- Fishburn IS, Kareiva P, Gaston KJ, Armsworth PR. 2009. The growth of easements as a conservation tool. *PLOS ONE* 4(3). doi:10.1371/journal.pone.0004996.
- Gómez-Baggethun E, de Groot R, Lomas PL, Montes C. 2010. The history of ecosystem services in economic theory and practice: From early notions to markets and payment schemes. *Ecol Econ* 69(6):1209–18. doi:10.1016/j.ecolecon.2009.11.007.
- Gonzalez P, Battles JJ, Collins BM, et al. 2015. Above-ground live carbon stock changes of California wildland ecosystems, 2001–2010. *Forest Ecol Manage* 348:68–77. doi:10.1016/j.foreco.2015.03.040.
- Joppa LN, Loarie SR, Pimm SL. 2008. On the protection of "protected areas." *P Natl Acad Sci USA* 105(18):6673–8. doi:10.1016/j.foreco.2015.03.040.
- Land Trust Alliance. 2011. 2010 National Land Trusts Census.
- Naidoo R, Balmford A, Costanza R, et al. 2008. Global mapping of ecosystem services and conservation priorities. *P Natl Acad Sci USA* 105(28): 9495–9500.
- Nelson E, Mendoza G, Regetz J, et al. 2009. Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. *Front Ecol Environ* 7(1):4–11. doi:10.1890/080023.
- Pachauri RK, Meyer LA. 2014. *Climate Change 2014: Synthesis Report*. Geneva: Intergovernmental Panel on Climate Change.
- Plieninger T, Ferranto S, Huntsinger L, et al. 2012. Appreciation, use, and management of biodiversity and ecosystem services in California's working landscapes. *Environ Manage* 50(3):427–40. doi:10.1007/s00267-012-9900-z.
- Pogodzinski JM, Sass TR. 1994. The theory and estimation of endogenous zoning. *Reg Sci Urban Econ* 24(5):601–30. doi:10.1016/0166-0462(94)02059-0.
- Rissman AR, Merenlender AM. 2008. The conservation contributions of conservation easements: Analysis of the San Francisco Bay Area Protected Lands Spatial Database. *Ecol Soc* 13(1):40.
- Rockström J, Steffen W, Noone K, et al. 2009. A safe operating space for humanity. *Nature* 461(7263):472–5. doi:10.1038/461472a.
- Sharp R, Tallis HT, Ricketts T, et al. 2015. InVEST V 3.1.1 User Guide. The Natural Capital Project, Stanford University, University of Minnesota, The Nature Conservancy, and the World Wildlife Fund.
- Sundberg JO. 2006. Private provision of a public good: Land trust membership. *Land Econ* 82(3):353–66.
- Turner RK, Daily GC. 2008. The ecosystem services framework and natural capital conservation. *Environ Resour Econ* 39:25–35.
- [USDA] US Department of Agriculture. 2013. LANDFIRE. [www.landfire.gov/index.php](http://www.landfire.gov/index.php).
- USDA. 2016. Vegetation classification and mapping. [www.fs.usda.gov/detail/r5/landmanagement/resourcemanagement/?cid=stelprdb5347192](http://www.fs.usda.gov/detail/r5/landmanagement/resourcemanagement/?cid=stelprdb5347192).



# Soil nitrate testing supports nitrogen management in irrigated annual crops

by Patricia A. Lazicki and Daniel Geisseler

*Soil nitrate ( $\text{NO}_3^-$ ) tests are an integral part of nutrient management in annual crops. They help growers make field-specific nitrogen (N) fertilization decisions, use N more efficiently and, if necessary, comply with California's Irrigated Lands Regulatory Program, which requires an N management plan and an estimate of soil  $\text{NO}_3^-$  from most growers. As  $\text{NO}_3^-$  is easily leached into deeper soil layers and groundwater by rain and excess irrigation water, precipitation and irrigation schedules need to be taken into account when sampling soil and interpreting test results. We reviewed current knowledge on best practices for taking and using soil  $\text{NO}_3^-$  tests in California irrigated annual crops, including how sampling for soil  $\text{NO}_3^-$  differs from sampling for other nutrients, how tests performed at different times of the year are interpreted and some of the special challenges associated with  $\text{NO}_3^-$  testing in organic systems.*

Growers in California face increasing pressure to use nitrogen (N) fertilizers efficiently to reduce the risk of nitrate ( $\text{NO}_3^-$ ) leaching to groundwater, which makes soil  $\text{NO}_3^-$  testing an important component of N management. However, soil  $\text{NO}_3^-$  sampling and interpretation are not straightforward. The soil  $\text{NO}_3^-$  pool is subject to additions and losses throughout the year, and a soil  $\text{NO}_3^-$  test gives a snapshot only of the  $\text{NO}_3^-$  present when the sample is taken.

In most agricultural soils,  $\text{NO}_3^-$  is the major inorganic form of N. Because of this, and its mobility in soil, it is the form

primarily taken up by plants in fertilized agricultural systems, although plants also take up ammonium ( $\text{NH}_4$ ) and to a lesser degree small organic molecules (Schimel and Bennett 2004). The soil  $\text{NO}_3^-$  pool may include N left over from the previous crop, N from recent fertilizer applications, N released from organic materials such as organic matter, manure or crop residues in a process known as mineralization, and N from irrigation water (Huggins and Pan 1993).

If winter rainfall is insufficient to leach it below the rooting zone, soil  $\text{NO}_3^-$  can accumulate and  $\text{NO}_3^-$  may be high in spring. However,  $\text{NO}_3^-$  can also be quickly leached with excess irrigation or heavy rainfall (Magdoff 1991; Spellman et al. 1996). Soil  $\text{NO}_3^-$  concentrations in

spring can therefore be extremely variable. In a recent study of drip-irrigated tomato fields in the Central Valley, Lazcano et al. (2015) reported  $\text{NO}_3^-$  concentrations in the top 10 inches ranging from 20 to well above 200 pounds per acre.

Irrigated agriculture presents both challenges and opportunities for efficient N management. A major advantage of irrigated agriculture is that water volume can be controlled to a much greater extent than in rain-fed systems. Furthermore, when irrigation systems have good uniformity, N can be applied with the irrigation water at any time during the season, rather than in one large dose early in the season (as with rain-fed systems). This enables growers to avoid excessive soil  $\text{NO}_3^-$  during early crop growth when the plant demand is low and the leaching risk is greater (fig. 1). In a well-managed irrigated system, both water and N applications are fit to crop needs to maximize N use efficiency. However, because excess irrigation can result in considerable  $\text{NO}_3^-$  leaching losses, irrigation management needs to be taken into account when obtaining samples and interpreting soil  $\text{NO}_3^-$  test results.

We reviewed methods for obtaining and interpreting soil  $\text{NO}_3^-$  samples that are appropriate for irrigated annual cropping systems in California. Similar principles apply to perennial crops, but we focused on annual crops as tissue

Online: <https://doi.org/10.3733/ca.2016a0027>

Published online December 15, 2016



Preplant soil samples should be taken in spring, as closely as possible to a planned fertilizer application and after any pre-irrigation.



analysis, not soil analysis, is the common N management tool for perennial crops.

## Soil sampling

Soil samples for  $\text{NO}_3^-$  analysis must be representative of the field or block from which they are taken. A test result from a nonrepresentative sample has little value. In a paper recently published in this journal, Geisseler and Miyao (2016) discussed strategies to obtain representative soil samples for phosphorus (P) and potassium (K). These sampling principles also apply to  $\text{NO}_3^-$  testing. However, there are several aspects growers and crop advisers need to be aware of when taking soil  $\text{NO}_3^-$  samples from irrigated fields:

- The  $\text{NO}_3^-$  concentration in the soil profile is affected by many factors related to weather and crop management. Results from the same field can differ considerably from one year to the next. For this reason, soil  $\text{NO}_3^-$  samples need to be taken every year.
- A heavy rainfall or irrigation right after soil samples are taken can reduce the  $\text{NO}_3^-$  present in the sampled layer considerably, making the test meaningless. Therefore, soil  $\text{NO}_3^-$  samples need to be taken as close as possible to planned fertilizer applications.
- Due to the mobility of  $\text{NO}_3^-$ , an accurate measure of its  $\text{NO}_3^-$  availability requires a sample of the main rooting zone. For vegetables, this is normally the top foot; for field crops, samples should be taken to at least 2 feet.

- The samples need to be kept cool and sent to the analytical lab quickly. If this is not possible, they should be quickly air-dried. This is important because N mineralization from organic sources continues in moist and warm samples, resulting in an overestimation of the  $\text{NO}_3^-$  present in the soil profile.

## Soil nitrate quick tests

Soil samples are normally analyzed by commercial labs. However, for routine field monitoring like that described in this paper, an on-farm quick test for  $\text{NO}_3^-$  has been developed, using inexpensive test strips. This quick test is especially useful for in-season testing, when the lag time between taking the sample and getting a result back from the lab is too long. Several studies with vegetables in California have demonstrated that quick tests are well correlated with lab analyses across the usual range of  $\text{NO}_3^-$  concentrations encountered (Breschini and Hartz 2002; Hartz et al. 1994; Hartz et al. 2000). They are accurate enough to be used to reliably identify fields that do not need sidedress N (Breschini and Hartz 2002). However, they are not as accurate as lab analyses, and it is recommended that growers periodically send in soil samples to a lab as well (Hartz et al. 1994).

## Preplant nitrate test (PPNT)

A preplant nitrate test (PPNT) is used to adjust the N application rate to site-specific conditions when a large proportion of the seasonal N requirements must be

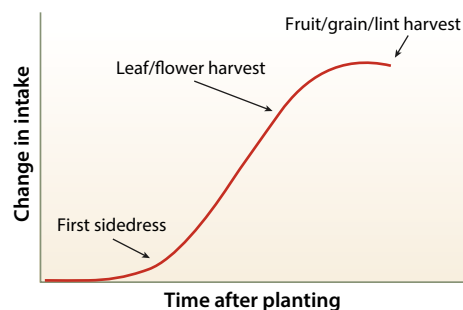


Fig. 1. Generalized pattern of N uptake in annual crops.

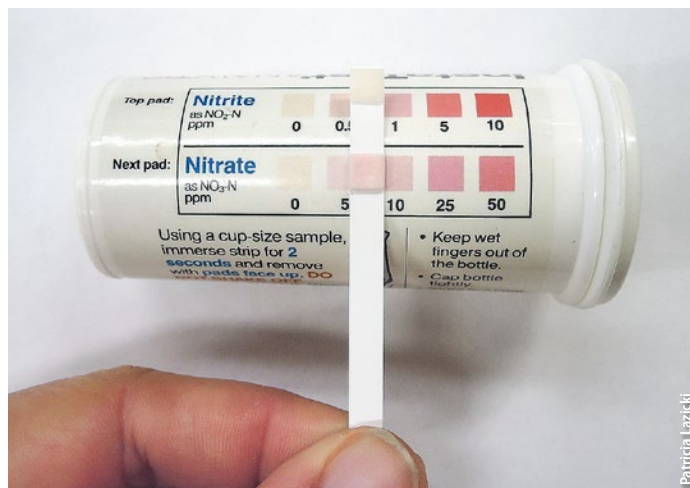
applied preplant. The soil sample is generally taken from the major rooting depth of the following crop. Since soil  $\text{NO}_3^-$  is directly available to plants and behaves like fertilizer  $\text{NO}_3^-$  (Vanotti and Bundy 1994), the fertilizer N application rate may be adjusted according to the  $\text{NO}_3^-$  present in the soil.

For most crops, a preplant nitrate-N ( $\text{NO}_3^-$ -N) concentration of 15 to 20 parts per million (ppm) indicates that sufficient soil N is present to meet N demand during the early growth stages (table 1). In mineral soils, ppm  $\text{NO}_3^-$ -N is generally converted to pounds per acre per foot of soil using conversion factors of 3 to 4, such that a concentration of 20 ppm corresponds to 60 to 80 pounds N per acre per foot of soil (54 to 71 kilograms per hectare in the top 30 centimeters). In soils with high organic matter concentration, lower factors should be used due to the lower bulk density.

In many crops, a small starter fertilizer application may still be beneficial for early crop development, even when soil



If the samples cannot be kept cool and sent to the lab immediately, they should be quickly air-dried in a thin layer.



Soil  $\text{NO}_3^-$  quick tests are an alternative to lab analyses when the results are needed quickly. However, they are not as accurate.





**Early season  $\text{NO}_3^-$  sampling provides a measure of crop-available soil N just prior to the period of maximum uptake, helping to guide fertilization.**

$\text{NO}_3^-$  exceeds the 20 ppm threshold (Stone 2000). While starter fertilizer is applied in a concentrated band near the roots of the seedlings, soil  $\text{NO}_3^-$  is more evenly distributed across the surface of the field. As roots of seedlings explore a limited soil volume early in the season, only a proportion of the soil  $\text{NO}_3^-$  is available at early growth stages. In addition, starter fertilizer generally contains N in the form of  $\text{NH}_4$ , which has been found to improve P uptake (Grunes 1959).

Adjusting fertilizer N recommendations based on preplant soil  $\text{NO}_3^-$  concentrations is a widespread practice in Europe and North America (Olfs et al. 2005). However, the usefulness of the PPNT in irrigated agriculture highly depends on irrigation type and management (Bilbao et al. 2004; Cela et al. 2013), as it may be several weeks before  $\text{NO}_3^-$  present in the soil at planting is taken up by growing plants (fig. 1; table 1). During this time, when plant water and N uptake are negligible and soils may be irrigated

TABLE 1. Example N uptake* during early growth of selected California crops			
Crop	Stage	N uptake (lb N/acre)	Reference
Barley	Sowing to tillering	15	Delogu et al. 1998
Wheat	Sowing to tillering	19–26	McGuire et al. 1998
Corn (grain)	Sowing to five leaves (V5)	3–7	Karlen et al. 1987
Corn (silage)	Sowing to six leaves (V6)	8–52	Geisseler et al. 2012
Cotton	Sowing to early square	10–46	Frittschi et al. 2003, 2004
Broccoli (summer)	First 20 days after sowing	35	Smith et al. 2015
Broccoli (winter)	First 70 days after sowing	30	Smith et al. 2015
Cauliflower	First month after transplanting	20–23	Rincón Sánchez et al. 2001
Celery	First month after transplanting	18	Feigin et al. 1982
Lettuce	First month after sowing	6–10	Bottoms et al. 2012
Onion	86 days after sowing	7–14	Biscaro et al. 2014
Potato	Sowing to tuber initiation	23–82	Lauer 1985; Lorenz 1947
Strawberry	Transplanting to April 1	10–32	Bottoms et al. 2013
Tomato	First month after transplanting	20–30	Hartz and Bottoms 2009

\* Numbers represent N accumulation in the aboveground biomass only, for all crops except potato and onion, where tuber and bulb N, respectively, are also included.

frequently to ensure crop germination and establishment,  $\text{NO}_3^-$  is at risk of being leached below the root zone. Test results may overestimate plant-available  $\text{NO}_3^-$ -N if rainfall or irrigation water leaches  $\text{NO}_3^-$ -N to deeper soil layers after the samples have been taken. If fields are pre-irrigated, preplant soil samples should be taken after the irrigation (Wyland et al. 1996).

## In-season soil nitrate tests

When most N can be applied during the growing season, it is preferable to apply a small amount of N as a starter and then take a  $\text{NO}_3^-$  test just prior to the sidedress application to determine the need for N fertilizer. Nitrogen uptake is generally highest during the second half of the vegetative growth phase (fig. 1). By taking the  $\text{NO}_3^-$  test just prior to when N uptake is high and when the root system is already well developed, the risk of  $\text{NO}_3^-$  leaching after the samples have been taken is greatly reduced. Due to the later date, N mineralized between planting and sidedressing is also included in the sample, making it a more accurate measure of crop-available soil N than a preplant test.

In systems where more than one sidedress application is not practical, the test value can be used to adjust the sidedress

N application rate, as described for the PPNT.

When N is applied several times during the growing season, as in conventionally fertilized vegetable systems, in-season soil  $\text{NO}_3^-$  values can be combined with estimates of N uptake during periods of maximum growth (table 2) to determine whether a fertilizer application can be skipped or postponed without affecting yield, and to calculate an application rate based on a target soil  $\text{NO}_3^-$ -N concentration. These calculations are demonstrated in figure 2.

Over the last two decades, much research has gone into developing robust thresholds above which sidedress N is not needed and an application can be delayed for California vegetable crops. Breschini and Hartz (2002) established experimental plots in 15 commercial lettuce fields on the Central Coast, using 20 ppm  $\text{NO}_3^-$ -N as a critical threshold. If  $\text{NO}_3^-$ -N in the top foot of these plots was greater than 20 ppm, no fertilizer was applied. If it was less than 20 ppm, enough fertilizer was applied to increase it to approximately 20 ppm (fig. 2). This threshold was chosen based on estimated maximum crop uptake rates.

On average, adjusting fertilizer rates based on in-season  $\text{NO}_3^-$  tests reduced total N application rates by 43% and

reduced postharvest residual N without reducing lettuce yields or quality. Most of the savings came from the first in-season application. Based on this and related trials, the threshold of 20 ppm is commonly used for cool-season vegetables in the Central Coast region (Hartz et al. 2000). Critical thresholds are crop-specific and depend on the maximum N uptake rate and the root system's efficiency. They may not be valid beyond the crop and region for which they were calibrated.

A crop's N uptake rate and the efficiency with which it uses soil and fertilizer N depend heavily on weather, as well as irrigation methods and timing. N demand may be low if crop growth is slowed by factors like cool weather or insufficient irrigation, and even if taken just before the period of maximum uptake, soil  $\text{NO}_3^-$  tests may overestimate available N if it is later leached with excess irrigation water. Thus, N application, weather and irrigation cannot be considered independently. UC Cooperative Extension specialists have developed a web-based decision support tool, called CropManage, which allows growers to calculate optimum fertilizer and irrigation rates based on soil  $\text{NO}_3^-$  (determined through soil testing) and predicted crop N uptake and water requirements (Cahn et al. 2015). So far, CropManage has been adapted for use in iceberg and romaine lettuce, spinach, celery, broccoli, cauliflower, cabbage and strawberry, and it is being expanded to other crops. CropManage is free and accessible online at [cropmanage.ucanr.edu](http://cropmanage.ucanr.edu).

### Pre-sidedress $\text{NO}_3^-$ test (PSNT)

A different threshold approach, the pre-sidedress  $\text{NO}_3^-$  test (PSNT), was developed for corn and other rain-fed annual crops in the humid regions of the northeastern and midwestern United States. Samples are taken from the major rooting zone just before the time of accelerated crop uptake. Like the approach described above, the PSNT uses a critical threshold above which a yield response to sidedress N is unlikely. However, the PSNT threshold is based on an empirically derived relationship between spring soil  $\text{NO}_3^-$  and the total amount of N supplied by the soil over the course of the growing season (Magdoff et al. 1984). If

TABLE 2. Example daily N uptake rates during periods of maximum uptake for selected California crops

Crop*	Stage	N uptake (lb N/acre/day)	Yield	Cropping season (days)†
Barley	Tillering to heading	2–3	6,870 lb/acre	220
Wheat	Tillering to booting	2–3	5,705 lb/acre	112
Corn (grain)	Nine leaves (V9) to silking (R1)	5–7	10,700 lb/acre	153
Corn (silage)	Six leaves (V6) to tassel (VT)	3–6	30.3 ton/acre‡	120
Cotton	Early square to early bloom	2–3	1,434 lb/acre	160
Broccoli (summer)	Month after sowing to harvest	4–6	Not given	86
Broccoli (winter)	70 days after sowing to harvest	3–5	Not given	139
Cauliflower	Month after transplanting to harvest	3–6	276 cwt/acre	96
Celery (summer)§	Month after emergence to harvest	3.5–4.5	1,041 cwt/acre	77
Celery (winter)	Month after transplanting to harvest	2.5–3.0	581 cwt/acre	120
Lettuce	Month before harvest	3–5	333 cwt/acre	Various
Onion	90 days after sowing to harvest	1.5–3.0	400–500 cwt/acre	105
Potato	Tuber initiation to mid tuber bulking	2–4	400–562 cwt/acre	140
Strawberry	April to mid-September	0.9–1.0	651 cwt/acre	NA
Tomato	Early fruit set to first red fruit	3.5–5.0	63.8 ton/acre	124

\* For references, see table 1.

† Length of cropping season determined from regional averages if not mentioned in the original text.

‡ Silage corn harvested at 70% moisture.

§ Zink 1966.

### Example 1: Calculating sidedress N need using an in-season nitrate test

- Lettuce N uptake during peak growth (table 2): 5 lb N/acre/day
- Sampling depth: 1 foot
- Soil test  $\text{NO}_3^-$ -N\* in the top foot: 20 ppm
- $\text{NO}_3^-$ -N in the top foot (lb N/acre): 60–80 lb N/acre†

Days of maximum lettuce growth supplied by soil N:

$$60\text{--}80 \text{ lb N/acre} \div 5 \text{ lb N/acre/day} = 12\text{--}16 \text{ days}$$

**Conclusion:** With a soil test concentration of 20 ppm  $\text{NO}_3^-$ -N, soil N can supply lettuce needs for about 2 weeks, even at maximum uptake, so sidedress may safely be delayed.

### Example 2: Raising soil $\text{NO}_3^-$ -N concentration to 20 ppm

- Sampling depth: 1 foot
  - Soil test  $\text{NO}_3^-$ -N in the top foot: 8 ppm
- $\text{NO}_3^-$ -N in the top foot (8 ppm  $\text{NO}_3^-$ -N): 24–32 lb N/acre†
- Target  $\text{NO}_3^-$ -N in the top foot (20 ppm  $\text{NO}_3^-$ -N): 60–80 lb N/acre

Sidedress N required to raise soil  $\text{NO}_3^-$ -N concentration to 20 ppm: 36–48 lb N/acre

**Conclusion:** A sidedress application of 36–48 lb N/acre will ensure sufficient soil N for maximum lettuce growth for about 2 weeks.

\* Some labs report nitrate concentration (ppm  $\text{NO}_3^-$ ) rather than concentration of nitrogen-as-nitrate (ppm  $\text{NO}_3^-$ -N). To convert  $\text{NO}_3^-$  to  $\text{NO}_3^-$ -N, multiply by 0.22.

† The conversion factor of ppm  $\text{NO}_3^-$ -N to lb N/acre is based on soil bulk density, and is normally between 3 and 4 for mineral soils. A value of 3.6 is often used for agricultural soils (Pettygrove et al. 2003). A lower factor is appropriate for soils that have been recently tilled or high organic matter soils.

Fig. 2. Sidedress calculations using an in-season soil nitrate test.



soil  $\text{NO}_3^-$  is predominantly derived from the mineralization of organic N, then the spring  $\text{NO}_3^-$  has a consistent relationship to the amount of N mineralized during the season under normal spring and summer weather conditions. In the Northeast and Midwest, threshold values for corn range between 20 and 30 ppm  $\text{NO}_3^-$ -N (Blackmer et al. 1989; Heckman et al. 1996; Magdoff et al. 1990). Thresholds have been established for different climatic conditions and a variety of crops, including corn, potatoes, wheat and cabbage (Bélangier et al. 2001; Cui et al. 2008; Heckman et al. 2002; Liu et al. 2003; Magdoff et al. 1990).

However, in areas with low winter precipitation, as in large parts of California,  $\text{NO}_3^-$  is often not leached from the root zone with winter rains, and soil  $\text{NO}_3^-$  present in spring may therefore either be carryover  $\text{NO}_3^-$  from the previous crop or soil N mineralized in early spring (Zebarth et al. 2009). Under these conditions, spring  $\text{NO}_3^-$ -N cannot be used to predict N mineralization during the growing season, resulting in a weak relationship between the test results and total N available for crop uptake (Cela et al. 2013; Ferrer et al. 2003; Spellman et al. 1996; Villar et al. 2000).

When winter rainfall is low, PSNT thresholds proposed in the research literature for irrigated corn have been inconsistent, ranging from 13 to 50 ppm in different studies (Cela et al. 2013; Ferrer et al. 2003; Spellman et al. 1996; Villar et al. 2000). These inconsistencies are likely due to high  $\text{NO}_3^-$  concentrations in the soil profile below the top foot (Spellman et al. 1996), leaching losses with irrigation water (Magdoff 1991) or low N mineralization potentials of the soils. This variability suggests that in areas with erratic and low winter rainfall, a PSNT threshold value is unlikely to reliably predict whether a sidedress application is needed by irrigated crops that are sidedressed only toward the beginning of a long season. In summary, PSNT thresholds developed for field crops in humid regions, which assume a consistent relationship between  $\text{NO}_3^-$ -N present in spring and mineralization over the course of the season, are not likely to be valid for irrigated California crops. In contrast, as discussed above, an  $\text{NO}_3^-$  test taken just before rapid crop uptake is a valid tool which allows growers to adjust fertilizer

rates for the N that is available at the time of sampling.

### Organic systems

Organic systems predominantly rely on N mineralized from organic sources. In traditional organic systems, N fertility comes from soil organic matter and organic amendments incorporated before planting, with no in-season fertilization. In these systems, in-season soil  $\text{NO}_3^-$  tests are useful only for monitoring soil N availability. However, some high-N organic fertilizer products are available that release most of their N within a few weeks, and these can be used in organic systems as sidedress materials (Bustamante and Hartz 2015; Hartz and Johnstone 2006). When these materials are used, a soil  $\text{NO}_3^-$  test prior to sidedressing may be able to guide application decisions.

A recent study that investigated the use of high-N products on 37 commercial organic processing tomato fields in the Sacramento Valley observed that a soil  $\text{NO}_3^-$  test at 3 weeks after transplanting correctly predicted if a field would become N-deficient 60% to 80% of the time (Bustamante and Hartz 2015). In this study, tomatoes on fields with a  $\text{NO}_3^-$ -N concentration of greater than 10 to 15 ppm usually did not develop late-season deficiencies. Fields responded to feather meal sidedressed up to 5 weeks after transplanting. Prediction inaccuracy was attributed to differences in irrigation management and reduced efficiency in some fields due to weed competition. These results suggest that a threshold approach similar to that used with conventionally fertilized vegetables may be applicable to organically fertilized crops in California. However, thresholds would not necessarily be similar to those used for conventional crops and would need to be extensively calibrated for each crop and for different soil types.

### In-season tissue N testing

Soil  $\text{NO}_3^-$  tests can be complemented with in-season plant tissue N analyses or measurements of leaf greenness to assess the N status of crops. However, while a soil test can show whether N is present in excess of crop demand, tissue analyses are usually only reliable for identifying N deficiencies. Tissue N thresholds tend to be better indexes of plant N status in field

and permanent crops than in vegetable crops (Hartz et al. 2000; Westerveld et al. 2003).

## Postharvest nitrate tests

Postharvest soil  $\text{NO}_3^-$  measurements provide a means of assessing whether N was applied in excess of crop need (Tremblay and Bélec 2006). Postharvest samples should be taken in a similar pattern to preplant or in-season samples but more deeply to determine whether  $\text{NO}_3^-$  is present below the main root zone. A depth of 3 to 4 feet is often used, in increments of 1 foot.

Postharvest  $\text{NO}_3^-$  reflects the balance of N inputs and N uptake during the growing season and also any N losses due to excess irrigation (Schröder 1999). Thus, low  $\text{NO}_3^-$  concentrations may be the result of adequate N management, or of excess irrigation that leached  $\text{NO}_3^-$  below the sampled layer. For irrigated crops, good management records can help interpret low post-harvest  $\text{NO}_3^-$  test results. Relatively high concentrations of  $\text{NO}_3^-$ -N below the main rooting zone suggest that adjustments need to be made to irrigation and fertilization practices. In high-yielding lettuce fields in central California, Bottoms et al. (2012) observed that no reductions of yield or quality occurred when postharvest  $\text{NO}_3^-$ -N concentrations were as low as 10 ppm in the top foot of soil. Higher concentrations may suggest excess N application.

Nitrate that is present in the soil after the crop is harvested is susceptible to loss if any leaching events occur prior to uptake by a subsequent crop. When postharvest  $\text{NO}_3^-$  concentrations are high in the root zone, growing a nonlegume winter cover crop that takes up the residual  $\text{NO}_3^-$  can considerably reduce the risk of  $\text{NO}_3^-$  leaching with winter rains.

## Scope of use, future research

Soil nitrate tests allow some of the guesswork to be taken out of N fertilization. Samples taken prior to planting and during the season allow growers to safely adjust fertilizer rates for available soil N, while postharvest tests allow them to evaluate whether N rates and irrigation were appropriate. However, nitrate testing has some features users need to be aware of: (1) Samples need to be taken and

handled properly for meaningful results, (2) irrigation management needs to be taken into account when interpreting test results and (3) soil  $\text{NO}_3^-$  tests do not measure N that will be released from organic sources such as manures, crop residues and soil organic matter over the course of the growing season.

This limitation is important for crops where most of the N needs to be applied

early in the season and when a large proportion of the crop's N requirement is mineralized from organic material during the season. Examples are crops grown in high organic matter soils and manured or cover-cropped fields, including organic systems. Since N release depends primarily on the type of amendment, soil properties, moisture and temperature, research that incorporates these factors into a

model that can predict N release after soil sampling will make soil  $\text{NO}_3^-$  testing a more useful tool in those systems. [CA](#)

*P.A. Lazicki is Assistant Specialist in the Department of Land, Air and Water Resources at UC Davis; D. Geisseler is UC Cooperative Extension Nutrient Management Specialist in the Department of Land, Air and Water Resources at UC Davis.*

## References

- Bélanger G, Walsh JR, Richards JE, et al. 2001. Predicting nitrogen fertilizer requirements of potatoes in Atlantic Canada with soil nitrate determinations. *Can J Soil Sci* 81:535–44.
- Bilbao M, Martínez JJ, Delgado A. 2004. Evaluation of soil nitrate as a predictor of nitrogen requirement for sugar beet grown in a Mediterranean climate. *Agron J* 96:18–25.
- Biscaro A, Cahn M, Smith R, Hartz T. 2014. Nitrogen, phosphorus and potassium uptake patterns of fresh-market onion production in southern California. American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America (ASA, CSSA, and SSSA) International Annual Meeting, Nov. 2–5, 2014. Long Beach, CA.
- Blackmer AM, Pottker D, Cerrato ME, Webb JE. 1989. Correlations between soil nitrate concentrations in late spring and corn yields in Iowa. *J Prod Agric* 2:103–9.
- Bottoms TG, Hartz TK, Cahn MD, Farrara BF. 2013. Crop and soil nitrogen dynamics in annual strawberry production in California. *HortScience* 48:1034–9.
- Bottoms TG, Smith RF, Cahn MD, Hartz TK. 2012. Nitrogen requirements and N status determination of lettuce. *HortScience* 47:1768–74.
- Breschini SJ, Hartz TK. 2002. Presidedress soil nitrate testing reduces nitrogen fertilizer use and nitrate leaching hazard in lettuce production. *HortScience* 37(7):1061–4.
- Bustamante SC, Hartz TK. 2015. Nitrogen management in organic processing tomato production: Nitrogen sufficiency prediction through early-season soil and plant monitoring. *HortScience* 50(7):1055–63.
- Cahn M, Hartz T, Smith R, et al. 2015. CropManage: An online decision support tool for irrigation and nutrient management. In: *Proc Western Nutrient Manage Conf*, Mar. 5–6, 2015. Reno, NV. Vol 11, p 9–14.
- Cela S, Berenguer P, Ballesta A, et al. 2013. Prediction of relative corn yield with soil-nitrate tests under irrigated Mediterranean conditions. *Agron J* 105:1101–6.
- Cui Z, Zhang F, Chen X, et al. 2008. On-farm evaluation of an in-season nitrogen management strategy based on soil N-min test. *Field Crop Res* 105:48–55.
- Delogu G, Cattivelli L, Pecchioni N, et al. 1998. Uptake and agronomic efficiency in winter barley and winter wheat. *Eur J Agron* 9:11–20.
- Feigin A, Letey J, Jarrell WM. 1982. Celery response to type, amount, and method of N-fertilizer application under drip irrigation. *Agron J* 74:971–7.
- Ferrer F, Villar JM, Stockle CO, et al. 2003. Use of a pre-sidedress soil nitrate test (PSNT) to determine nitrogen fertilizer requirements for irrigated corn. *Agronomie* 23:561–70.
- Frittschi FB, Roberts BA, Rains DW, et al. 2003. Response of irrigated Acala and Pima cotton to nitrogen fertilization: Growth, dry matter partitioning, and yield. *Agron J* 95:133–46.
- Frittschi FB, Roberts BA, Rains DW, et al. 2004. Fate of nitrogen-15 applied to irrigated Acala and Pima cotton. *Agron J* 96:646–55.
- Geisseler D, Lazicki PA, Pettygrove GS, et al. 2012. Nitrogen dynamics in irrigated forage systems fertilized with liquid dairy manure. *Agron J* 104:897–907.
- Geisseler D, Miyao G. 2016. Soil testing for P and K has value in nutrient management for annual crops. *Calif Agr* 70(3):152–9.
- Grunes DL. 1959. Effect of nitrogen on the availability of soil and fertilizer phosphorus to plants. *Adv Agron* 11:369–96.
- Hartz TK, Bendixen WE, Wierdsma L. 2000. The value of presidedress soil nitrate testing as a nitrogen management tool in irrigated vegetable production. *HortScience* 35(4):652–6.
- Hartz TK, Bottoms TG. 2009. Nitrogen requirements of drip-irrigated processing tomatoes. *HortScience* 44:1988–93.
- Hartz TK, Johnstone PR. 2006. Nitrogen availability from high-nitrogen-containing organic fertilizers. *HortTechnology* 16(1):39–42.
- Hartz TK, Smith RF, Schulbach KF, LeStrange M. 1994. On-farm nitrogen tests improve fertilizer efficiency, protect groundwater. *Calif Agr* 48(4):29–32.
- Heckman JR, Govindasamy R, Prostak DJ, et al. 1996. Corn response to sidedress nitrogen in relation to soil nitrate concentration. *Commun Soil Sci Plant Anal* 27:575–83.
- Heckman JR, Morris T, Sims JT, et al. 2002. Pre-sidedress soil nitrate test is effective for fall cabbage. *HortScience* 37(1):113–7.
- Huggins DR, Pan WL. 1993. Nitrogen efficiency component analysis: An evaluation of cropping system differences in productivity. *Agron J* 85:898–905.
- Karlen DL, Sadler EJ, Camp CR. 1987. Dry matter, nitrogen, phosphorus, and potassium accumulation rates by corn on Norfolk Loamy Sand. *Agron J* 79:649–56.
- Lauer DA. 1985. Nitrogen uptake patterns of potatoes with high-frequency sprinkler-applied N fertilizer. *Agron J* 77:193–7.
- Lazcano C, Wade J, Horwath WR, et al. 2015. Soil sampling protocol reliably estimates preplant  $\text{NO}_3^-$  in SDI tomatoes. *Calif Agr* 69:222–9.
- Liu X, Ju X, Zhang F, Chen X. 2003. Nitrogen recommendation for winter wheat using N-min test and rapid plant tests in North China Plain. *Commun Soil Sci Plant Anal* 34:2539–51.
- Lorenz OA. 1947. Studies on potato nutrition III: Chemical composition and uptake of nutrients by Kern County potatoes. *Amer Potato J* 24:281–93.
- Magdoff FR. 1991. Understanding the Magdoff presidedress nitrate test for corn. *J Prod Agric* 4:297–305.
- Magdoff FR, Jokela WE, Fox RH, Griffin GF. 1990. A soil test for N availability in the northeastern United States. *Commun Soil Sci Plant Anal* 21:1103–15.
- Magdoff FR, Ross D, Amadon J. 1984. A soil test for nitrogen availability to corn. *Soil Sci Soc Am J* 48:1301–4.
- McGuire AM, Bryant DC, Denison RF. 1998. Wheat yields, nitrogen uptake, and soil moisture following winter legume cover crop vs. fallow. *Agron J* 90:404–10.
- Olfs HW, Blankenau K, Brentrup F, et al. 2005. Soil- and plant-based nitrogen-fertilizer recommendations in arable farming. *J Plant Nutr Soil Sci* 168:414–31.
- Pettygrove S, Hartz TK, Hanson B, et al. 2003. Nutrient Management in Cool-Season Vegetables. UC ANR Pub 8098. Oakland, CA.
- Rincón Sánchez L, Pellicer Botía C, Sáez Sironi J, et al. 2001. Crecimiento vegetativo y absorción de nutrientes de la coliflor. *Invest Agr Prod Prot Veg* 1:19–29.
- Schimel J, Bennett J. 2004. Nitrogen mineralization: Challenges of a changing paradigm. *Ecology* 85:591–602.
- Schröder JJ. 1999. Effect of split applications of cattle slurry and mineral fertilizer-N on the yield of silage maize in a slurry-based cropping system. *Nutr Cycl Agroecosys* 53:209–18.
- Smith R, Cahn M, Hartz TK. 2015. Survey of Nitrogen Uptake and Applied Irrigation Water in Broccoli, Cauliflower and Cabbage Production in the Salinas Valley. Fertilizer Research and Education Program Final Report. [www.cdfa.ca.gov/is/ffldrs/frep/pdfs/completedprojects/11-0558-SA\\_Smith.pdf](http://www.cdfa.ca.gov/is/ffldrs/frep/pdfs/completedprojects/11-0558-SA_Smith.pdf).
- Spellman DE, Rongni A, Westfall DG, et al. 1996. Pre-sidedress nitrate soil testing to manage nitrogen fertility in irrigated corn in a semi-arid environment. *Commun Soil Sci Plant Anal* 27:561–74.
- Stone DA. 2000. The effects of starter fertilizers on the growth and nitrogen use efficiency of onion and lettuce. *Soil Use Manage* 16:42–8.
- Tremblay N, Bélec C. 2006. Adapting nitrogen fertilization to unpredictable seasonal conditions with the least impact on the environment. *HortTechnology* 16:408–12.
- Vanotti MB, Bundy LG. 1994. An alternative rationale for corn nitrogen fertilizer recommendations. *J Prod Agric* 7:243–9.
- Villar P, Villar JM, Ferrer F, et al. 2000. Optimización de la fertilización nitrogenada en maíz en suelos calcáreos del área regada por los canales de Urgell (Lleida). *Invest Agr Prod Prot Veg* 15:105–23.
- Westerveld SM, McKeown AW, Scott-Dupree CD, et al. 2003. How well do critical nitrogen concentrations work for cabbage, carrot and onion crops? *HortScience* 38:1122–8.
- Wyland LJ, Jackson LE, Chaney WE, et al. 1996. Winter cover crops in a vegetable cropping system: Impacts on nitrate leaching, soil water, crop yield, pests and management costs. *Agric Ecosyst Environ* 59:1–17.
- Zebarth BJ, Drury CF, Tremblay N, et al. 2009. Opportunities for improved fertilizer nitrogen management in production of arable crops in eastern Canada: A review. *Can J Soil Sci* 89:113–32.
- Zink FW. 1966. Celery growth and nutrient absorption studies. *Calif Agr* 20(7):10.



It is the policy of the University of California (UC) and the UC Division of Agriculture and Natural Resources (UC ANR) not to engage in discrimination against or harassment of any person in any of its programs or activities (Complete nondiscrimination policy statement can be found at <http://ucanr.edu/sites/anrstaff/files/187680.pdf>)

Inquiries regarding ANR's nondiscrimination policies may be directed to John Sims, Affirmative Action Compliance Officer, University of California, Agriculture and Natural Resources, 2801 Second Street, Davis, CA 95618, (530) 750-1397.

Visit *California Agriculture* online:

<http://calag.ucanr.edu>

[www.facebook.com/CaliforniaAgriculture](https://www.facebook.com/CaliforniaAgriculture)

[twitter @Cal\\_Ag](https://twitter.com/Cal_Ag)



Like us on  
Facebook!

## University of California Agriculture and Natural Resources

### *California Agriculture*

1301 S. 46th Street  
Building 478, MC 3580  
Richmond, CA 94804

[calag@ucanr.edu](mailto:calag@ucanr.edu)  
Phone: (510) 665-2163  
Fax: (510) 665-3427

## Upcoming UC and UC ANR events



### UC Davis Bee Symposium: Keeping Bees Healthy

<http://http://honey.ucdavis.edu/events/2017-bee-symposium/>

**Date:** May 7, 2017  
**Time:** 8:30 a.m. to 5:00 p.m.  
**Location:** UC Davis Conference Center  
**Contact:** Amina Harris [aharris@ucdavis.edu](mailto:aharris@ucdavis.edu) or  
Liz Luu [luu@caes.ucdavis.edu](mailto:luu@caes.ucdavis.edu)



### Barn to Yarn

<http://ucanr.edu/?calitem=272300>

**Date:** May 13, 2017  
**Time:** 9:00 a.m. to 2:00 p.m.  
**Location:** Hopland Research and Extension Center, Hopland, CA  
**Contact:** Hannah Bird (707) 744-1424 ext 105



### California State 4-H Field Day

[http://4h.ucanr.edu/4-H\\_Events/SFD/](http://4h.ucanr.edu/4-H_Events/SFD/)

**Date:** May 27, 2017  
**Time:** 8:00 a.m. to 6:00 p.m.  
**Location:** UC Davis, West Quad  
**Contact:** Alyssa Sankey [ajsankey@ucanr.edu](mailto:ajsankey@ucanr.edu) or (530) 750-1340