California Agriculture

January–March 2020 | Volume 74 Number 1

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

California Agriculture

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

Director of Publishing, Executive Editor: Jim Downing
Managing Editor: Deborah Thompson
Senior Editor: Hazel White
Senior Writer and Editor: Lucien Crowder
Art Director: Will Suckow

ASSOCIATE EDITORS

Animal, Avian, Aquaculture & Veterinary Sciences: John Angelos, Maurice Pitesky
Economics & Public Policy: Rachael Goodhue, Julie Guthman, Mark Lubell, Kurt Schwabe
Food & Nutrition: Amy Block Joy, Lorrene Ritchie
Human & Community Development: Rob Bennaton, Martin Smith
Land, Air & Water Sciences: Hoori Ajami, Khaled Bali, Yufang Jin, Sanjai Parikh
Natural Resources: Ted Grantham, William C. Stewart
Pest Management: Kent Daane, James Stapleton, Florent Trouillas
Plant Sciences and Agronomy: Daniel Geisseler, Matthew Gilbert, Stephen Kaffka, Astrid Volder

ORDERS AND SUBSCRIPTIONS

2801 Second Street, Room 181A; Davis, CA 95618-7779
Phone: (530) 750-1223; Fax: (530) 756-1079; calag@ucanr.edu

EDITORIAL

2801 Second Street, Room 184; Davis, CA 95618-7779
(530) 750-1223; calag.ucanr.edu

California Agriculture (ISSN 0008-0845, print, linking; ISSN 2160-8091, online) is published quarterly. Postmaster: Send change of address "Form 3579" to *California Agriculture* at the address above.

©2020 The Regents of the University of California

California Agriculture is a quarterly, open-access, peer-reviewed research journal. It has been published continuously since 1946 by University of California Agriculture and Natural Resources (UC ANR). There are about 10,000 print subscribers.

Mission and audience. *California Agriculture* publishes original research and news in a form accessible to an educated but non-specialist audience. In the last readership survey, 33% of subscribers worked in agriculture, 31% were university faculty or research scientists and 19% worked in government.

Electronic version of record. In July 2011, the electronic journal (calag.ucanr.edu) became the version of record. Since then, some research article are published online only. All articles published since 1946 are freely available in the online archive, calag.ucanr.edu/Archive/.

Indexing. The journal provides article metadata to major indexing services, including Thomson (Web of Science), AGRICOLA, the Directory of Open Access Journals and EBSCO (Academic Search Complete), and has high visibility on Google Scholar. All articles are posted to eScholarship, UC's open-access repository. In the 2018 Thomson JCR, the journal's impact factor was 1.44.

Authors. Most authors (75%) are among the roughly 1,000 academics affiliated with UC ANR, including UC Cooperative Extension specialists, advisors and academic coordinators; and faculty in the following UC colleges: UC Berkeley College of Natural Resources, UC Davis College of Agriculture and Environmental Sciences, UC Davis School of Veterinary Medicine, and UC Riverside College of Natural and Agricultural Sciences. Submissions are welcome from researchers based at government agencies and at other campuses and research institutes.

Article submission and review. Guidelines for authors are here: calag.ucanr.edu/submitarticles/. The journal uses a double-blind peer-review process described at calag.ucanr.edu/About/. Roughly 50% of all submissions are rejected by the editors without peer review due to a mismatch with the journal's scope or clear weaknesses in the research. Of the subset of submissions that enter the peer-review process, roughly 60% are ultimately accepted. All accepted manuscripts are edited to ensure readability for a non-specialist audience.

Letters. The editorial staff welcomes letters, comments and suggestions. Please write to us at the address below, providing your contact information.

Print subscriptions. These are free within the United States and $24 per year abroad. Go to: calag.ucanr.edu/subscribe/ or write or call.

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*, 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.

UNIVERSITY OF CALIFORNIA

UNIVERSITY OF CALIFORNIA
Agriculture and Natural Resources

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 the University's equal employment opportunity policies may be directed to: Affirmative Action Contact and Title IX Officer, University of California, Agriculture and Natural Resources, 2801 Second Street, Davis, CA 95618, (530) 750-1397. Email: titleixdiscrimination@ucanr.edu. Website: http://ucanr.edu/sites/anrstaff/Diversity/Affirmative_Action/.

FSC
www.fsc.org
MIX
Paper from responsible sources
FSC® C003287

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 for more information.

Contents

JANUARY–MARCH 2020 • VOLUME 74, NUMBER 1

News and opinion

RESEARCH NEWS

Research and review articles

COVER: View of the Russian River near Hopland, Mendocino County. A recent UC Cooperative Extension research project in the upper Russian River and Navarro River watersheds demonstrates how water use accounting can support the development of solutions for managing limited water supplies. *Photo by George Rose.*

OUTLOOK

Hasty responses to foodborne illness outbreaks impact California growers

Four major foodborne illness outbreaks in 3 years have led to stricter requirements for leafy greens growers that may satisfy corporate buyers and reassure the public, but also highlight a serious need for more food safety research.

Brooke Latack, University of California Cooperative Extension (UCCE) Livestock Advisor, Imperial, Riverside and San Bernardino counties

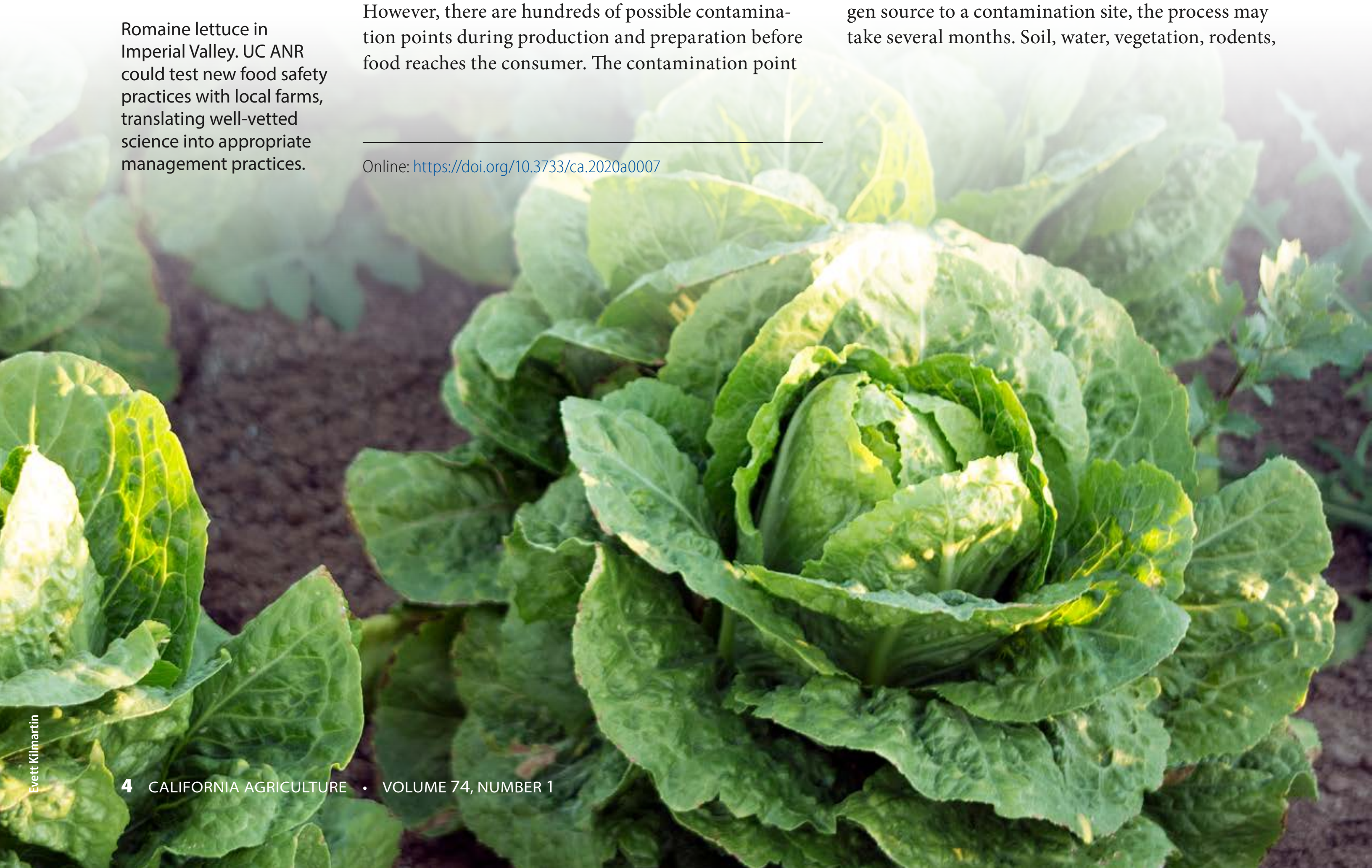
Rebecca Ozeran, UCCE Livestock and Natural Resources Advisor, Fresno and Madera counties

In the last 3 years the United States has seen four major foodborne illness outbreaks related to leafy greens, which resulted in 399 cases of foodborne illness. Altogether, 180 people were hospitalized and six people died. These outbreaks were well beyond the severity of foodborne illness we had typically seen prior to 2017. Romaine lettuce, the identified source of all four outbreaks, was recalled, thousands of consumers were told to throw out what they had in their refrigerator and a nationwide questioning of U.S. food safety has ensued.

The U.S. food system is extremely complex and livestock operations, produce growers and retail produce buyers have made significant efforts to address and mitigate food safety risks in this complex system. However, there are hundreds of possible contamination points during production and preparation before food reaches the consumer. The contamination point of fresh produce is particularly difficult to trace, since each produce handler is aware only of the previous handler and not the entire system. The agency involved in the traceback process, often the Food and Drug Administration (FDA) or Centers for Disease Control and Prevention (CDC), depending on the size and severity of the outbreak, must trace from consumer to grocery store to distributor to shipper to processor to the multiple farms the processor procures produce from. Identifying the point of contamination is therefore very difficult, and sometimes impossible. For example, investigators of the 2017 leafy green *Escherichia coli* (*E. coli*) O157:H7 outbreak were never able to identify the source of the contaminated produce.

Even if the investigating agency can trace the pathogen source to a contamination site, the process may take several months. Soil, water, vegetation, rodents,

Online: https://doi.org/10.3733/ca.2020a0007



Romaine lettuce in Imperial Valley. UC ANR could test new food safety practices with local farms, translating well-vetted science into appropriate management practices.

Evett Kilmartin

wild animals and nearby animal facilities — all potential vectors of pathogens — are then tested for the outbreak pathogen strain. However, studies have shown that pathogens present at one time may no longer be found within as little as a month, which is why the exact sources of many outbreaks remain uncertain, such as in the spring of 2018.

Spring 2018 outbreak

In spring 2018, a total of 210 people got sick and five died of hemolytic uremic syndrome, an extreme illness caused by *E. coli* O157:H7 bacteria that produce Shiga toxin (CDC 2018; FDA 2018a). The outbreak lasted several weeks and impacted people in 36 states. A major difference between this outbreak and the 2017 outbreak was the number of illness incidents — in the 2017 outbreak, only 25 people got sick, which meant that there were 185 more epidemiological points in the 2018 outbreak to help track the pathogen source to a food, distributor and farm.

Through the traceback process in 2018, FDA and CDC narrowed down the possible causes to chopped romaine lettuce by day 10 of the outbreak investigation. Because the outbreak started in spring, when the California Central Valley and coastal regions were only just beginning to harvest lettuce, the contaminated romaine lettuce was most likely grown in the desert region. The desert region includes the Imperial Valley and southwest Arizona and harvests lettuce all winter and for several weeks in spring (fig. 1).

The timing and food product associated with the outbreak can hinder or help an investigation. For example, the fall 2018 lettuce outbreak was very likely to have originated in coastal California farms, and was traced to a farm there. Conversely, during periods of the year when many geographic areas may be producing the product associated with an outbreak, much more time must be spent finding the common source of the contaminated product.

In spring 2018, investigators initially had no way to trace the contaminated chopped romaine lettuce precisely, because many farms produce romaine lettuce in the desert region and chopped and bagged romaine lettuce usually contains lettuce from a variety of farms. Also, the lettuce could have been contaminated during packaging at a processing facility rather than at any of the farms. The traceback process could have stalled, but a week after romaine was identified as the contaminated food source eight inmates in an Alaska correctional facility became ill from whole-head romaine with the same strain of *E. coli*. Because each head of lettuce can be connected to a specific distributor or processor, this information accelerated the investigation. As a result, the FDA was able to confirm that the romaine had come from the Yuma, Arizona, region.

Investigators with FDA and CDC collected environmental samples in June, July and August to test possible reservoirs of contamination. They found the outbreak strain of *E. coli* in three samples in the sediment of an irrigation canal near Yuma. In the desert region, the only source of water for crops is the Colorado River, via open irrigation canals, so it could be assumed water from that canal was used to irrigate romaine fields. If *E. coli* was in the canal at the time of the last irrigation before harvest, then the irrigation water could have been the vector that contaminated the romaine. However, *E. coli* doesn't spontaneously grow in canals. It had to come from somewhere else — specifically, humans or animals.

A tenuous link to a nearby feedlot resulted in media reports that the feedlot was to blame, although there was no evidence to implicate any particular source of the *E. coli*. FDA and CDC never detected the outbreak strain of *E. coli* on the feedlot premises. They released a final environmental assessment about this outbreak that lacked a clear cause of contamination (FDA 2018b). The feedlot may have been the source, but any cattle or manure that had carried the pathogen were long gone by the time FDA and CDC collected samples, so investigators had no way to test them.

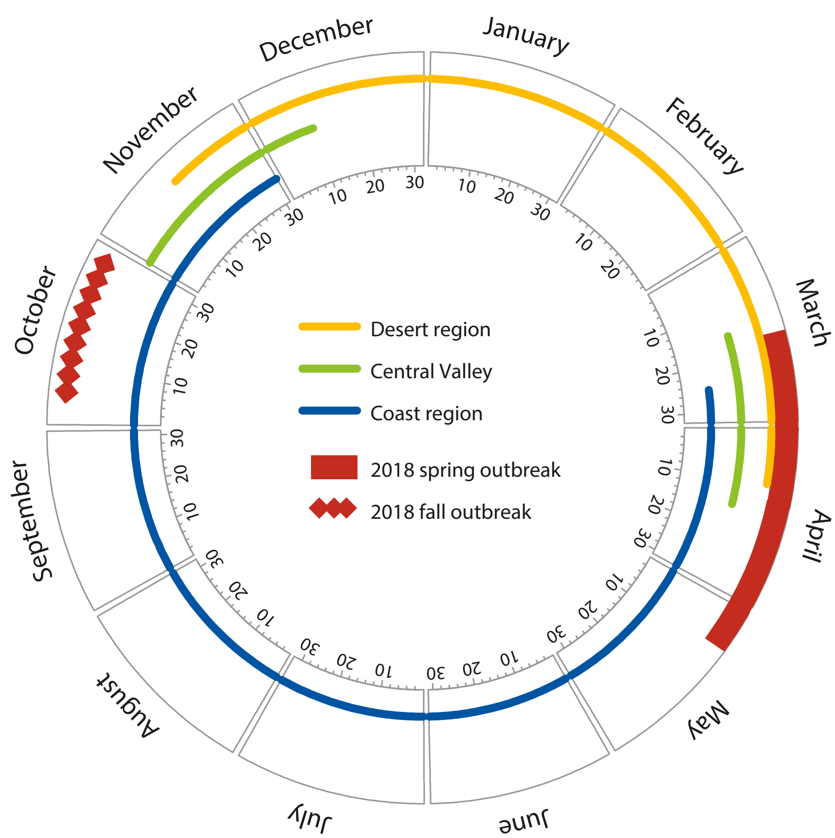


FIG. 1. Three agricultural regions produce most of the supply of U.S. leafy greens: the desert regions of southwest Arizona and southeast California, including the Imperial Valley; the Central Valley region of California; and the coast region of California. The spring 2018 outbreak of foodborne illness from romaine lettuce began while the desert harvests were well underway, which helped investigators locate the contamination point in Yuma. The fall 2018 outbreak coincided with the harvest period in the coast region.

There are many possible sources of *E. coli* in the canal in spring 2018:

- Wildlife carrying *E. coli* may have drunk, swum or walked in the canals.
- Dustborne *E. coli* may have reached the canal from cattle in the Yuma feedlot.
- People withdrawing water upstream may have contributed *E. coli* to the canal water by using improperly cleaned equipment or putting their hands into the water.
- People occasionally use the canals to wash themselves, and someone may have shed *E. coli* while bathing.
- The *E. coli* may have come from a source upstream and settled out of the water over time, living in the sediments for weeks (Jamieson et al. 2005).

Legislation, stricter industry policies

Food safety practices are not new to the U.S. food supply. Various agencies created and continue to revise regulations mandating training and management practices to reduce the risk of pathogens entering the food system. The United States codified requirements for food production and handling as long ago as 1938 (Federal Food, Drug, and Cosmetic Act), with some key updates such as the Hazard Analysis and Critical Control Point (HACCP) procedures in 1996 and the Food Safety Modernization Act (FSMA) in 2011.

What is a pathogen?

A pathogen is an organism (bacterium, virus, parasite, fungus) that causes disease. More than 250 pathogens cause foodborne illness, but eight of them are responsible for 96% of foodborne illness cases in the United States.

What is a foodborne pathogen outbreak?

When two or more people develop a foodborne illness from the same pathogen, usually in a common food source, it is considered an outbreak. In the United States, there are certain levels of illness that are expected and viewed as "normal." A sudden increase in the number of cases of a specific disease compared to what is normally expected helps agencies identify potential outbreaks.

Which agencies are involved in outbreak response?

City, county and state agencies are typically involved in foodborne pathogen outbreaks. The agencies responding depend on the number and location of the affected consumers. When foodborne illness affects consumers in multiple states, the CDC and FDA become involved in the traceback process. Since there are many agencies responsible for responding to foodborne pathogen outbreaks, databases such as PulseNet have been launched to allow multiple agencies to quickly connect illness cases in their area to existing outbreaks and use the data to more rapidly identify the source of contamination.

All farms are federally mandated to comply with a basic level of good agricultural practices (GAPs), and, in 2016, the FSMA Final Rule on Produce Safety implemented new inspection responsibilities for the FDA and new standards of practice for farms and processors. Agricultural commodity groups and buyer groups have also formalized food safety interventions as best practices.

Whether federally mandated, buyer-required, or led by agricultural commodity groups, food safety practices include activities and infrastructure to address four vectors of pathogens: humans, other animals, water and soil. Examples are hand-washing stations for on-farm employees, no harvest in areas where wildlife have entered a field, thresholds for microbe concentrations in irrigation water, and a minimum temperature regime for composted manure.

Among the most detailed and transparent industry-led food safety programs are the California and Arizona leafy greens marketing agreements (LGMAs), which include strict metrics for growers: https://lgma.org/food-safety-practices/ (California) and www.arizonaleafygreens.org/guidelines (Arizona). Leafy greens growers, processors and others in the industry created the LGMAs in 2007. LGMA-certified farms now represent about 90% of the U.S. leafy greens supply. The metrics are updated as new scientific information becomes available, as laws change or in response to major outbreaks.

The FSMA was lauded by grocery stores, consumer protection groups and others for its regulatory impact on large agricultural operations (Strauss 2011). However, many large buyers and third-party audit programs have stricter standards than FSMA. For example, growers must undergo more frequent audits under the LGMA certification requirements than under FSMA (Doering 2018).

Much less transparent and more stringent are buyer-led food safety programs. Large buyers can demand specific practices are implemented before they will purchase produce, and they control enough of the market that growers must comply or risk having no sales (Havinga 2006).

Growers have told researchers (e.g., Hardesty and Kusunose 2009; Stuart 2008) about some of the requirements they must follow, but most buyer requirements are not publicized. We discovered a 2007 version of the "On-Farm Produce Standards" required by the Food Safety Leadership Council, which then included buyers such as Disney, McDonald's, Walmart, and Darden restaurants (Olive Garden and other chains), representing significant market power. Requirements included soil analyses if a field had ever been used for anything other than growing produce; destruction of potentially contaminated crops if animals access a field; a ¼-mile buffer from animal grazing and a 1-mile buffer from any concentrated animal feeding operation (CAFO); and microbiological testing of "high risk products (leafy greens, tomatoes, green onions, herbs, berries sprouts, etc.)" (FSLC 2007).

Recent impacts on growers

After the spring 2018 Yuma outbreak, various organizations and corporate produce buyers wanted to quickly rebuild consumer trust. Despite the lack of a clear cause of the outbreak, these groups immediately and strongly responded to the possibility that the feedlot contributed to it. The California LGMA metrics now state that leafy greens cannot be grown within 1 mile of CAFOs (e.g., feedlots and dairies) with more than 80,000 animals, and no leafy greens can be grown within 1,200 feet of CAFOs with 1,000 or more animals (Ward 2018). The previous restriction was a buffer of 400 feet between leafy greens fields and CAFOs of any size.

The biggest buyers influence the entire produce-buying sector (Fister Gale 2006; Havinga 2006; Ribera et al. 2012). Other buyers may decide, in order to remain competitive and entice customers, to adopt similar or even more stringent food safety policies. Various groups have noted this potential "arms race" of food safety requirements (Palma et al. 2010), in which growers are subject to ever-tightening requirements. While large-scale leafy greens growers may be able to accommodate the new FSMA and LGMA requirements without losing significant production acreage, small lettuce growers with fields within 1,200 feet of a CAFO will struggle to stay in the leafy greens industry, because there are no guarantees for higher prices to growers adopting these practices. Produce from fields within the new buffers will be unmarketable — a potentially major loss of income simply due to location. Our conversations with growers indicate buyers may be demanding even stricter buffers than those required by LGMA, including minimum distances to grazing animals.

While there are small farm exemptions and exceptions in FSMA, small growers still have to comply with new monitoring, recordkeeping and reporting requirements as of January 2020. These requirements are difficult to understand, even to determine one's eligibility for an exemption. Altogether, compliance is more expensive for smaller farms than for large farms (Hardesty and Kusunose 2009; Karp, Baur et al. 2015). Although small growers are rarely implicated in foodborne illness outbreaks, they are subject to the regulatory consequences of a large outbreak and are confronted with barriers that may make small-scale production financially nonviable (DeLind and Howard 2008; Karp, Baur et al. 2015).

Converting to an alternative crop is not necessarily a viable option to help these growers stay afloat. Many economic and experiential barriers make crop conversion a significant challenge, such as the lack of expertise in growing alternative crops; the different equipment and labor needed; and the realities that alternate crops may not suit the local climate or soils, or the grower may be a land lessee with crop options limited by the landowner (Pollans 2017; Rodriguez et al. 2008). In addition, some buyer food safety policies have expanded buffer restrictions to crops that are not typically consumed fresh, such as grains, nuts and dried beans (Gennet et al. 2013).

Decisions made without science

Popular press coverage of the 2017 and 2018 outbreaks called for "safer" leafy greens, criticized the U.S. food safety system and outright accused feedlots for the spring 2018 outbreak. The complex traceback process frustrated everyone as it trudged forward and ended without certainty about the outbreak origin. Unfortunately, the need for quick action led to costly changes in management systems that weren't backed by scientific evidence or evaluated for their impact on agriculture. The changes increased costs for growers, increased hostility in the agriculture community and allowed the intervention of retail corporations, who are largely uninvolved in agriculture in these specific growing conditions. Impacted growers in Imperial County and the San Joaquin Valley will need to make tough decisions about staying in business, and our supply of leafy greens may look different over time — more expensive, more seasonal and more imports.

Many requirements imposed by corporate buyers are based on science that may not be appropriate for the system where they are applied. For example, to reduce the risk of pathogen contamination in leafy greens production during sprinkler irrigation, growers with type B water (i.e., untreated canal water — the most common type of agricultural water in the Imperial Valley) are now required to treat the water with approved antimicrobials, such as chlorine, within 21 days of harvest. They must also test the irrigation water for indicator bacteria monthly, and if they are irrigating within 21 days of harvest, they must test the water twice during that period. However, there are gaps in data and information regarding the efficacy of the water testing protocol (FDA 1998); and using chemicals to clean irrigation water has not been thoroughly researched to understand the potential negative impacts to the soil and productivity.

There is also little evidence, and even less of a scientific consensus, that the buffer distances will reduce the risk of pathogen movement or that the animal capacity thresholds indicate a critical level of risk. The previous setback distances were based on a study by Berry et al. (2015) in Nebraska near a 6,000-head feedlot. Although this study provided excellent data, it didn't represent the significantly larger livestock operations found in California or their arid, low-desert environment. The principle is seemingly valid — the risk of contamination should decrease as distance from a contamination source increases — but the recently implemented distances from CAFOs (see Ward 2018) are less so. Moreover, CAFOs are not the only


Jack Kelly Clark

possible source of pathogens. Increased buffer distances do nothing to protect against other contamination sources.

New corporate food safety policies that dictate stricter farming practices provide the perception of enhanced food safety. That perception, regardless of whether it is supported by data, may rebuild consumer trust and provide the corporation with an edge against competitors. But this enforcement of stricter requirements is especially troubling given that the requirements are typically not publicized, and therefore not subject to industry scrutiny, scientific rebuttal or affirmation, or any accountability on the part of the buyer to uphold their own standards (Stuart 2008). In summary, buyers have carte blanche to demand that growers shoulder the burdens of reassuring the public without regard to whether the demands are supported by science.

Without scientific analysis, new required agricultural practices in the name of food safety may backfire. For example, a decade ago many growers on the Central Coast removed noncrop vegetation, including trees and vegetative buffer strips, to comply with processor and retailer food safety requirements (Stuart 2008). However, increased bare soil correlates to increased erosion, water contamination and *E. coli* prevalence (Karp, Gennet et al. 2015), which could result in food contamination downstream — exactly

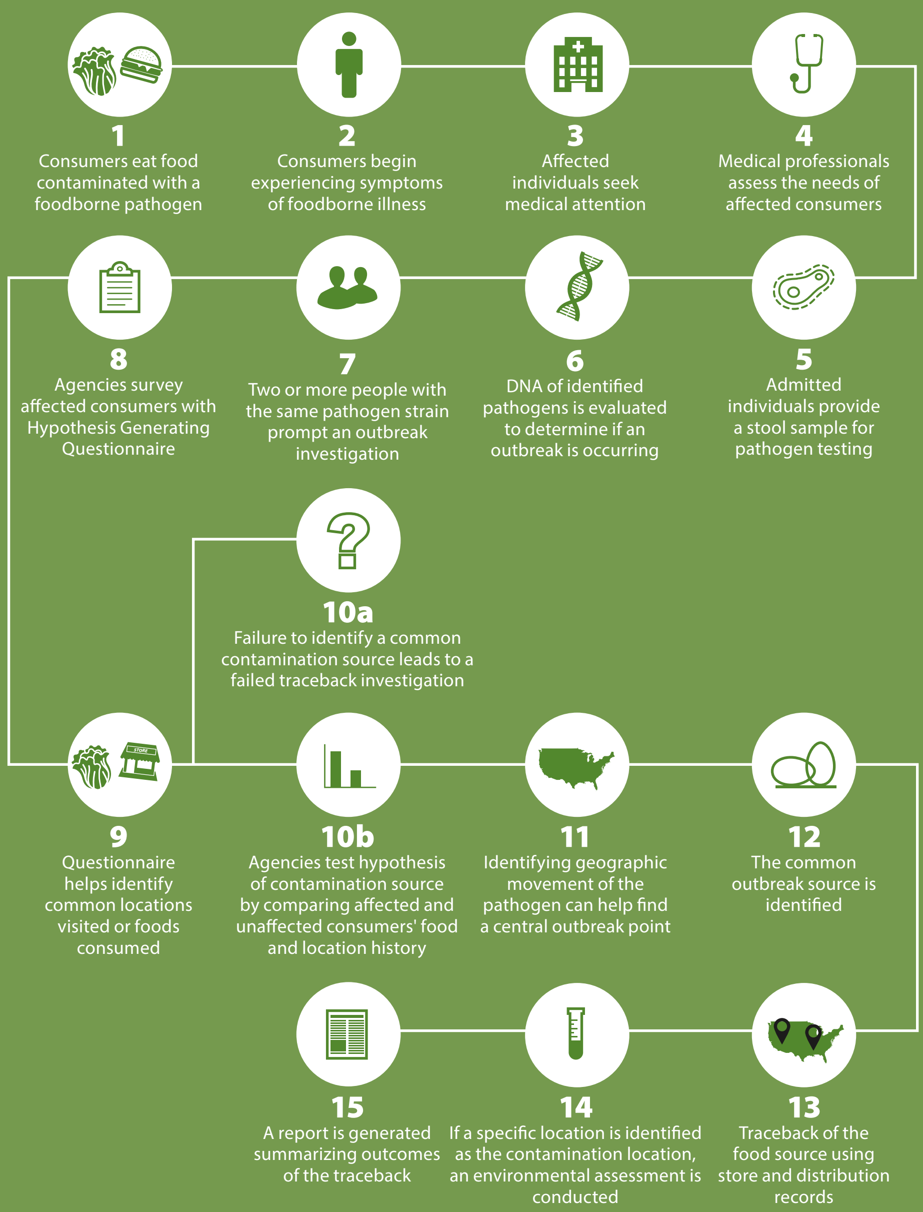


FIG. 2. Foodborne pathogen outbreak traceback process.

The traceback process

An outbreak begins with consumers eating food contaminated with a foodborne pathogen (fig. 2). In terms of traceback, what makes the process more difficult is the fact that not all people who consume the food and develop the illness seek medical attention. For serious illnesses such as those caused by *E. coli* O157:H7, people are likely to seek medical attention, but for less severe illnesses such as salmonellosis, otherwise healthy individuals may experience only mild symptoms not requiring medical attention (table 1). Low rates of reporting these illnesses decreases the data points epidemiologists can use to trace back the pathogen to a source.

Epidemiologists rely heavily on those affected by the pathogen remembering the food they have consumed within an appropriate time period. However, if a patient shows symptoms a week after food was consumed, remembering what they ate can be extremely difficult. The patient may know that they had a salad last week but may not know what leafy greens were in that salad or where they obtained the greens. Retailer receipts and loyalty cards can help, but they don't always have the information needed, such as the brand name or item description.

Food recollection also helps investigators identify foods that the affected population consumed more frequently than the average population consumed them. For example, if within an outbreak week 46% of nonaffected people had eaten lettuce and 98% of affected people ate lettuce, the large the opposite of the stated goal. This is just one reason why we want to ensure that future changes in practice are thoroughly evaluated and have a positive impact on food safety.

Risk management

Though we have seen an increase in the number of foodborne illness outbreaks over the last 30 years, the trend may not be related to unsafe production practices. Increases in leafy greens consumption and healthy eating influences have increased the quantity of uncooked foods being consumed, which increases the likelihood of foodborne illness. For example, leafy lettuce availability increased 1,856% from 1970 to 2005 (Wells and Buzby 2008).

Since our food is grown in a dynamic system and not a closed, sterile environment, no matter the lengths we go to to reduce the risk of outbreaks, we will never achieve 0% risk. We must acknowledge that a problem as complex as the risk of foodborne illness outbreaks is not ever solved, even with the best science. We may in fact reveal more questions with more science. As Powell et al. (2013) note, management decisions are judgment calls informed by science and other evaluations of risk amidst uncertainty.

However, there are clear ways to reduce the impacts of outbreaks. For example, recent widespread use of

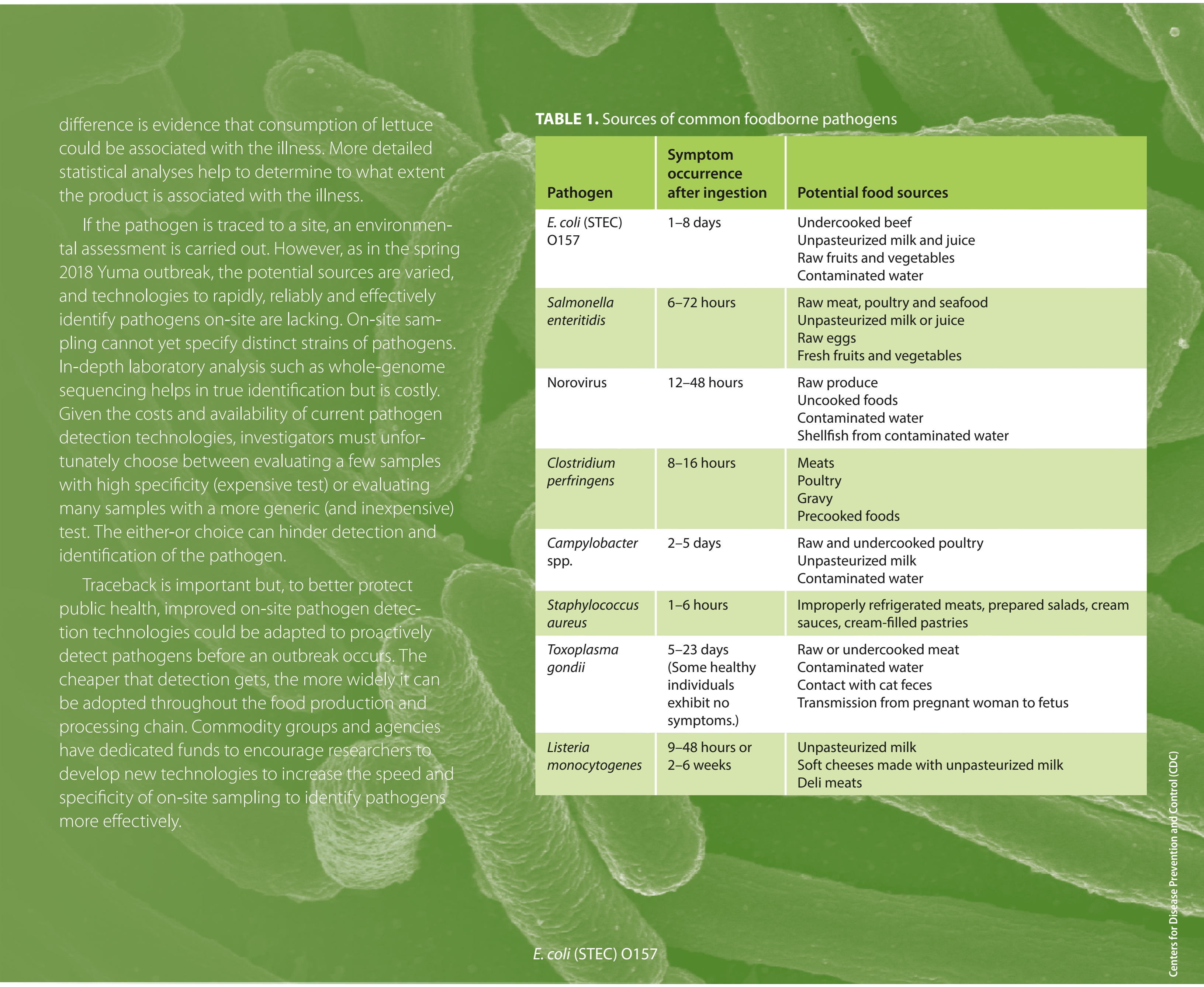
difference is evidence that consumption of lettuce could be associated with the illness. More detailed statistical analyses help to determine to what extent the product is associated with the illness.

If the pathogen is traced to a site, an environmental assessment is carried out. However, as in the spring 2018 Yuma outbreak, the potential sources are varied, and technologies to rapidly, reliably and effectively identify pathogens on-site are lacking. On-site sampling cannot yet specify distinct strains of pathogens. In-depth laboratory analysis such as whole-genome sequencing helps in true identification but is costly. Given the costs and availability of current pathogen detection technologies, investigators must unfortunately choose between evaluating a few samples with high specificity (expensive test) or evaluating many samples with a more generic (and inexpensive) test. The either-or choice can hinder detection and identification of the pathogen.

Traceback is important but, to better protect public health, improved on-site pathogen detection technologies could be adapted to proactively detect pathogens before an outbreak occurs. The cheaper that detection gets, the more widely it can be adopted throughout the food production and processing chain. Commodity groups and agencies have dedicated funds to encourage researchers to develop new technologies to increase the speed and specificity of on-site sampling to identify pathogens more effectively.

TABLE 1. Sources of common foodborne pathogens

Pathogen	Symptom occurrence after ingestion	Potential food sources
E. coli (STEC) O157	1–8 days	Undercooked beef Unpasteurized milk and juice Raw fruits and vegetables Contaminated water
Salmonella enteritidis	6–72 hours	Raw meat, poultry and seafood Unpasteurized milk or juice Raw eggs Fresh fruits and vegetables
Norovirus	12–48 hours	Raw produce Uncooked foods Contaminated water Shellfish from contaminated water
Clostridium perfringens	8–16 hours	Meats Poultry Gravy Precooked foods
Campylobacter spp.	2–5 days	Raw and undercooked poultry Unpasteurized milk Contaminated water
Staphylococcus aureus	1–6 hours	Improperly refrigerated meats, prepared salads, cream sauces, cream-filled pastries
Toxoplasma gondii	5–23 days (Some healthy individuals exhibit no symptoms.)	Raw or undercooked meat Contaminated water Contact with cat feces Transmission from pregnant woman to fetus
Listeria monocytogenes	9–48 hours or 2–6 weeks	Unpasteurized milk Soft cheeses made with unpasteurized milk Deli meats



E. coli (STEC) O157

Centers for Disease Prevention and Control (CDC) harvest location labels enabled consumers to avoid potentially contaminated romaine in the 2019 outbreak. The many potential sources of foodborne pathogens and possible early interventions could be more thoroughly studied. New technologies for food traceability and for detecting pathogens; new techniques of assessing and reducing on-farm and processing risks; and new partnerships with agencies to accelerate the traceback process could all help reduce the number of people who get sick from foodborne pathogens. A systematic risk assessment and risk model could move discussions of food safety concerns toward actual risk reduction. For example, practical models of risk assessment could indicate crop harvests that need more sampling for pathogens, additional washes during processing, or a delay in harvesting or repurposing a harvest for animal feed.

UC ANR could bridge science gap

The recent outbreaks and reactions from the public, commodity groups, produce buyers and growers have indicated gaps in research on livestock-produce interactions and traceback through the U.S. food system. UC researchers, such as those with the Western Institute for Food Safety and Security at UC Davis, study a variety of food safety topics and influence food safety practices. They have been awarded recent grants for improving sanitation technologies, identifying movement of pathogens through animal operations and studying the potential of wildlife to move pathogens into fields.

However, existing research does not adequately inform the agricultural community on how to adapt practices in the face of changing food safety pressures. This is where UC Agriculture and Natural Resources, and especially UC Cooperative Extension farm advisors, could provide a valuable service. Because of the strong relationships we establish in our communities, we can test new and adaptive food safety practices with local partners in the farming community. Especially important is extension work with small growers to minimize the impact of regulatory changes on their bottom line. With greater collaboration and information sharing among UC food safety researchers and UC Cooperative Extension academics, we could better address gaps in food safety knowledge across the state.

As advisors and specialists, we could be critical points in the reduction of food pathogen risk. We have multiple areas of expertise to help define the direction of food safety research and translate the best available scientific information into management practices that are not only effective in reducing the risk of foodborne illness for consumers but also feasible for growers to implement. We need changes that reduce the risk of pathogen movement in our food system and not changes that simply address perceptions of safety. While the leafy greens industry and retailers must respond quickly with the best available information, it is our responsibility as researchers to provide them with well-vetted, relevant science to ensure that changes they do make don't have unforeseen consequences. CA

References

Berry EE, Wells JE, Bono JL, et al. 2015. Effect of proximity to a cattle feedlot on *Escherichia coli* O157:H7 contamination of leafy greens and evaluation of the potential for airborne transmission. Appl Environ Microb 81(3):1101–10.

[CDC] Centers for Disease Control. 2018. Multistate Outbreak of E. coli O157:H7 Infections Linked to Romaine Lettuce (Final Update). www.cdc.gov/ecoli/2018/o157h7-04-18/index.html (accessed Dec. 3, 2018).

DeLind LB, Howard PH. 2008. Safe at any scale? Food scares, food regulation, and scaled alternatives. Agric Human Values 25(3):301–17.

Doering C. 2018. It's not easy being green: Romaine lettuce E. coli outbreak rattles food, grocery industries. Food Dive. www.fooddive.com/news/its-not-easy-being-green-romaine-lettuce-e-coli-outbreak-rattles-food-g/543448/ (accessed Oct. 23, 2019).

FDA. 1998. Guide to Minimize Microbial Food Safety Hazards for Fresh Fruits and Vegetables. Center for Food Safety and Applied Nutrition. www.fda.gov/regulatory-information/search-fda-guidance-documents/guidance-industry-guide-minimize-microbial-food-safety-hazards-fresh-fruits-and-vegetables (accessed Nov. 14, 2019).

FDA. 2018a. FDA Investigated Multistate Outbreak of E. coli O157:H7 Infections Linked to Romaine Lettuce from Yuma Growing Region. www.fda.gov/Food/RecallsOutbreaksEmergencies/Outbreaks/ucm604254.htm (accessed Dec. 3, 2018).

FDA. 2018b. Memorandum to the File on the Environmental Assessment. www.fda.gov/downloads/AboutFDA/CentersOffices/OfficeofGlobalRegulatoryOperationsandPolicy/ORA/ORAElectronicReadingRoom/UCM624633.pdf (accessed Mar. 19, 2019).

Fister Gale S. 2006. McDonald's USA: A golden arch of supply chain food safety. Food Saf Mag Feb/Mar. www.foodsafetymagazine.com/magazine-archive1/februarymarch-2006/mcdonalds-usa-a-golden-arch-of-supply-chain-food-safety/ (accessed Oct. 22, 2019).

[FSLC] Food Safety Leadership Council. 2007. Food Safety Leadership Council On-Farm Produce Standards Version 1.0. 19 p.

Gennet S, Howard J, Lanholz J, et al. 2013. Farm practices for food safety: An emerging threat to floodplain and riparian ecosystems. Front Ecol Environ 11(5):236–42.

Hardesty S, Kusunose Y. 2009. Growers' Compliance Costs for the Leafy Greens Marketing Agreement and Other Food Safety Programs. UC Small Farm Program Research Brief. 16 p.

Havinga T. 2006. Private regulation of food safety by supermarkets. Law Pol 28(4):515–33.

Jamieson RC, Joy DM, Lee H, et al. 2005. Resuspension of sediment-associated Escherichia coli in a natural stream. J Environ Qual 34:581–9.

Karp DS, Baur P, Atwill ER, et al. 2015. The unintended ecological and social impacts of food safety regulations in California's Central Coast region. BioScience 65(12):1173–83.

Karp DS, Gennet S, Kilonzo C, et al. 2015. Comanaging fresh produce for nature conservation and food safety. PNAS 112(35):11126–31.

Palma MA, Ribera LA, Paggi M, Knutson R. 2010. Food safety standards for the U.S. fresh produce industry. Policy Issues 8.

Pollans MJ. 2017. Farming and eating. J Food Law Pol 13:99–112.

Powell DA, Erdozain S, Dodd C, et al. 2013. Audits and inspections are never enough: A critique to enhance food safety. Food Control 30(2):686–91.

Ribera LA, Palma MA, Paggi M, et al. 2012. Economic analysis of food safety compliance costs and foodborne illness outbreaks in the United States. HortTechnology 22(2):150–6.

Rodriguez JM, Molnar JJ, Fazio RA, et al. 2008. Barriers to adoption of sustainable agriculture practices: Change agent perspectives. Renew Agr Food Syst 24(1):60–71.

Strauss DM. 2011. An analysis of the FDA Food Safety Modernization Act: Protection for consumers and boon for business. Food Drug Law J 66(3):353–76.

Stuart D. 2008. Constrained choice and ethical dilemmas in land management: Environmental quality and food safety in California agriculture. J Agr Environ Ethic 22:53–71.

Ward A. 2018. New Resources Help LGMA Members Comply with Updated Metrics. California Leafy Green Handler Marketing Agreement. https://lgma.org/2018/10/new-resources/ (accessed Nov. 12, 2019).

Wells HF, Buzby JC. 2008. Dietary Assessment of Major Trends in U.S. Food Consumption, 1970-2005. US Department of Agriculture Economic Research Service. Economic Information Bulletin No. 33. 27 p.

NEWS

Research highlights

Recent articles from the Agricultural Experiment Station campuses and UC ANR's county offices, institutes and research and extension centers.

Envisioning optimal land use in Pajaro Valley

The Pajaro Valley is a highly productive California agricultural region comprising parts of Santa Cruz, Monterey and San Benito counties. For decades, more water has been pumped from the valley's aquifers than has been replenished, resulting in decreased aquifer levels and seawater intrusion. Researchers from UC Davis and UC Cooperative Extension (UCCE), along with colleagues from universities in Iran and Mexico, conducted a study to estimate the sustainable carrying capacity of agricultural land in the valley — that is, to determine which uses of land might minimize groundwater withdrawals while maximizing agricultural profit. The researchers built a simulation model that accounted for the valley's hydrology, water use patterns and groundwater storage. Next, they constructed an optimization model to determine which crop acreages, given constraints on uses of water and land, would maximize profit. Finally, combining the two models, they estimated the optimal land distribution — that is, how much land could be devoted to various crop types without causing excessive groundwater overdrafts. Ultimately, they identified an optimal land use scenario that, over 25 years, would entail a 15% reduction in agricultural acreage — resulting in an 8.5% reduction in food production, just a 4% loss in profit and ultimately 79% less aquifer depletion.

The authors emphasize that they do not mean to dictate how land and water should be used. Rather, they present their work as a "vision of what can ideally be accomplished" when water management strategies "harmonize individual decisions and shared natural resources."

Garza Díaz LE, DeVincentis AJ, Sandoval Solis S, et al. 2019. Land-use optimization for sustainable agricultural water management in Pajaro Valley, California. J Water Res Plan Man 145(12). doi:10.1061/(ASCE)WR.1943-5452.0001117

Groundwater recharge and nutrient management can reduce nitrate contamination

Nitrate contamination of groundwater-derived supplies of drinking water — caused primarily by use of nitrogen fertilizers on agricultural land — can cause serious human health problems if nitrate concentrations exceed 10 milligrams per liter of drinking water. Concentrations above that level have been detected in more than 450 wells that supply community water systems in California. To evaluate means of reducing nitrate in water supplied from public wells and nearby domestic wells, two UC Davis researchers — Mehrdad Bastani (a doctoral candidate in the Department of Civil and Environmental Engineering) and Thomas Harter (a UCCE specialist based in the Department of Land, Air and

Agriculture in the Pajaro Valley is extremely productive, but decades of groundwater pumping have led to challenges such as seawater intrusion.

Online: https://doi.org/10.3733/ca.2020a0005

Water Resources) — modeled water flow and contaminant transport in the Modesto basin, which lies within the Central Valley aquifer system.

Focusing on a specific public well in an economically disadvantaged community near Modesto, they assessed the effects on nitrate concentrations of managed aquifer recharge and of improved nutrient management practices on local agricultural land. They evaluated a business-as-usual scenario; a scenario involving agricultural changes such as replacing almond orchards with low-impact crops such as alfalfa or wine grapes; and several groundwater recharge scenarios. The researchers found that when groundwater recharge was increased while nitrate leaching from agriculture was simultaneously decreased, nitrate in drinking water could be reduced by 80% over 60 years (compared to the business-as-usual scenario). They also found that recharging groundwater regularly would produce far better results than would recharging only during times of high water availability.

Bastani M, Harter T. 2019. Source area management practices as remediation tool to address groundwater nitrate pollution in drinking supply wells. J Contam Hydrol 226:103521. doi:10.1016/j.jconhyd.2019.103521

For strawberry growers, birds may help as much as they hurt

Amid rapid intensification of agriculture around the world, biodiversity conservation in agricultural areas has become the subject of considerable research. Diversified farming systems — characterized by integration of crop and noncrop vegetation on and near farms — have gained attention for their ability to retain biodiversity. Many species that benefit from biodiversity efforts can provide growers valuable services such as pollination and insect control. But efforts to conserve bird populations are sometimes controversial because birds can harm crops as well as help them.

Efforts to conserve bird populations in agricultural areas are sometimes controversial because birds can both help crops and harm them.

Research comparing the services and disservices that birds provide to strawberry growers on California's Central Coast was recently conducted by researchers from UC Berkeley's Department of Environmental Science, Policy and Management; UC Davis's Department of Wildlife, Fish and Conservation Biology; and colleagues from other institutions. The researchers designed an experiment that allowed birds access to certain strawberry plots and denied them access to others. They found that birds damage strawberries at about the same rate that they prevent insects from damaging the berries. They also found that farms surrounded by landscapes with more seminatural vegetative cover exhibit greater richness of bird species — as well as greater abundance of insectivorous as opposed to strawberry-eating birds.

These results, the researchers write, highlight the need for land managers to consider both the services and disservices that birds provide. With new funding from the U.S. Department of Agriculture, the authors are now studying, on a wider array of strawberry farms, the impact of farmland diversification on the benefits and costs associated with birds. Further, they are using molecular diet analysis to determine which bird species provide pest control benefits.

Gonthier DJ, Sciligo AR, Karp DS, et al. 2019. Bird services and disservices to strawberry farming in Californian agricultural landscapes. J Appl Ecol 56(8). doi:10.1111/1365-2664.13422

Growers: On-farm food loss driven by retailer requirements

Partly because food disposal is associated with environmental harm, food loss and food waste have gained greater attention as policy issues in recent years. Little research, however, has delved into growers' experiences with and viewpoints on food loss and waste. Two years ago, three researchers at UC Davis — Anne Gillman (then a postdoctoral scholar in the Department of Human Ecology, now a professor at American River College), David C. Campbell (then associate dean in the College of Agricultural and Environmental Sciences, now retired) and Edward S. Spang (assistant professor in the Department of Food Science and Technology) — sought to fill this knowledge gap by conducting interviews with 25 growers of fresh produce in California.

A primary insight of the interviews was that, from the growers' perspectives, on-farm losses mostly occur as a result of forces beyond their control. For example, losses can occur because of unpredictable weather or because buyers of farm products demand consistent quantities of flawless produce. The researchers argue that because on-farm losses are often tilled into the soil or used as animal feed — whereas food lost at the retail or consumer level often goes to landfill, producing environmental problems such as methane emissions — growers who decline to harvest edible but unmarketable items may prevent future environmental harm. The researchers also argue that, although food loss is a problem requiring a solution, efforts to increase the proportion of produce that flows from farm to fork must be pursued with an awareness that the environmental risk of food losses can increase as food moves closer to the consumer.

Gillman A, Campbell DC, Spang ES. 2019. Does on-farm food loss prevent waste? Insights from California produce growers. Resour Conserv Recy 150:104408. doi:10.1016/j.resconrec.2019.104408

Regional approach to U.S. bioeconomy proposed

A bioeconomy, broadly defined, is an economic system in which renewable biological resources replace fossil fuels and in which processed biomass fulfills society's requirements for food, feed, fuel and more. Attempts to establish effectively functioning bioeconomies have taken different forms in different countries but — according to Laura Devaney (a researcher at Dublin City University who in 2017 conducted research as a Fulbright scholar at UC Berkeley) and Alastair Iles (an associate professor in UC Berkeley's Department of Environmental Science, Policy and Management) — the U.S. bioeconomy has so far attained only a "marginal status." The two researchers characterize the U.S. bioeconomy as a highly fragmented system — one in which federal visions for bioeconomic development have had little impact.

To gain further understanding of the obstacles that impede development of the U.S. bioeconomy, the researchers interviewed stakeholders from government departments, multinational corporations, start-ups, universities and nonprofit organizations. A key insight derived from the interviews was that the U.S. bioeconomy might thrive if it were organized around regions — agglomerations of neighboring states with similar resource bases, industrial infrastructures and cultural identities. The authors build on this insight by developing a map of regional bioeconomic governance — proposing a "polycentric governance system" in which states and regions, "in keeping with their regional strengths," create clusters of activity in bioeconomic research, production and processing.

Devaney L, Iles A. 2019. Scales of progress, power and potential in the US bioeconomy. J Clean Prod 56(8). doi:10.1016/j.jclepro.2019.05.393

Avocado rootstocks show promising salinity tolerance

In many places around the world, agricultural production is hampered by water quality challenges such as increased salinity. Avocado production is highly sensitive to salt; indeed, along with avocado root rot, salinity threatens the long-term survival of the California avocado industry. Avocado production typically involves grafting scions, or aboveground plant matter, onto rootstocks, the selection of which influences the crop's salinity tolerance. Researchers from UC Riverside's Department of Botany and Plant Sciences and its Department of Environmental Sciences grafted scions of the commonly grown Hass variety onto three rootstocks — R0.05, Dusa and PP40 — to assess tree performance under high-salinity irrigation conditions and control irrigation conditions.

The researchers allowed the trees to grow for 2 years and 8 months before they began salinity treatments. Fruit was harvested 15 months after treatments had begun and tree survival was assessed some months thereafter. The researchers report that trees grown on the three rootstocks displayed comparable canopy damage (42% to 48% more damage than trees in the control group). One-third of the trees grafted on R0.05 and PP40 died, as did 57% of trees grafted on Dusa — whereas 100% of trees in the control group survived. On average, trees under the salinity treatment bore 63% less fruit than did trees under the control treatment. Nonetheless, the three rootstocks performed better under the high-salinity conditions than other rootstocks previously investigated. The researchers suggest that the three rootstocks — which have also been verified as tolerant of root rot — are prime candidates for further trials and eventual use in commercial avocado operations.

Acosta-Rangel AM, Li R, Celis N, et al. 2019. The physiological response of 'Hass' avocado to salinity as influenced by rootstock. Sci Hortic-Amsterdam 256:108629. doi:10.1016/j.scienta.2019.108629

Drip irrigation may be appropriate for organic spinach production

Over the last decade, California acreage devoted to spinach production has increased by more than 30%. In 2017, the farm-gate value of the state's spinach crop amounted to more than $240 million. The spinach industry is threatened, however, by spinach downy mildew disease, which thrives in the wet canopy conditions typically associated with sprinkler irrigation. At the same time, spinach is highly dependent on nitrogen fertilizer application, so irrigation water must be applied efficiently to minimize nitrogen leaching. Three researchers — Aliasghar Montazar, a UCCE advisor in Imperial and Riverside counties; Michael Cahn, a UCCE advisor in Monterey County; and Alexander Putnam, a UCCE assistant specialist based in UC Riverside's Department of Microbiology and Plant Pathology — conducted experiments at the UC Desert Research and Extension Center to investigate whether drip irrigation is viable in organic spinach production and in management of spinach downy mildew disease. Comparing sprinkler irrigation with multiple configurations of drip line depth and spacing, the researchers determined that plots irrigated by drip lines after emergence displayed lower incidence of downy mildew. They also observed a somewhat lower yield in the drip-irrigated plots. The researchers concluded that drip irrigation in organic spinach production might conserve water and manage downy mildew, but that additional work is necessary to optimize drip line system design and nitrogen management practices.

Montazar A, Cahn M, Putnam A. 2019. Research advances in adopting drip irrigation for California organic spinach: Preliminary findings. Agriculture-Basel 9(8). doi:10.3390/agriculture9080177

Drip irrigation in organic spinach production shows promise as a means of conserving water and managing disease.

COLLABORATIONS

Natural history for all Californians

The California Naturalist program, which links the state's residents with their natural surroundings, is making strides toward addressing its diversity challenges.

It was only in 2014 that UC California Naturalist became a UC Agriculture and Natural Resources (ANR) statewide program — but already the program has delivered its trademark 40-hour certification course to thousands of Californians. The program's instructors, in the classroom and in the field, have introduced students to the fundamentals of environmental science and to the wonders of California's habitats, natural history and more. The program exposes students to science-based content, teaches them practical skills and provides them opportunities for stewardship in areas such as habitat restoration, education and community and citizen science. The California Naturalist program, which fosters deep relationships with dozens of partner organizations, has established itself as an important resource for environmental education and stewardship training across broad swaths of the state.

All that said, the program has encountered — and is working to overcome — challenges in the realm of diversity and inclusiveness. The most common profile of an individual who earns California Naturalist certification is a white, college-educated woman over the age of 50. The California Naturalist program, because it aims to more closely reflect the state's diversity — and in particular to increase participation by young, Latino and African-American Californians — is pursuing several strategies to engage a broader audience, reduce barriers to participation in the program and increase the cultural relevance of the California Naturalist experience.

One approach is to partner with workforce development organizations such as conservation corps. Under this approach, California Naturalist partners with a workforce development organization to codesign a specialized version of the course that achieves greater relevance for participants. In Southern California, for example, California Naturalist has teamed up with the National Forest Foundation (NFF), three national forests, and several workforce development programs that serve diverse communities. The NFF, with the aid of workforce development organizations and the U.S. Forest Service, recruits young people into a youth engagement program called Junior Field Rangers. The NFF helps participants prepare for the program, notably by arranging for them to earn California Naturalist certification. Junior Field Rangers interact with the public at cooperating national forests, with duties including educating visitors about forest stewardship, water resources and sustainable recreation. Dania Gutierrez, the NFF's Southern California program manager, reports that as many as 300 students have participated in the Junior Field Rangers program since its inception.

Online: https://doi.org/10.3733/ca.2020a0006

California Conservation Corpsmembers support a nature discovery field trip at the Hopland Research and Extension Center.

Hannah Bird

California Conservation Corpsmembers identify organisms collected during a bioblitz at the Hopland Research and Extension Center.

Students and instructor from the National Forest Foundation Angeles/San Gabriel Mountains course displaying their CalNat certificates.

Elsewhere in the state, California Naturalist is strengthening its relationship with the California Conservation Corps (CCC), a state department whose dual missions are to restore and enhance California's natural resources and to foster the personal and professional development of "corpsmembers," who range in age from 18 to 25. The corpsmembers, who spend a year engaged in "project work" such as trail repair and invasive species removal, very much reflect the diversity of the state, says Hunt Drouin, the CCC's program development manager.

California Naturalist and the CCC are now partnering to pilot a course in which corpsmembers earn California Naturalist certification as part of their service. In April, about 30 corpsmembers based at the CCC's residential center in Ukiah will travel daily to UC ANR's nearby Hopland Research and Extension Center for a specially designed immersion course. The curriculum, to accommodate corpsmembers' somewhat unpredictable schedules, will be compressed into one week (compared to the usual 10 or so). The course will help corpsmembers develop skills particularly relevant to their work and will provide them enhanced instruction in areas such as fire prevention. Representatives of three CCC residential programs elsewhere in the state will observe and assess the pilot course; according to California Naturalist Director Gregory Ira, the result could be broader adoption of the California Naturalist program across the CCC.

Funding for the pilot project is provided by a Renewable Resources Extension Act Capacity Grant. Additional funding comes from several private donors and from the CCC Foundation, which will cover fees for students who exercise the option, available to anyone who earns California Naturalist certification, to receive four units of college credit from UC Davis Continuing and Professional Education. Under a separate arrangement, all corpsmembers became eligible last year to apply a portion of the educational scholarship they receive upon completion of their service to enrollment in a California Naturalist course.

Thanks in part to the collaborations discussed here, California Naturalist is making strides toward achieving its diversity, equity and inclusion objectives. Between 2015 and 2017, for example, Latino representation in California Naturalist courses increased to 9% from 3%. California Naturalist — by pursuing additional initiatives such as scholarship programs, equity pricing and collaborations with community colleges and tribes — is working to build a yet more inclusive community of naturalists around the state.

— Editors

An LA Conservation Corpsmember learns how to use a refractometer to determine salinity of a local waterbody during a California Naturalist course at the SEA Lab.

RESEARCH ARTICLE

Cover crop and mulch practices reduce agricultural pollutant loads in stormwater runoff from plastic tunnels

Results from a trial with two raspberry growers in coastal California suggest that using a barley cover crop or mulch can reduce potential groundwater pollutants in soil and leachate.

by Oleg Daugovish, Ben Faber, Eta Takele, Jamie Whiteford and Laosheng Wu

Abstract

Macrotunnel production systems contribute over $1 billion to California's economy, but despite increased use, guidance to help macrotunnel growers limit agricultural pollutant loads in rainfall-induced runoff is sparse. Using raspberry as a model crop, we evaluated four runoff management practices during two rainy seasons of the normal 3-year raspberry production cycle: barley cover crop seeded at 500 pounds per acre, weed barrier fabric, yard waste mulch spread 2 to 3 inches thick, and polyacrylamide (PAM). Treatments were applied to 300-foot-by-6-foot-wide post rows. Barley cover crop and mulch reduced combined nitrate and nitrite nitrogen in runoff by 21% to 48% at some runoff events and reduced nitrate nitrogen in soil and leachate to groundwater by 52% to 90%. All treatments reduced turbidity and phosphorus levels in runoff and had 75% to 97% less sediment accumulation compared with bare soil. Additionally, all treatments except PAM reduced weed densities by 48% to 87% compared with bare ground, which reduced the costs of weed management. Barley cover crop had the lowest estimated costs (~$60.00 per tunnel period), while PAM and mulch were highest (~$193.00 per tunnel period).

Online: https://doi.org/10.3733/ca.2020a0004

Macrotunnel production has been increasing in coastal counties of California and is poised for expansion due to its recent adoption as a standard practice by the U.S. Department of Agriculture (USDA NRCS 2019). In high tunnel production, crops are grown within plastic-covered structures to enhance crop performance, extend production seasons and to protect crop quality. While most caneberries, some strawberries, cut flowers, herbs and leafy greens are widely grown under plastic in California, contributing $1 billion to the state's economy, in other states small fruits, melons and nuts are also grown in high tunnel systems. This interest in plasticulture tunnels is driven by many factors: increased production due to season expansion; reduced exposure to deleterious weather events; consumer demand for fresh, local produce; and national interest in reducing transportation-related greenhouse gas emissions, amongst other concerns. Unfortunately, it comes at a time when climate-induced weather pattern changes, particularly shorter-duration, higher-frequency storm events, are expected to become the norm (Westra et al. 2014).

The plastic covering hoop structures can reduce the available permeable surface of a field's production area by over 90%, which increases the volume of

In coastal California, most caneberries, some strawberries, cut flowers, herbs and leafy greens are grown in plastic-covered structures like the ones shown here.

Jamie Whiteford

water likely to run off a field in a storm event (RCDMC 2014). During rains, water intercepted by plastic covers is channeled into post rows (furrows with tunnel-supporting posts), accelerating soil erosion, especially on slopes, which ultimately degrades surface water quality. In California, surface water quality is regulated by the State Water Resources Control Board through the Irrigated Lands Regulatory Program (ILRP 2017). To protect water quality, California regional water quality control boards have adopted different measures to regulate pollutants in water from agricultural operations, including implementation of best management practices (BMPs) (Lu et al. 2008). Typical pollutants in areas with exceedances of total maximum daily loads (TMDLs) include nitrogen, sediment, phosphorus and pesticides, such as chlorpyrifos. Many surface water TMDL exceedances occur during the rainy season, indicating the need for practices that address stormwater runoff. In some areas, management practices that reduce rain-induced leaching of soluble pollutants into groundwater may also be needed.

Stormwater management treatments

In this project we compared treatment efficacies and costs of untreated tunnel post rows with rows treated under four different practices in plastic-covered raspberry operations at Somis (Ventura County) and Santa Maria (Santa Barbara County), California. Both sites were on moderate slopes (2% to 10%), but the beds were planted on the contour to reduce runoff and were on a 1% slope at both sites. The post row treatments were selected based on previous work (M. Cahn, personal communication) and potential feasibility for caneberry operations. Each treatment was applied to 6-foot-by-300-foot post rows (each row is an 1,800–square foot plot) in an experiment with randomized complete block design with three replications at both sites. Site conditions are described in table 1. The project focused on the rainy seasons of 2016–2017 and 2017–2018.

The four treatments were as follows:

A *barley cover crop* ('U.C. 476') was seeded in 2016 (July at Somis and November at Santa Maria) at 500 pounds per acre with a seed spreader, lightly raked into the soil and established with sprinkler irrigation used for delivering overhead water to newly planted raspberry roots (a standard propagation approach). At both locations we reseeded barley at the same rate during the second rainy period of the project (January 2017) to increase cover crop density in areas lacking ground cover.

Weed block fabric (DayBlack/Premium Weedmat, Dewitt) is commonly used in organic and hydroponic production systems. Fabric was unrolled and pinned by hand to cover the post-row surface between raspberry beds prior to post installation. The fabric remained in place during the experiment and was unpinned and rolled up at the end of the project for potential reuse.

Yard waste mulch from local suppliers (Agromin for Somis and Santa Barbara County Public Works Green Waste for Santa Maria) was delivered to the project sites. Mulch was a woody < 2-inch screened material with < 20% fine components. Different mulch sources at the two sites were used because the distance between sites and volume requirements for each site were prohibitively large to source from a single supplier. Mulch was delivered by tractor to post rows, where it was spread with rakes to cover the entire post row with a 2- to 3-inch thick layer. At both locations mulch was applied once prior to post installation and persisted throughout the trial period.

Polyacrylamide (PAM; Soil Binder DC, J.R. Simplot Company), a nontoxic soil-binding polymer, was applied prior to rain events (or as needed based on efficacy) at a rate of 2 pounds per acre. In 2016–2017, PAM was mixed with water and applied with a backpack sprayer, but due to plugging of nozzles we dispersed dry PAM to post rows instead in 2017–2018 and observed similar efficacy and increased ease of application.

Runoff and soil collection, data analyses

In the 2016–2017 season, we collected runoff samples by hand (grab samples) within 30 min from the beginning of the runoff generation, approximately 25 feet away from the ends of each of the treatment post rows (to prevent potential runoff mixing from adjacent post rows). About 250 milliliters of runoff water in each sample were brought from field sites to the UC Cooperative Extension (UCCE) Ventura County lab and immediately tested for turbidity using a turbidimeter (Model 2100P, Hach Company, Loveland, Colo.), acidified with sulfuric acid to reach pH 3 and either shipped immediately to the ANR analytical lab at UC Riverside or stored at 4°C until shipment. Levels of nitrogen forms (nitrate [NO_3], nitrite [NO_2] and ammonium [NH_4]) and total nitrogren and phosphorus were determined using a

TABLE 1. Site characteristics in raspberry tunnel runoff management project

Experimental site	Soil type	Organic matter	pH	Slope, %	Rainfall, total in inches, 2016–2017	Rainfall, total in inches, 2017–2018	Plastic cover on tunnels
Somis	Mocho loam	1.8	7.8	5	16.63	6.74	Duration of the project
Santa Maria	Oceano sand	2.3	6.1	9	18.84	6.48	Feb–May each year

Barley cover crops

Weed block fabric

Yard waste mulch

Polyacrylamide

Untreated

Treatments applied to raspberry tunnel post rows at Somis and Santa Maria.

Discrete Analyzer AQ2 (Seal Analytical Inc., Mequon, Wis.).

In 2017–2018, we collected grab samples as described above. We also collected runoff in 5-gallon buckets installed at 25 feet from the end of post rows (passive samplers) to intercept first flush of runoff at soil surface level. Additionally, we installed suction lysimeters (AGQ Labs, Oxnard, Calif.) about 30 feet away from the ends of the post rows at 8-inch depth at Santa Maria and 8- and 24-inch depths at Somis and collected leachate (water that has percolated through soil) after rains.

In 2017–2018 we also collected sediment from the buckets after runoff occurred, and the sediment samples were dried and weighed at the UCCE Ventura County lab. In April 2018, we took soil samples (15 cores per plot at 0- to 6-inch and 6- to 12-inch depths) that were analyzed for soil moisture, nitrate nitrogen (NO_3-N) and phosphorus content.

Weed densities and raspberry shoots

Weed numbers were determined by counting all germinated weeds in each 1,800–square foot plot at each site on three dates. Predominant weed species at Somis were little mallow (*Malva parviflora*) and annual sowthistle (*Sonchus oleraceus*), and horseweed (*Conyza canadensis*) and annual bluegrass (*Poa annua*) at Santa Maria. Additionally, in April 2018 at Somis we counted the numbers of volunteer raspberry shoots (suckers) in all plots.

Runoff, weed and cane data were analyzed using the GLM Procedure in SAS (SAS version 9.0, SAS Institute, Cary, N.C.) with the overall error rate controlled by Tukey-Kramer adjustment.

Bare ground allows erosion and weeds, which then move into crop beds.

TABLE 2. Soil moisture and nitrate nitrogen in 0- to 12-inch soil profile three days after rain (3.25 inches) under raspberry post row treatments, March 29, 2018

Treatments	Somis		Santa Maria	
	Moisture	Nitrate nitrogen	Moisture	Nitrate nitrogen
	%	*ppm*	*%*	*ppm*
Untreated	18.5 b	28 a	8.7 ab	11.2 a
Fabric	18.4 b	22 a	7.6 b	2.3 b
Mulch	20.8 a	7.8 b	8.9 a	9.8ab
Barley	19.6 ab	4.4 b	8.7 ab	4.7 b
PAM	18.3 b	35 a	8.4 ab	8.4 b

Treatment means with the same letter in each column are not significantly different at $P = 0.05$.

Economic analyses

We calculated the costs of each treatment for the 1,800–square foot experiment plot and then extrapolated the costs into a per acre basis for one tunnel use period. A tunnel use period covers a 3-year production cycle of raspberry from establishment until termination. Costs of treatments included materials, labor and equipment when applicable. Granular dry PAM formulation application to soil was used in the analyses. We also adjusted the treatment's costs if it provided weed control benefit. In addition, some treatments can serve for more than one tunnel use period. Therefore, we distributed the costs accordingly.

Treatment effects on runoff and water retention

Not all treatments had runoff during light rains. Barley cover crop and yard waste mulch likely interfered with low flows and aided water retention in post rows. We observed slower flows and greater puddling in post rows with barley or mulch than in other treatments or untreated soil (data not shown). Soil sampled 3 days after rain in March 2018 at Somis had 8% to 12% (w/w) greater moisture content at both sampling depths under mulch compared with other treatments (table 2). Mulch also conserved more soil moisture than fabric at Santa Maria (table 2).

Nitrogen in runoff

Combined nitrite and nitrate (NOx) levels in runoff samples ranged from 0.29 to 6.48 milligrams per liter (mg/L) over two seasons of sampling. This variability is due to the intensity and frequency of the rains during this period, which also affected the accumulated fertigated nitrogen that occurred between rain events.

Fabric and PAM did not reduce nitrate or nitrite in runoff compared with untreated soil at any of the sampling dates at both locations and sampling seasons (data not shown), while mulch was equally ineffective in 2016–2017 in reducing NOx in runoff at both locations. During one out of five runoff events in 2016–2017, barley reduced NOx levels in runoff by 48% ($P = 0.023$) compared with untreated soil, but not significantly during other rain events of that season (data not shown).

During two out of five runoff events (March 10, 2018 and March 13, 2018) at Somis in 2017–2018, barley reduced NOx levels in runoff by 71% and 82% ($P < 0.05$) and mulch reduced them by 67% and 91% ($P < 0.1$) compared with untreated soil, but reductions were not significant at other sampling events. At Santa Maria, none of the treatments had significant impact on NOx in runoff when compared with untreated soil ($P > 0.1$) (data not shown).

All treatments at Somis were effective in reducing ammonium in runoff in 2016–2017 compared with untreated soil (table 3), but only barley was effective in 2017–2018. The overall greater average levels of ammonium in 2017–2018 were likely due to use of passive samplers that intercepted the first flush of runoff, which may have had a greater concentration of pollutants than runoff collected later (such as with grab samples in 2016–2017). Ammonium is typically carried on sediments, so lower ammonium would indicate less sediment movement.

This suggests that barley cover crop and yard waste mulch can reduce both the concentration of dissolved ammonium nitrogen in runoff and the volume of runoff, leading to potential reductions in nitrogen losses to the environment compared with untreated soil.

Nitrate nitrogen in soil and leachate

Soil under barley and mulch had significantly less nitrate nitrogen compared with other treatments in March 2018 at Somis (table 2). At Santa Maria, all treatments except for mulch had 25% to 81% less nitrate nitrogen than that of untreated soil, although mulch was also similar to all other treatments. Mulch deterioration might have reduced its efficacy at Santa Maria.

At Santa Maria, nitrate nitrogen levels in leachate collected at 8-inch depth on all sampling dates ranged from 12 to 27 parts per million (ppm) in PAM and untreated plots, which was 52% to 80% greater ($P < 0.05$) than those in other treatments (data not shown). At Somis a similar trend was observed: nitrate nitrogen levels in leachate under PAM and untreated soil were 7 to 22 ppm, which was 80% to 90% greater ($P < 0.01$) than those under barley or mulch. Leachate nitrate concentrations under fabric were not different ($P = 0.8$) from those in untreated soil (data not shown).

These results suggest that barley and mulch can reduce nitrate nitrogen in soil and leachate. Mulch and cover crop (including straw and stubble) act as a barrier to runoff water with dissolved nitrogen and sediment and may retain nitrogen to be used for cover crop growth and for residue and mulch decomposition.

Turbidity, sediment and phosphorus in runoff

Turbidity (a measure of suspended sediment loads) in first flush of runoff was reduced 5- to 10-fold by all treatments compared with untreated soil at both locations in 2018 (figs. 1 and 2). These results were similar to turbidity in grab samples taken in 2017 and 2018 (data not shown), which suggests that all treatments were effective in reducing waterborne sediments on site.

Additionally, 75% to 97% less sediment was collected from passive samplers in all treated post rows compared with those in untreated soil, as shown for March 10, 2018 (fig. 3). Relatively high sediment load in fabric treatment resulted from deposits of soil on top of the fabric during removal of plastic from raspberry beds. Similar to the

TABLE 3. Average ammonium concentrations of five runoff events (grab samples in 2016–2017) and passive samples (2017–2018) at Somis

Treatments	Ammonium, mg/L	
	2016–2017	2017–2018
Barley	0.04 b	0.47 b
Fabric	0.04 b	3.59 ab
Mulch	0.06 b	0.57 ab
PAM	0.05 b	1.30 ab
Untreated	0.24 a	5.94 a

Treatment means with the same letter in each column are not significantly different at $P = 0.1$.

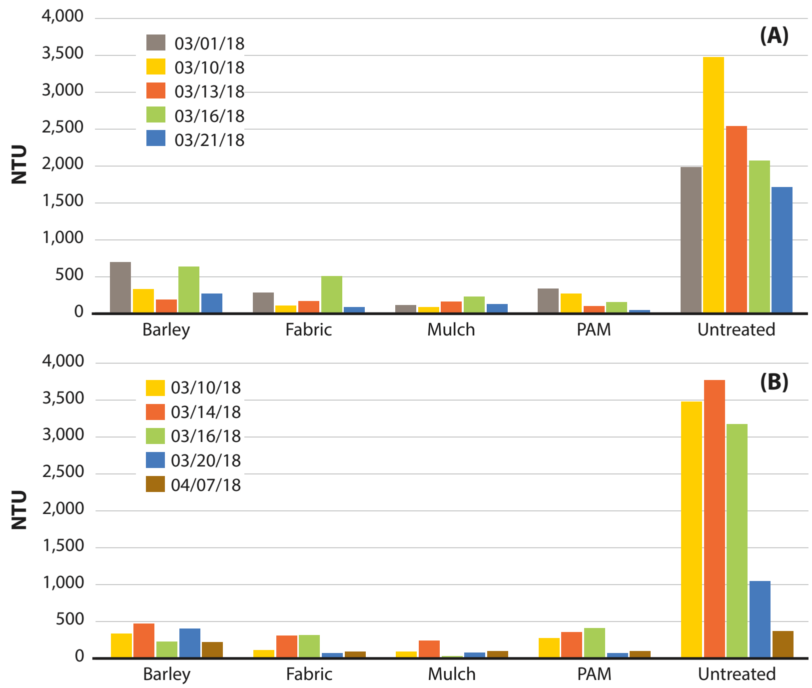


FIG. 1. Turbidity (in Nephelometric Turbidity Units, NTU) in first flush of runoff in 2018 at Somis (A) and Santa Maria (B). Untreated > rest (at $P = 0.05$) at all dates.

FIG. 2. Turbidity of runoff water in first flush of runoff from raspberry post rows with different treatments and untreated bare soil at Somis on March 10, 2018.

March 10 rain event, we observed significantly lower sediment levels after other rains in all treated post rows compared with untreated rows (data not shown). We also observed fewer erosion channels in treated post rows compared with untreated plots at both sites during the trial.

Besides the agronomic benefits, retaining soil in the field is also a good pesticide management practice because soil-adsorbed pesticides will stay in the field and not end up in receiving bodies of water. In a previous study, Mangiafico et al. (2009) showed that concentrations of the harmful insecticide chlorpyrifos in runoff were linearly related to sample turbidity. This suggests that retaining waterborne sediments on-site is an effective method for mitigating runoff of this pesticide. Preventing soil movement with these post row treatments may also reduce the costs of sediment removal from receiving waterways and associated environmental impacts (Tundu et al. 2018).

Phosphorus levels in the first flush of runoff samples were reduced by 24% to 85% in all treatments compared with untreated soil at Somis in 2018, except for PAM on Feb. 27, 2018 (fig. 4). Lack of efficacy of PAM on that date may have resulted from deterioration of the PAM seal due to soil disturbance (foot traffic during cane pruning) after PAM application and before runoff sample collection. At Somis in 2016–2017 and Santa Maria in 2018, we observed a similar reduction in phosphorus by all post row treatments compared with untreated soil (data not shown). Since phosphorus is normally adsorbed to soil particles (Zhang et al. 2016), reduction in turbidity and phosphorus in runoff samples from treated post rows followed a similar trend. Reducing losses of phosphorus from production fields may help prevent eutrophication in receiving waterways when this microelement is limiting for algal growth (Correll 1996).

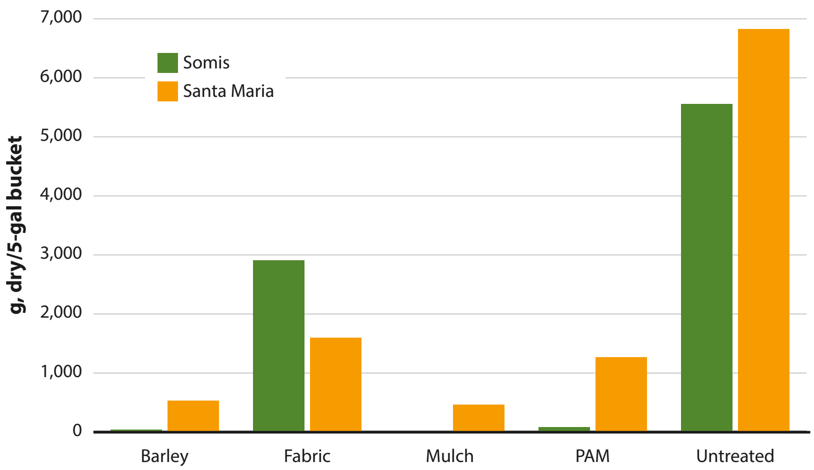


FIG. 3. Sediment collected after 3.25 inches of rain on March 10, 2018, in passive samplers in treated and untreated raspberry post rows. Untreated > rest (at $P = 0.05$).

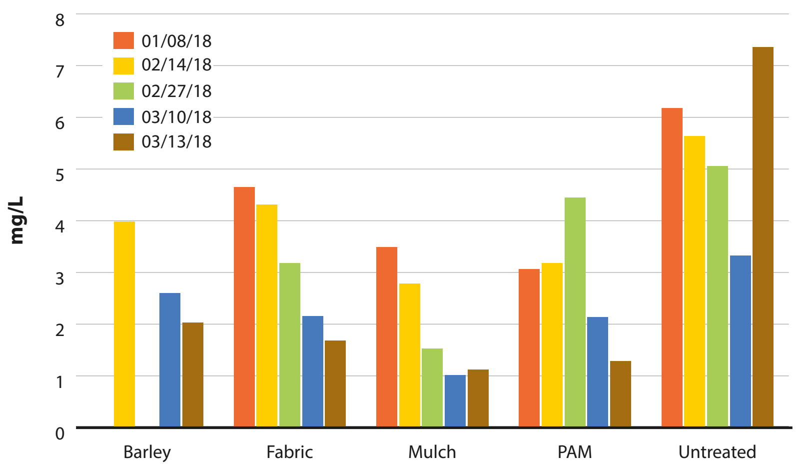


FIG. 4. Total phosphorus in first flush of runoff in 2018 at Somis. Untreated > the rest ($P = 0.05$), except PAM on 02/27/2018 (similar to untreated, $P = 0.23$).

Control of weeds, raspberry shoots

Since tunnel post rows receive water and retain soil moisture, conditions are favorable for weed growth. At both locations weed barrier fabric provided nearly complete weed control (table 4) with only occasional weed germination in areas where soil was deposited on the top of the fabric. Application of PAM did not provide control, and weed densities in PAM-treated rows were similar to those in untreated plots. Yard waste mulch provided 81% to 90% weed control at Somis but did not control weeds in two out of three evaluation dates at Santa Maria (table 4). Mulch at Santa Maria was much finer compared with the one at Somis, and likely decomposed more rapidly, allowing weed growth.

Barley cover crop provided 86% and 42% weed control on two evaluation dates at Somis, but after barley was reseeded, high germination of little mallow occurred (Jan. 17, 2018, table 4). Incorporation of barley during reseeding likely disturbed hard-coated weed seeds sufficiently to break dormancy; however, mallow was controlled before seed production when barley was mowed in spring. Barley cover crop

TABLE 4. Weed densities in post rows (plants per 1,800 ft^2–post row) at Somis and Santa Maria

	Somis			Santa Maria		
Treatments	**11/23/2016**	**02/15/2017**	**01/17/2018**	**02/01/2017**	**04/06/2017**	**02/16/2018**
Untreated	206 a	651 a	625 a	7 a	76 a	244 a
Fabric	4.3 b	10 d	2 b	0 b	1 b	11 c
Mulch	21 b	126 cd	90 b	5 a	65 a	99 b
Barley	27 a	338 bc	1,686 a	1 b	42 a	138 b
PAM	173 a	487 a	610 a	3 ab	52 a	136 b

Treatment means with the same letter in each column are not significantly different at $P = 0.05$.

at Santa Maria provided 87% and 43% weed control at two out of three evaluation dates.

At Somis in 2018, we observed 3.5 more volunteer raspberry shoots ($P = 0.001$) in post rows with mulch compared with other treatments or untreated plots (data not shown). Unlike weeds, raspberry shoots were able to penetrate mulch and establish, likely benefiting from the greater soil moisture content under it (table 2).

These results show that weed barrier fabric, mulch and barley (when adequately applied and managed) can effectively reduce weed control costs in raspberry tunnel post rows, but greater volunteer raspberry shoot management may be required if mulch is used.

Costs of post row treatments

To estimate the costs of the barley cover crop, we obtained machine use and labor hours for seeding, raking and mowing from cost studies for raspberry production (Bolda et al. 2017). Cover crop treatment at 500 pounds per acre costs $29.42 for the treatment area minus the weed control benefit of about $18.60, resulting in the net cost approximates of $10.83 for the treatment, or $59.55 per acre per tunnel period (table 5).

The amount of weed block fabric required for the experimental plot area (1,800 square feet) was 0.22 roll, priced at $349.31 per roll. Ninety

TABLE 5. Sample costs of raspberry tunnel post row treatments based on a study at Somis and Santa Maria

Materials and labor	Costs/tunnel cycle/treatment area*	Costs/tunnel cycle/acre†
	$	$
Fabric		
Fabric cost (one roll covers 8,071 ft²) at $349.31/roll	77.90	428.47
Pins (90 for treatment area of 1,800 ft²) at $0.12/pin	10.80	59.40
Labor (two people at 0.5 hour each) at $15.00/hour	15.00	82.50
Total cost for fabric treatment	103.70	570.37
Reuse of fabric for another planting:		
Unpinning cost (two people at 0.5 hour each)	15.00	82.50
Pinning back for the planting (two people at 0.5 hour each)	15.00	82.50
Total cost with fabric reuse (two tunnel cycles)	133.70	735.37
Total cost per tunnel cycle	66.85	367.68
Less weed control cost in post rows at $300/ac/year (100% weed control)	−37.19	−204.55
Total fabric treatment cost	**29.66**	**163.14**
Mulch		
Mulch cost (90 ft³ for 1,800 ft²) at $15/yd³ ($0.56/ft³): 495 ft³/ac	50.00	275.00
Delivery and spreading: 0.74 hours at $15/hour	11.10	61.05
Total cost for mulch treatment	61.10	336.05
Less weed control in post rows at $300/ac/year (70% weed control)	−26.03	−143.18
Total mulch treatment cost	**35.07**	**192.87**
Cover crop		
Cover crop planting:		
500 lbs/ac (43,560 ft²) at $20/50 lbs (two times)	8.26	45.45
Labor hours for light tilling with hand rototiller:		
Two people (20 min each) at $15/hour (two times for two seedings)	10.00	55.00
Mowing (two times): Two people (20 min/each) (two times for two seedings)	10.00	55.00
Machine cost: mowing at $14/acre (from cost studies)	0.58	3.18
Weedwacker (same as mowing)	0.58	3.18
Less weed control in post rows at $300/ac/year (50% control)	−18.60	−102.27
Total cover crop treatment cost	**10.83**	**59.55**
Polyacrylamide (PAM)		
PAM cost (application at 2 lbs/ac at $4/lb (six times application)	1.98	10.91
Labor at 250 min/ac and wage rate $15/hour (six times application)	15.50	85.23
Total PAM cost	17.48	96.14
Less weed control cost in the post rows	0.00	0.00
Total PAM treatment cost	**34.96**	**192.27**

* The treatment area consists of one post row (1,800 ft²); one tunnel cycle = 3 years.
† One acre = 5.5 post rows; one tunnel cycle = 3 years.

metal pins were used to pin the 1,800–square foot fabric area at a cost of $0.12 per pin. The labor needed for spreading and pinning the fabric in the experiment plot was 1 hour (two workers at 0.5 hour each) at $15 per hour. Assuming the fabric serves two tunnel periods, only half of the cost of the fabric material is applied to one tunnel period. Fabric also provides 100% weed control in post rows. Therefore, the cost of fabric treatment per tunnel period is $29.66 for the treatment area, or $163 per acre for one tunnel period.

The volume of applied yard waste mulch should be sufficient to cover the entire post row with a 2- to 3-inch thick layer. Ninety cubic feet of mulch, priced at $0.56 per cubic foot ($15 per cubic yard), was applied to the 1,800–square foot treatment area. Delivery and spreading on flat ground with a front end loader and spreader costs $270 per acre. In cases where smaller equipment is used, it would take more labor — at least a day for two people to spread an acre, as it is a slow process and depends on how well the mulch spreads out in the field. In terms of weed control, mulch controlled 70% of the weeds in post row areas. Mulch treatment cost is one of the highest at $35.07 for the treatment area, or $192 per acre per tunnel period.

The PAM product (Soil Binder DC) was applied at 2 pounds per acre (0.083 pounds for the 1,800 square feet) and was priced at $4.00 per pound. PAM was applied six times per tunnel period; hence, the total PAM cost for this treatment is $1.98 for the treatment area. The labor cost for applying PAM was calculated at 250 minutes per acre (10.33 minutes for the 1,800–square foot treatment area) per time at a wage of $15 per hour. Therefore, the PAM treatment cost became $34.96 per post row, or $192.27 per acre.

The costs of the treatments in this study were very low: 0.7% to 2.4% of the total cultural costs of raspberry production (Bolda et al. 2017). This suggests that little investment in soil and runoff management can be cost-effective over time for sustainable plasticulture crop production.

Next steps

During this trial, California was experiencing the drought of 2011–2019, and these treatments were used in periods when lower runoff and sediment movement would have been expected. However, we observed similar treatment efficacy during low (< 0.2 inches) and high (> 1 inch) rainfall events in these trials, which suggests the treatments were resilient during wet periods. The four treatments in the study all reduced runoff flows and sediment transport (and consequently phosphorus movement) compared with the untreated rows. However, additional work on runoff flow rates and the effect of infiltration on soluble nitrogen forms is needed to more fully quantify the treatment effects with respect to nitrogen balance in these systems.

Our treatment cost analysis serves as a template for tunnel users to assess the feasibility of inputs and costs in their production systems, which may be different from those in this study. During the project we conducted several outreach events for growers and field workers where we displayed the treatments and discussed the in-progress results. At the end of the project, we developed bilingual guidelines for runoff management to facilitate treatment adoptions. These guidelines are available online at https://ucanr.edu/sites/ucceventura/files/304038.pdf (English) and https://ucanr.edu/sites/ucceventura/files/304039.pdf (Spanish). These resources enable tunnel users to select best management practices to protect their fields from soil and nutrient losses and to comply with runoff regulations aimed at protecting the environment. CA

O. Daugovish is Strawberry and Vegetable Crops Advisor and B. Faber is Soils and Water, Avocados and Minor Subtropicals Advisor, UC Cooperative Extension (UCCE) Ventura County; E. Takele is Farm Management/Agricultural Economics Area Advisor, UCCE Riverside County; J. Whiteford is District Scientist, Ventura County Resource Conservation District; and L. Wu is Professor of Soil and Water Science and UCCE Water Management Specialist in the Department of Environmental Sciences, UC Riverside.

We greatly acknowledge help and contributions from Driscoll/Reiter AC, AGQ lab and funding from the California Department of Food and Agriculture.

References

Bolda M, Tourte L, Murdock J, Sumner D. 2017. Sample Costs to Produce and Harvest Fresh Market Raspberries - Primocane Bearing - Central Coast Region. UC ANR, UC Cooperative Extension, Agricultural Issues Center. 36 p.

Corell D. 1996. The role of phosphorus in the eutrophication of receiving waters: A review. J Env Quality 27(2):261–6.

[ILRP] Irrigated Lands Regulatory Program. 2017. Eastern San Joaquin River Watershed Agricultural Order. SWRCB/OCC Files A-2239(a)–(c). www.waterboards.ca.gov/public_notices/petitions/water_quality/a2239_sanjoaquin_ag.shtml

Lu J, Wu L, Faber B. 2008. Erosion control and runoff management. In: Newman J (ed.). *Greenhouse and Nursery Management Practices to Protect Water Quality*. UC ANR publication 3508. p 83–96.

Mangiafico S, Newman J, Merhaut D, et al. 2009. Nutrients and pesticides in stormwater runoff and soil water in production nurseries and citrus and avocado groves in California. HortTechnology 19(2):360–7.

[RCDMC] Resource Conservation District of Monterey County. 2014. Stormwater erosion and runoff on Salinas and Pajaro valley farms. Technical paper. www.rcdmonterey.org/images/docs/publications/rcdmc-valley-runoff-and-erosion.pdf

SAS Institute. 2007. SAS version 9. Cary, NC.

Tundu C, Tumbare M, Onema JM. 2018. Sedimentation and its impacts/effects on river system and reservoir water quality: case study of Mazowe catchment, Zimbabwe. Int Assoc Hydrological Sci 377:57–66.

Westra S, Fowler HJ, Evans JP, et al. 2014. Future changes to the intensity and frequency of short-duration extreme rainfall. Rev Geophys 52(3). https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2014RG000464

[USDA –NRCS] US Department of Agriculture Natural Resources Conservation Service. 2019. National conservation practice standards. EQIP 2019-1. www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/eqip/

Zhang L, Du Y, Du C, et al. 2016. The adsorption/desorption of phosphorus in freshwater sediments from buffer zones: the effects of sediment concentration and pH. Environ Monit Assess 188(1):13. www.ncbi.nlm.nih.gov/pubmed/26638155

RESEARCH ARTICLE

Financial effect of limiting pesticide use near schools for almonds in nine counties depends on soils and weather

Results from a study using field location, soil hydrologic group and historical weather data suggest new regulations would not often disrupt the standard fungicide spray program for almonds and losses would be small.

by Rachael E. Goodhue, Karen Klonsky, Christopher DeMars, Steve Blecker, John Steggall, Minghua Zhang and Robert Van Steenwyk

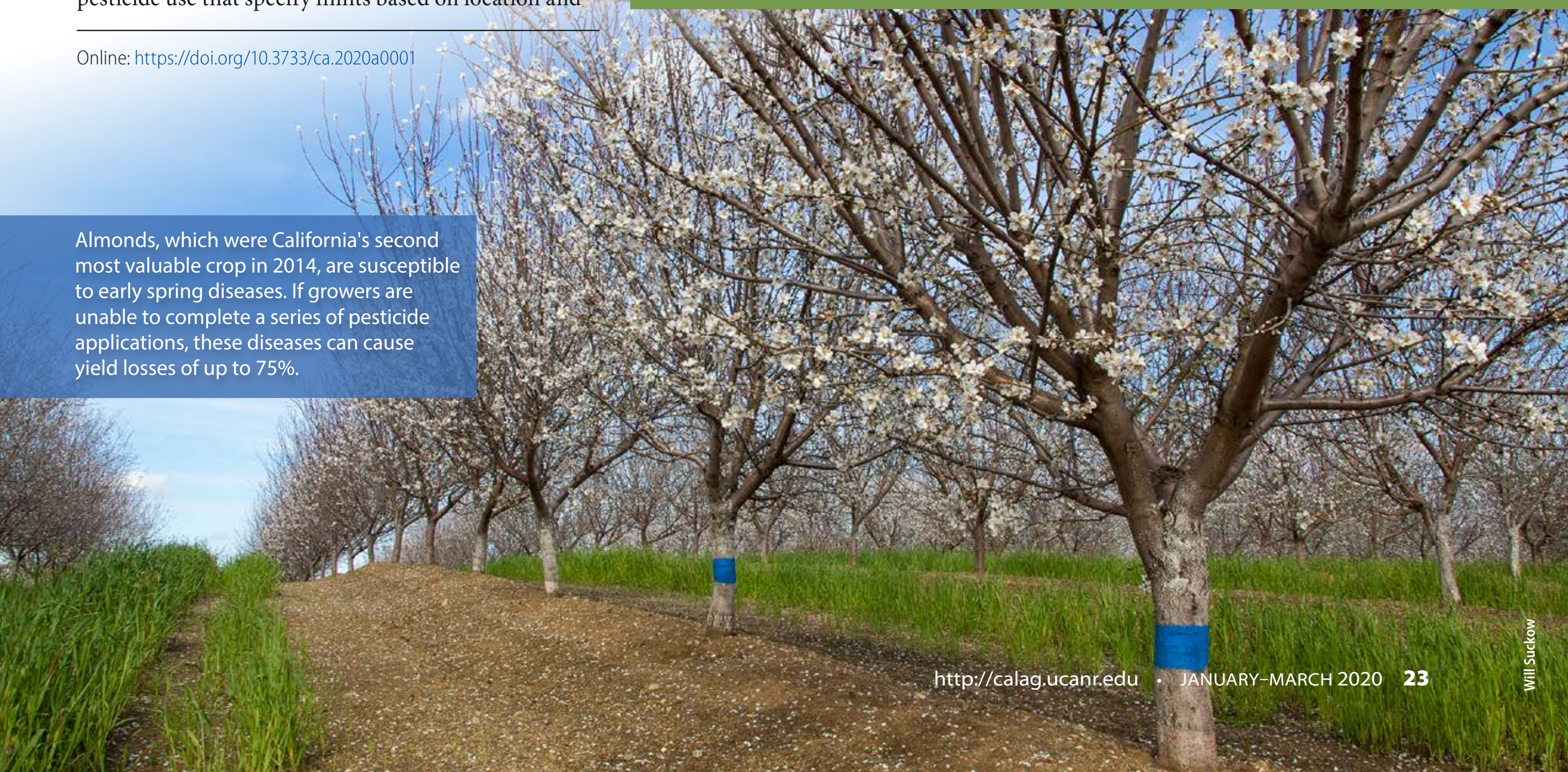
Abstract

Effective Jan. 1, 2018, the California Department of Pesticide Regulation enacted a regulation regarding the use of pesticides near public K-12 schools and licensed child day care centers, including a provision that bans specific types of applications, including air-blast and air-assist, during weekday school hours (6 a.m. to 6 p.m.) to provide an additional safety margin for pesticide exposure beyond those provided by other regulations. We considered the financial effect on almond growers in nine counties, accounting for four-fifths of total almond production in 2014, if they had been unable to complete a standard spring disease management program on any buffer zone acreage. Results indicated that total annual losses for those counties if such a regulation had been in effect would have been $8.7 million, with per-acre losses ranging from 22% to over 50% of total operating costs, depending on the county. However, using a methodology that took into account historical weather and soil hydrologic group data, we estimated average annual losses in the nine counties among almond growers would have been under $0.2 million because the regulation would have affected the number of sprays completed for relatively few acres in relatively few years.

Economic analyses can provide policymakers with a more complete picture on the potential impacts of pesticide regulations on agriculture. Employing historical pesticide use data is common in this type of analysis (Steggall et al. 2018); however, incorporating additional detail, such as weather and soil type, into the analysis can further refine how many acres would be impacted and how often. The interplay of soil type, historical weather and pesticide use data can be used to estimate field conditions and therefore whether or not the field can be accessed by spray equipment for critical pesticide applications. The example used in this study focuses on springtime disease management in almond, which can be critical in preventing yield loss.

While the California Department of Pesticide Regulation (DPR) has used restrictions on applications based on weather conditions and locations near sensitive sites for specific active ingredients for some time, most notably for fumigants, a recent regulation applied broadly to most pesticide applications based on location and day and time of application. Regulations on pesticide use that specify limits based on location and

Online: https://doi.org/10.3733/ca.2020a0001



Almonds, which were California's second most valuable crop in 2014, are susceptible to early spring diseases. If growers are unable to complete a series of pesticide applications, these diseases can cause yield losses of up to 75%.

Will Suckow

time of application can reduce the total economic impact on an industry compared to broad regulations that limit all applications. Specifically, DPR enacted a regulation regarding the use of pesticides within a quarter mile of K-12 public schools and licensed child day care centers (collectively called schoolsites), which went into effect Jan. 1, 2018 (DPR 2017a, 2017b). Prior to this regulation, DPR was charged with a number of directives to promote the safe use of pesticides near schools and child care centers through the Healthy Schools Act of 2000 and its subsequent amendments (DPR 2019). Among other provisions, the 2018 regulation prohibits specific types of pesticide applications, including air-blast and air-assist spraying, on weekdays from 6 a.m. to 6 p.m. The purpose of this prohibition was to "provide an extra margin of safety and minimum standards for applications near schools and child day care facilities (schoolsites)" (DPR 2018).

We estimated potential net revenue losses for almond growers in nine California counties due to this provision. Specifically, we assessed losses due to weather and soil conditions that would have prevented growers from treating acreage within a buffer zone with fungicides more than once outside of the banned time window. (We focused on disease management as insect and weed control tend to have more flexible timing and those applications could therefore be more easily adjusted in order to comply with the regulations.) Almonds were selected for three reasons: (1) the substantial California almond acreage and crop value (second most valuable California crop in 2014 [CDFA 2015a]); (2) the importance in almond disease management of air-blast or air-assist pesticide applications early in the year when rain events might restrict access to orchards; (3) almond production has the largest acreage within the specified buffer (7,245 acres, roughly 1% of planted acreage). In the nine counties studied, the 2017 Census of Agriculture reported 5,955 operations with almond acreage, and the average number of acres per operation was 172 (USDA NASS 2019). Both numbers were higher than in the 2012 Census of Agriculture, which reported 5,284 operations with almond acreage in these counties, with 142 acres as the average per operation (USDA NASS 2014).

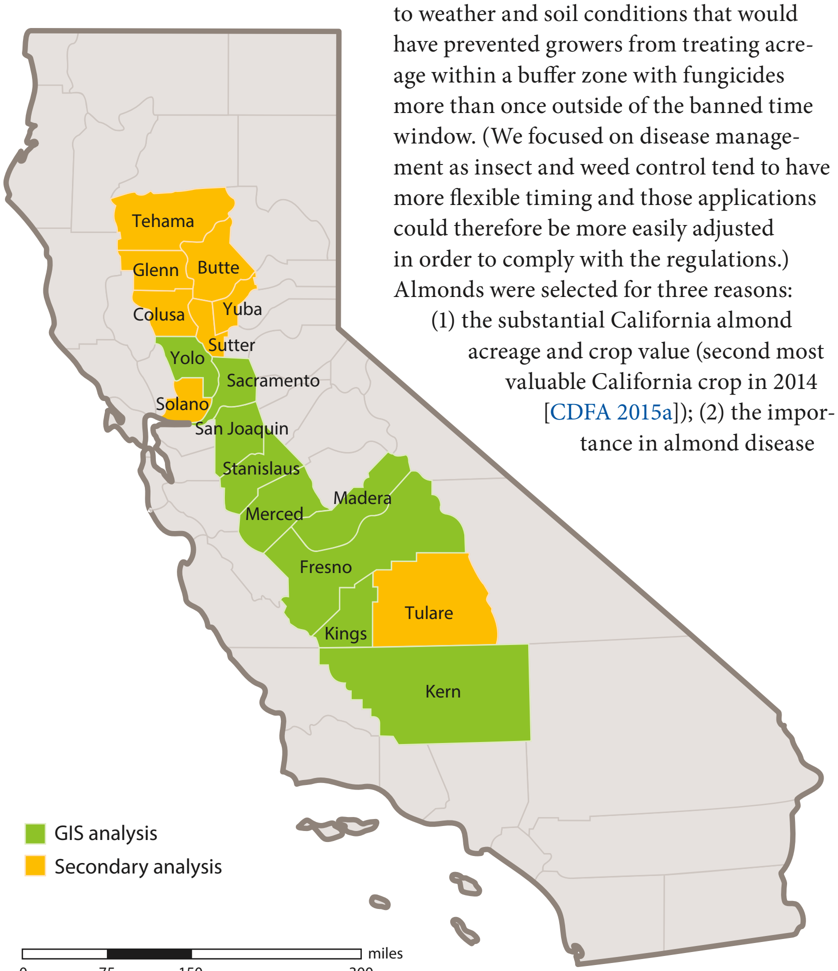


FIG. 1. Losses due to the regulation were studied in nine almond-producing counties, representing 80% of production, where information was available on GIS-based buffer zone acreage by soil hydrologic group. In a secondary analysis, using conservative assumptions regarding soils and buffer zone acreage, losses due to the regulation were estimated for eight additional counties, accounting for almost all the remaining California almond production.

The nine counties — Fresno, Kern, Kings, Madera, Merced, Sacramento, San Joaquin, Stanislaus and Yolo — represented 81% of the total California production value for almond in 2014. These counties were chosen because of the availability of information on GIS-based buffer zone acreage by soil hydrologic group. Using conservative assumptions regarding soils and buffer zone acreage, we estimated losses for eight additional counties — Butte, Colusa, Glenn, Solano, Sutter, Tehama, Tulare and Yuba — that account for virtually all of the remaining California almond production (fig. 1). Seven of these eight counties in the secondary analysis are located in the northern Sacramento Valley, which tends to receive higher rainfall than the other almond-growing regions.

We followed the general methodology presented in Steggall et al. (2018), integrating data on pesticide use with GIS data and weather and soil data to provide a precise picture of potential regulatory impacts. Pesticide use data allowed identification of fields using restricted application methods; GIS data identified orchards near schoolsites; weather and soil type data determined when applications could be made.

Our analysis was limited in scope. We estimated the cost only of a specific regulatory provision for a specific crop in specific counties for a specific disease management program, not statewide costs to all agriculture, or even to the entire almond industry. We did not assess any market or nonmarket benefits that may be realized from the regulation, such as improved child health outcomes, and thus did not evaluate the overall efficiency or net social welfare impact of the regulation.

Control of almond spring diseases

Almonds are the earliest blooming of all deciduous fruit, nut and vine crops in California. The first bloom for the Nonpareil cultivar starts about the second week of February with 100% petal fall by late February or early March. The pink bud stage precedes bloom by about one week. The precise start of bloom depends on temperatures in January and early February. Geographically, the bloom starts in the southern San Joaquin Valley and northern Sacramento Valley before proceeding to the Sacramento Delta region. Total bloom period for each region occurs within about two weeks.

Almonds are susceptible to a number of early spring diseases. If uncontrolled, diseases can cause yield losses of up to 75%, according to our communications with UC Cooperative Extension (UCCE) and U.S. Department of Agriculture (USDA) personnel, growers and pest control advisers. The extent of yield loss depends on disease inoculum present, amount of rain and number of rain events, and temperature, which affects disease development. Precipitation also impacts whether a treatment can be made and treatment efficacy. Growers typically apply a fungicide at pink bud followed by a second application within 7 to 10 days at full bloom. These two applications are for brown rot and, to a lesser extent, green fruit rot and anthracnose control. A third treatment is applied at petal fall, 7 to 10 days after the second application, principally for shot hole and anthracnose control. Thus, three critical fungicide applications are often made within 14 to 20 days.

TABLE 1. Revenues and estimated net revenue losses per acre in a year with only one bloom spray completed*

Southern San Joaquin Valley† Estimated yield loss 15%		
County	Revenue/acre	Net revenue losses/ acre
Fresno	$7,308	$975
Kern	$7,196	$958
Kings	$7,945	$1,071
Madera	$7,008	$930
Tulare	$8,449	$1,146
Northern San Joaquin/southern Sacramento valleys Estimated yield loss 15%		
County	Revenue/acre	Net revenue losses/ acre
Merced	$7,915	$1,066
Sacramento	N/A	N/A
San Joaquin	$9,778	$1,346
Solano	$4,127	$498
Stanislaus	$8,228	$1,113
Yolo	$5,397	$689
Northern Sacramento Valley Estimated yield loss 25%		
County	Revenue/acre	Net revenue losses/ acre
Butte	$6,149	$1,416
Colusa	$5,389	$1,226
Glenn	$4,748	$1,066
Sutter	$4,175	$923
Tehama	$4,506	$1,006
Yuba	$5,839	$1,339

* Net revenue equals total revenue minus unrealized spraying costs.

† Reported southern San Joaquin Valley losses based on the maximum of the 0%–15% yield loss range.

Sources: CDFA 2015b, authors' calculations.

Estimated yield losses from reduced fungicide applications vary by region. If only one of the three applications can be completed, yield losses will be 0% to 15% in the southern San Joaquin Valley, 15% in the northern San Joaquin Valley and 25% in the Sacramento Valley, according to UCCE and USDA personnel, growers and pest control advisers. If two applications can be completed, yield losses generally will be minimal, assuming that inoculum levels are low owing to an ongoing disease management program.

The majority of fungicides are ground applied, usually in daytime. When the ground is too wet to operate ground equipment, fungicides are applied aerially. However, aerial applications have two disadvantages: (1) they are slightly less efficacious than ground applications and (2) the fixed surcharge for aerial applications is often not cost effective for growers with small acreages. Accordingly, under heavy rain pressure ground applications may be advanced or delayed a few days from their optimal timing rather than replaced with aerial applications. UC plant pathologists suggest that a 3- or 4-day window around the optimal time provides acceptable control. The fungicide application rate may be increased to partially compensate for less than optimal timing.

Our analysis did not address the effect of weather itself. Instead, it addresses the differences in the effect of weather with and without the regulation. Regardless of the number of sprays a grower could apply, the regulation would only have an effect on yield, revenue and production costs if the number of sprays would have been different with the regulation than without it — that is, if a grower could not spray on a weekend or on a weekday between 6 p.m. and 6 a.m. when the regulation was not in effect, then there was no incremental loss due to the regulation.

Study approach

To capture the spatial and temporal dimensions of the regulation, the day and time of fungicide applications to almond between July 1, 2013, and June 30, 2014, in orchards that intersect a schoolsite buffer were extracted from DPR's Pesticide Use Reporting (PUR) database.

The composition hydrologic group of an orchard's soil has a strong influence on the delay between a rain event and when mechanized sprayers can be used. Soils with high sand content (group A) drain faster and can support ground equipment sooner than soils with a high clay content (groups B, C and D). To quantify the impact of the differences in soil drainage on yield losses, we calculated buffer acreage within each soil hydrologic group using the Natural Resources Conservation Service Soil Survey Geographic Database (SSURGO) soil spatial layer.

Growers typically apply a fungicide at pink bud (A) followed by a second application within 7 to 10 days at full bloom (B). These two applications are for brown rot and, to a lesser extent, green fruit rot and anthracnose control. A third treatment is applied at petal fall (C), 7 to 10 days after the second application, principally for shot hole and anthracnose control.

The authors' analysis of historical weather and soil data suggests that average annual losses among almond growers in the study area would have been less than $0.2 million, as the pesticide regulation would have affected relatively few acres in relatively few years.

Using potential yield loss information and the UC IPM Pest Management Guidelines (Haviland et al. 2017), we developed a typical disease management spray program, which was then simulated using soil hydrologic group data for buffer zone acreage and 10 years of weather data, including information on temperature, precipitation and wind, to determine the number of sprays that would be affected. The time period for the weather analysis, 1996 to 2005, was selected to match available data regarding almond bloom stages.

There are a number of limitations of our analysis that may lead to over- or underestimation of losses in the nine counties. First, the analysis assumed schools and day care centers were open on all weekdays. Thus, losses may be smaller than estimated because growers could make applications on weekdays when schools were not occupied (e.g., holidays). Second, the data did not differentiate between bearing and nonbearing acres, which could overestimate losses because nonbearing acreage would not be impacted. This consideration was more than offset by the substantial recent increase in almond acreage, the source of a third limitation: The analysis was based on almond acreage and pesticide use data from July 1, 2013, to June 30, 2014, so it does not include acreage that came into production in more recent years.

A final important limitation is that the time intervals we considered did not account for recommended limitations on fungicide applications designed to protect bees pollinating almond orchards, so losses may be underestimated. The California Almond Board (n.d.) recommends that fungicide applications be made in the late afternoon and evening so that the product is dry before bees begin foraging in the morning once pollen shed begins. With early morning applications not recommended, applications are limited to only a portion of the 6 p.m. to 6 a.m. interval permitted in the formal regulation.

TABLE 2. Buffer zone acreage in nine counties of main study

County	Soil hydrologic group*				Total
	A	B	C	D	
	acres				
Southern San Joaquin Valley					
Fresno	525	0	245	63	833
Kern	592	108	168	27	895
Kings	137	76	70	0	283
Madera	557	143	264	181	1,145
Total	1,811	327	747	271	3,156
Northern San Joaquin/southern Sacramento valleys					
Merced	821	0	289	139	1,249
Sacramento	0	0	0	0	0
San Joaquin	952	13	155	0	1,120
Stanislaus	844	68	1,444	12	2,368
Yolo	0	6	177	90	273
Total	2,617	87	2,065	241	5,010
Grand total	**4,428**	**414**	**2,812**	**512**	**8,166**

* Land categorization assumes that land with a high water table is provided with sufficient drainage. Sources: Natural Resources Conservation Service Soil Survey Geographic Database (SSURGO) soil spatial layer, DPR's Pesticide Use Reporting data.

Typical spray program

A typical spray program includes sprays in each of three bloom stages: (1) pink bud, which is the first day of bloom, (2) full bloom, the midpoint between first and last day of bloom and (3) petal fall, the last day of bloom. Ground applications are possible if the soil is not too wet, which is a function of the amount and duration of precipitation and soil hydrologic group. The following rules were used to determine the 12-hour time blocks (6 a.m. to 6 p.m. and 6 p.m. to 6 a.m.) in which an application could be completed successfully:

- If a spray could have been made within 3 days of its optimal time, then there was no yield loss.
- Nighttime ground applications were possible if rain history and soil type permitted.

- A successful spray required no rain events during the 12-hour block when the application was made and in the 12-hour blocks proceeding and following that block.
- Weekend sprays were permitted during the day or night.
- Applications could have been made if wind speed was < 10 mph for at least 6 hours in a block of 12 hours.

These rules were applied to each 12-hour time block to determine whether a weekday nighttime ground spray or a weekend spray was possible. Spray possibilities in the absence of the regulation also included weekday daytime sprays. The numbers of sprays possible with and without the regulation within the optimal time windows were compared for each bloom period.

Spraying cost reduction per acre

When fewer sprays are applied, treatment costs decline. In our study, reductions in treatment costs decreased the net revenue losses per acre due to the regulation. According to UC Cost and Return Studies (Duncan et al. 2016; Pope et al. 2016), missing one or two sprays reduces spraying costs by $40 and $81 per acre, respectively. As is always the case, growers' costs can vary. If a grower's costs differ from these values, the net revenue per acre losses will differ as well.

Net revenue losses per acre

The most drastic impact of weather on a typical spray program would be to prevent any bloom sprays from occurring. However, weather data indicate that this outcome is extremely unlikely. Based on weather patterns during the study period, we estimated net revenue losses per acre when only one spray could be completed for 17 major almond-growing counties, organized by region (table 1). Losses per acre for southern San Joaquin Valley counties are reported for 15% yield losses, the upper bound of the estimated 0% to 15% range.

Butte County in the northern Sacramento Valley has the largest estimated net revenue loss per acre: $1,416. Although the northern Sacramento Valley had the largest percentage yield loss (25%), yields are higher in other production regions. San Joaquin County in the northern San Joaquin Valley had the second-largest estimated net revenue loss ($1,346 per acre). Comparing the revenue losses in table 2 to operating costs, 2016 UC cost studies for conventional almond production report total operating costs per acre of $3,332 for the southern San Joaquin Valley, $2,251 for the northern San Joaquin Valley and $2,267 for the Sacramento Valley (Duncan et al. 2016; Pope et al. 2016; Yaghmour et al. 2016). If only one spray was completed, per-acre losses would have ranged from 22% to over 50% of total operating costs, depending on the county. (CDFA does not report almond revenues per acre for Sacramento County.)

TABLE 3. Estimated losses on buffer zone acreage in a year with only one bloom spray completed

County	Soil hydrologic group				Total
	A	B	C	D	
Southern San Joaquin Valley					
Fresno	$511,980	$0	$238,924	$61,438	$812,342
Kern	$567,373	$103,507	$161,011	$25,877	$857,768
Kings	$146,693	$81,377	$74,953	$0	$303,023
Madera	$518,121	$133,019	$245,573	$168,366	$1,065,079
Northern San Joaquin/southern Sacramento valleys					
Merced	$875,186	$0	$308,074	$148,174	$1,331,434
Sacramento	$0	$0	$0	$0	$0
San Joaquin	$1,281,106	$17,494	$208,584	$0	$1,507,184
Stanislaus	$939,541	$75,698	$1,607,461	$13,358	$2,636,058
Yolo	$0	$4,131	$121,873	$61,970	$187,974
Total	**$4,840,000**	**$415,226**	**$2,966,453**	**$479,183**	**$8,700,862**

Buffer zone acreage

Table 2 reports the number of acres within a buffer zone for each county by soil type and in total. Acreage impacts differed across counties. Stanislaus County had almost twice as much buffer zone acreage as Merced County, which had the second-highest buffer zone acreage. Sacramento County had no acreage within a buffer zone. On a percentage basis, for the other acounties buffer zone acreage ranged from 0.45% (Kern County) to 1.89% (San Joaquin County) of total harvested acreage reported by CDFA (CDFA 2015b). Overall, buffer zone acreage was 0.97% of harvested acreage.

Incorporating weather data, soils data and the time delay for entering fields after a rain event revealed that in the 10 years we analyzed, the regulation would have led to losses in zero to three of those years for an orchard in the buffer zone, depending on the combination of county and soil hydrologic group.

Losses from incomplete spray program

Before calculating annual losses averaged over a multiyear period, we calculated losses in a year when the spray program was not completed on any buffer zone acreage. Net revenue losses in a year when only one spray could be completed (table 3) were calculated by multiplying net revenue losses per acre (table 1) by total buffer zone acreage (table 2). If, in the same year, only a single spray was applied to all almond acreage in buffer zones in all nine counties, total losses in that year would be approximately $8.7 million.

Share of years when spray program incomplete

Incorporating weather data, soils data and the time delay for entering fields after a rain event revealed that in the 10 years we analyzed, the regulation would have led to losses in zero to three of those years, depending on the combination of county and soil hydrologic group. Intuitively, that number seems small. However, our objective was to identify years in which there would have been losses due to the regulation compared to no regulation, given the weather. In other words, if weather alone would have prevented a grower from entering an orchard with a specific soil hydrologic group, the resulting loss was not due to the regulation but to the weather.

That said, the more rain events there were, the more likely that the regulation would have had an effect. The El Niño year 1998 accounted for most of the instances when the regulation would have reduced the number of possible sprays. Storms were heavy and persistent. The National Agricultural Statistics Service reported a 34% reduction in yield for 1998 compared to 1997 and 1999 (USDA NASS 2004).

Table 4 summarizes the share of years from 1996 to 2005 when only one fungicide application could be completed for each county–soil hydrologic group combination with and without the regulation. The first set of columns reports the number of years in which only one application could be completed under the regulation for each soil type, the second set of columns reports the number of years in which only one application could be completed without the regulation being in effect, and the third reports the impact of the regulation. It only has an impact when the number of years in which only one application completed is larger under the regulation. For example, only one spray could be completed 10% of the time on soil hydrologic group B in Fresno County regardless of whether or not the regulation was in effect, so the impact of the regulation was zero. For soil hydrologic group C in Fresno County, in contrast, only one application could be completed 30% of the time if the regulation was in effect, but only one application could be completed 10% of the time without the regulation, so the impact of the regulation was an increase of 20%.

TABLE 4. Percentage of years when only possible to complete one spray: 1996–2005

	Soil hydrologic group											
	With regulation				Without regulation				Increase with regulation			
County	A	B	C	D	A	B	C	D	A	B	C	D
Southern San Joaquin Valley												
Fresno	0	10	30	30	0	10	10	10	0	0	20	20
Kern	0	10	10	10	0	10	10	10	0	0	0	0
Kings	0	0	10	10	0	0	10	10	0	0	0	0
Madera	0	10	30	30	0	10	10	10	0	0	20	20
Northern San Joaquin/southern Sacramento valleys												
Merced	0	10	10	20	0	0	10	10	0	10	0	10
Sacramento	0	0	10	20	0	0	10	20	0	0	0	0
San Joaquin	0	0	10	20	0	0	10	20	0	0	0	0
Stanislaus	0	10	10	20	0	0	10	10	0	10	0	10
Yolo*	10	30	40	40	0	20	30	30	10	10	10	10

* Yolo County percentages based on Glenn County weather data.

TABLE 5. Estimated annual net revenue losses averaged across years: 1996–2005

	Soil hydrologic group				
County	A	B	C	D	Total
Southern San Joaquin Valley					
Fresno	$0	$0	$47,785	$12,288	$60,073
Kern	$0	$0	$0	$0	$0
Kings	$0	$0	$0	$0	$0
Madera	$0	$0	$49,115	$33,673	$82,788
Northern San Joaquin/southern Sacramento valleys					
Merced	$0	$0	$0	$14,817	$14,817
Sacramento	$0	$0	$0	$0	$0
San Joaquin	$0	$0	$0	$0	$0
Stanislaus	$0	$7,570	$0	$1,336	$8,906
Yolo	$0	$413	$12,187	$6,197	$18,797
Total annual net revenue losses averaged over 10 years	**$0**	**$7,983**	**$109,087**	**$68,311**	**$185,381**

Losses averaged across years

Net revenue losses averaged over the 10-year period of this study were calculated by multiplying the total net revenue losses in a year in which only one spray could be completed (table 3) by the share of years in which only one spray could be completed (table 4). The results were the "expected" annual revenue losses (table 5). These losses did not represent the net revenue loss in any one year. Rather, the results adjusted the loss estimate to reflect how often growers were able to apply only one spray during bloom.

Total losses in the nine counties where buffer zone acreage data were available averaged across 10 years were less than $0.2 million annually. This was relatively small for a crop with total 2014 market value of $6.4 billion across eight of the nine counties (excluding Sacramento, which does not report almond revenues separately). However, it is important to keep in mind that even though industry-level losses may be small, growers with affected acreage will incur larger percentage losses, up to 30% depending on county and soil hydrologic group. Further, losses are not sustained evenly across years.

Other counties

In the other eight counties, we assumed that 2% of acreage was within the buffer zone and all of this acreage was in soil hydrologic group D. This share of acreage within the buffer zone was larger than the maximum county share for the nine counties and twice as large as the overall share of acreage for the nine counties analyzed. Assuming that all affected acreage was in soil hydrologic group D provided an upper bound for the effect of soil group on estimated losses.

Under these assumptions, estimated net revenue losses in a year in which only one spray could be applied were $4.36 million to $4.72 million, depending on how harvest costs were affected by yield. Losses averaged over 10 years were $0.54 million to $0.58 million. The conservative assumptions regarding buffer zone acreage and soil type contributed to this relatively large estimate, albeit to an unknown extent.

Methodology fine-tunes losses

Overall, projected losses from this policy were anticipated to be small relative to gross revenues for the nine almond-producing counties based on 2014 acreage data. Orchard location, soil hydrologic group and weather data were the key determinants of the losses. If only location data were available, losses would have been $8.7 million. Incorporating soil type and weather data resulted in average losses of $0.2 million annually.

There are a few caveats to keep in mind. All else being equal, the significant growth in almond acreage since 2014 would increase losses above those estimated here. Additionally, these losses were not statewide losses; almonds are produced in other counties too. Finally, these were total losses and did not look at the distribution of losses, which were borne by relatively few growers.

These findings illustrate that evaluating the economic impacts of pesticide use policies with explicit spatial and/or temporal limitations requires incorporating these dimensions into the economic analysis. In this specific case, we found that the regulation, limited by spatial and temporal criteria, was projected to have a relatively small economic effect. Importantly, GIS data on orchard location identified roughly 1% of planted acreage that was in a buffer, and weather data plus soil hydrologic group data each reduced losses by an order of magnitude. Apart from the conclusion regarding appropriate methodology, the implication of this result for policymakers is that economic losses can be reduced if regulations are designed to restrict pesticide use in the specific locations and time periods identified as having undesirable effects rather than applying to a broader set of locations and time periods. CA

R.E. Goodhue is Professor and K. Klonsky was UC Cooperative Extension Specialist Emerita, Agricultural and Resource Economics, UC Davis; C. DeMars is Ph.D. candidate and M. Zhang is Adjunct Professor, Department of Land, Air and Water Resources, UC Davis; S. Blecker is Senior Environmental Scientist, Office of Pesticide Consultation and Analysis, California Department of Food and Agriculture, Sacramento, and Research Associate, Department of Department of Agricultural and Resource Economics, UC Davis; J. Steggall is Senior Environmental Scientist, Office of Pesticide Consultation and Analysis, California Department of Food and Agriculture, Sacramento, and Research Associate, Department of Land, Air and Water Resources, UC Davis; and R. Van Steenwyk is UC Cooperative Extension Specialist Emeritus, Department of Environmental Science, Policy, and Management, UC Berkeley.

References

California Almond Board. n.d. Honeybee Best Management Practices for California Almonds. www.almonds.com/sites/default/files/honey_bee_best_management_practices_for_ca_almonds%5B1%5D.pdf (accessed Sept. 15, 2018).

[CDFA] California Department of Food and Agriculture. 2015a. California Agricultural Statistics Review 2014-2015. www.cdfa.ca.gov/Statistics/PDFs/2015Report.pdf (accessed Apr. 4, 2018).

CDFA. 2015b. California County Agricultural Commissioners' Reports Crop Year 2012-2013. www.nass.usda.gov/Statistics_by_State/California/Publications/AgComm/2013/2013cropyearcactb00.pdf (accessed Apr. 4, 2018).

[DPR] California Department of Pesticide Regulation. 2017a. Text of Final Regulation: Title 3. California Code of Regulations Div. 6. Pesticides and Pest Control Operations Chap. 3. Pest Control Operations Subchap. 2. Work Requirements. www.cdpr.ca.gov/docs/legbills/rulepkgs/16-004/16-004_final_text.pdf (accessed Apr. 4, 2018).

DPR. 2017b. Regulation to Address Pesticide Use Near Schools and Child Day Care Facilities. www.cdpr.ca.gov/docs/enforce/school_notify/regulation_presentation.pdf (accessed Apr. 4, 2018).

DPR. 2018. Regulation to Address Pesticide Use Near Schools and Child Day Care Facilities. www.cdpr.ca.gov/docs/dept/prec/2018/031618_regulation_address_pesticide.pdf (accessed May 10, 2019).

DPR. 2019. Healthy Schools Act Fact Sheet. www.cdpr.ca.gov/docs/pestmgt/pubs/hsa_factsheet.pdf (accessed Oct. 8, 2019).

Duncan RA, Holtz BA, Doll DA, et al. 2016. Sample Costs to Establish an Orchard and Produce Almond, San Joaquin Valley North. UC Cooperative Extension. Department of Agricultural and Resource Economics, UC Davis, University of California, Davis. http://coststudies.ucdavis.edu/current/ (accessed Apr. 4, 2018).

Haviland DR, Symmes EJ, Adaskaveg JE, et al. 2017. Almond: *UC IPM Pest Management Guidelines*. UC ANR Pub 3431. Oakland, CA: UC ANR. www2.ipm.ucanr.edu/agriculture/almond/ (accessed May 29, 2019).

Pope KS, Lightle DM, Buchner RP, et al. 2016. Sample Costs to Establish an Orchard and Produce Almond, Sacramento Valley. UC Cooperative Extension. Department of Agricultural and Resource Economics, UC Davis. http://coststudies.ucdavis.edu/current/ (accessed Apr. 4, 2018).

Steggall J, Blecker S, Goodhue R, et al. 2018. Economic and pest management analysis of proposed pesticide regulations. In *Managing and Analyzing Pesticide Use Data for Pest Management, Environmental Monitoring, Public Health, and Policy*. Zhang M, Jackson S, Robertson M, Zeiss M (eds.). ACS Symposium Series 1283. Oxford, UK: Oxford Univ. Pr.

[USDA NASS] US Department of Agriculture National Agricultural Statistics Service. 2004. Noncitrus fruits and Nuts: Final Estimates 1997-2002. Statistical Bulletin NumberSB-985 (03). May. https://downloads.usda.library.cornell.edu/usda-esmis/files/f1881k89j/b5644w19n/wd376069z/noncitrusfrtnutest_Noncitrus_Fruits_and_Nuts_-_Final_Estimates__1997-2002.pdf (accessed October 5, 2019).

USDA NASS. 2014. 2012 Census of Agriculture. www.nass.usda.gov/Publications/AgCensus/2012/

USDA NASS. 2019. 2017 Census of Agriculture. www.nass.usda.gov/Publications/AgCensus/2017/

Yaghmour M, Haviland DR, Fitchner EJ, et al. 2016. Sample Costs to Establish an Orchard and Produce Almond, San Joaquin Valley South. UC Cooperative Extension. Department of Agricultural and Resource Economics, UC Davis. http://coststudies.ucdavis.edu/current/ (accessed May 11, 2019).

155,486

4-H youth engage in Healthy Living, STEM & Agriculture, Civic Engagement, and Leadership activities

6,154

UC Master Gardener volunteers gave 539,325 hours to make home and community gardens more sustainable

CALIFORNIA NATURALIST

3,490

Certified California Naturalists provided 46,740 hours of volunteer service in environmental stewardship

9 RECS

Research and Extension Centers discovering new ways to safeguard an abundant and healthy food supply

290

UC Cooperative Extension Advisors and Specialists living and working in local communities

UC CE

In **58** California counties

You are here.

So are we.

An investment in UC ANR represents an investment in California's present and future.

UC Agriculture and Natural Resources brings the power of UC research in agriculture, natural resources, nutrition and youth development to local communities to improve the lives of all Californians.

UC ANR academics and staff work directly with farmers, livestock producers and natural resource managers, with youth in communities and classrooms, with gardeners and naturalists and many more. Tens of thousands of UC ANR volunteers help to extend our reach.

These efforts make a difference in the air we breathe, the water we drink and the food we eat. They support a healthy and abundant food supply, our natural environment, a vibrant economy, healthy communities and the development of a qualified workforce.

State support is not adequate.

State, federal and county funding only provide basic support for research and extension. We rely on the generosity of individuals, corporations and foundations to meet the biggest challenges facing California.

For information about the benefits of supporting our research and programs, please visit **donate.ucanr.edu**.

UNIVERSITY OF CALIFORNIA
Agriculture and Natural Resources

RESEARCH ARTICLE

Job satisfaction assessments of agricultural workers help employers improve the work environment and reduce turnover

A new agricultural job satisfaction survey indicated worker turnover was associated with communication, pay, nature of agricultural work, and family commitments.

by Malcolm Hobbs, Emanuelle Klachky and Monica Cooper

California has been faced with a shortage of farm labor in recent years (Charlton and Taylor 2013; Gonzalez-Barrera 2015; Martin 2018), primarily attributed to a decline in the number of Mexican migrant workers coming to the United States, who compose the majority of the labor force. Compounding the decline from abroad, migration within the United States has also dropped as farm labor has undergone a demographic transition: workers are more likely to be older, female and living with children (Fan et al. 2015). Labor shortages appear to have especially affected support activities, such as labor contractors (Hertz and Zahniser 2013). For example, the Napa County vineyard industry experienced an estimated 12% shortage of laborers in 2017 (Peri 2018).

The agricultural industry is responding to this labor shortage in three ways (Martin 2018). First, growers are increasingly relying on machines to stretch worker productivity or as a substitute for hand labor (Downing 2018). Second, they are seeking to replace lost workers with a new labor source — for example, women (Hobbs and Cooper 2017) and H2-A guest workers, although the complications of providing housing in coastal California have limited the viability of the H2-A guest workers option. The third way is the focus of this study: offsetting the labor shortage by boosting retention of existing workers through increased job satisfaction.

Abstract

Addressing the current labor shortage in California agriculture will require a multi-pronged approach, one of which may be increasing retention of current workers through improved job satisfaction. We developed a questionnaire to evaluate the job satisfaction of agricultural workers in 11 categories, tested the reliability of the questionnaire, and its relationship with worker turnover, in a sample of 665 vineyard workers. In our study, four sources of job satisfaction predicted turnover among Napa vineyard workers: communication, pay, nature of agricultural work, and family commitments. Improving these areas may increase job satisfaction and retention of existing workers to stabilize the agricultural workforce.

Online: https://doi.org/10.3733/ca.2020a0002

Results from a survey of 611 Napa County vineyard workers indicate that workers were very satisfied with the nature of agricultural work, but dissatisfied with their commute and the health consequences of working in vineyards.

Malcolm Hobbs

High job satisfaction, defined as a "pleasurable or positive emotional state resulting from one's . . . job experience" (Locke 1976), is linked to positive effects on both employees and organizations, with evidence of a causal relationship (Erdogan et al. 2012). Benefits include lower worker turnover (Griffeth et al. 2000; Lambert et al. 2001; Tnay et al. 2013), increased work performance (Judge et al. 2001), lower absenteeism (Wegge et al. 2007) and healthier workers (Faragher et al. 2005).

Job satisfaction has been categorized in numerous ways, but core categories include the type of work performed, (financial) rewards, professional growth or promotional opportunities, supervision, and co-workers (Wood et al. 2011). Additional categories may be included under specific circumstances (e.g., difficulty of commute), and the most salient categories often differ between occupations (Singh and Loncar 2010).

Conversations on how to address satisfaction in the agricultural workplace understandably tend to focus on pay and benefits, with some acknowledgment that reducing harassment and favoritism is also beneficial (Martin 2018). Because the nature of the relationship between job satisfaction and turnover goes beyond financial compensation, companies may seek to reduce turnover by adopting strategies that carry a lower financial burden. This includes respectful treatment of workers, ensuring a safe workplace, providing workers a diversity of tasks and promotional opportunities, and formalizing labor relations procedures (e.g., grievance processes, formal orientations) (Strochlic and Hammerschlag 2006).

Despite decades of research on job satisfaction in other occupations (Martin et al. 2011), there has been a paucity of research on agricultural workers. To date, the few studies of satisfaction in California agriculture have been primarily based on interviews of workers (e.g., Billikopf 1999; Strochlic and Hammerschlag 2006). Building on this qualitative work, we developed a quantitative survey to identify and describe the job satisfaction categories that drive turnover in a population of Napa County vineyard workers. We investigated how satisfaction may vary by three key demographics — employment status (seasonal vs. permanent), gender and age. And we conducted a limited set of follow-up interviews with a selection of participating workers to explore specific issues raised in the survey.

Collectively, these results provide feedback to agricultural employers from their workers on how their company is performing in various aspects of job satisfaction, which strategies and activities they should invest in to boost job satisfaction, and how they can adapt their strategies to target specific worker demographics. We envision the agricultural industry adopting this survey tool to formally evaluate their progress toward improved job satisfaction and increased workforce sustainability.

Surveying vineyard workers

In summer 2018, we surveyed 611 vineyard crew members and 54 of their immediate supervisors from 14 companies operating out of Napa County (table 1). There were an estimated 10,000 vineyard workers in Napa County in 2018, and our survey therefore captured approximately 6.5% of the workforce. Participating employers learned about the study through contact with or recruitment by the UC Cooperative Extension research team or by advertisement at industry meetings. Under previous arrangements with their employer, survey participants completed the questionnaire in small groups (typically < 25) while at work and were paid their normal hourly rate while they participated.

Since all participants were Spanish speaking, the study was conducted in Spanish by a bilingual research assistant who displayed the questions on a flipchart and also read them aloud in Spanish. Participants were encouraged to signal when they did not fully understand a questionnaire item, whereupon the research assistant provided additional explanation. Responses were collected using electronic devices (Turning Technologies, Youngstown, OH), which allowed participants to respond anonymously. We also conducted semistructured follow-up interviews in Spanish to gather specific details from workers about a subset of the

TABLE 1. Demographics of sample population who participated in the Napa vineyard workers survey, 2018

Counts by employment status, job role and gender					
	Seasonal crew	**Permanent crew**	**Tractor driver***	**Irrigator†**	**Supervisor**
Total	391	194	33	6	54
Female	120	43	1	0	4
Male	271	150	32	6	50
Counts by type of employer (*n* = 14)					
	Female	**Male**	**Seasonal crew**	**Permanent crew**	**Supervisor**
Vineyard‡ (6)	11	52	19	44	5
Management company (5)	145	267	278	116	47
Labor contractor (3)	13	121	94	34	2
Total	169	440	391	194	54
Age characteristics					
	Female	**Male**	**Seasonal crew**	**Permanent crew**	**Supervisor**
Age range	23–56	18–75	18–75	18–69	29–63
Mean age (+ SD)	36.0 (10.3)	35.7 (12.2)	35.3 (12.2)	36.6 (10.5)	44.2 (9.5)

Totals may not add up to total sample size (611) or sub-sample sizes because participants declined to answer some questions.

* Three tractor drivers also worked as irrigators and six tractor drivers were seasonal crew.

† One irrigator was also part of seasonal crew.

‡ Employed directly by vineyard.

TABLE 2. Summary of key themes for 22 permanent workers interviewed

Theme	Example
Commuting	
Commutes are long, tiring and costly	"You are earning mostly to pay the gas." "After 2, 3 weeks it is already tiring to go so far." "One leaves at night and arrives at night." "Hour and a half going and another hour and a half returning . . .. That's 3 hours."
Rotate between vineyards to shorten commute part of season	"But it could be that, for example, if they send us far away, they should send us there for a week and then replace us." "The crews [should] rotate, not spend all the season in one place. For example, one week they send a crew and then they replace them, send them somewhere else."
Company buses and public transport	"I would always [prefer my own transportation] because as a woman you have . . . the children . . . you have to get there quickly if someone has an emergency . . . with the [company] van how are you going to return?" "I think they [company vans] are good because those who don't [own a car], they give it to them." You wouldn't . . . use public transport if the city could facilitate transportation? "No." If the company had a transportation program, would you like to use it? "No, I wouldn't." "I think it's easier like this [with own transport]. Because sometimes when we leave work, we need to pick up the kids from school, and you want to get there fast."
Health consequences	
Concern about chemical and pesticide exposure	"When they are applying it, the smell gets to you." "The powder also gets to you." "We are worried because it is in these places where the cancers arise most." "We all know there are residues." "It is not going to affect you right now, but it will affect you in the long run." "As they work in other vineyards . . . the wind is blowing [the pesticide] over here."
Companies take heat illness seriously	"When it's over 95 . . . they send you home. It's very dangerous to work in such high temperatures . . . but in other places they do make them work." "The contractors don't want to stop their people." "Here, when you start feeling the heat the supervisor come in they ask you how you're feeling, tell us if you feel bad, if you do we'll leave, but they are watching the temperature and if it reaches a certain temperature, we leave."
Companies follow re-entry guidelines	"Here . . . whenever they spray they leave the necessary time for the possibly harmful effects to pass before you can enter the block." "When applying chemicals in a field they do not let you in until the hours that have to pass passed. You do not go to this one, they put you to another where it is not where they spray."
Improve communication between different companies about spraying	"The crew leader who is there at that moment needs to pay attention and call a supervisor to tell them we should work elsewhere." More communication between the companies? "Yes, so that if the neighbor is spraying, the other company can move their people to the other side." "The crew leader who is working . . . [should be] paying attention and . . . calls the supervisor so that we can get out of there when they are spraying nearby."
Appreciate provision of equipment	"In other companies they also give shoes, boots for work, either one or two per year." "Here they do give us shears, they give us gloves, lenses, vests, the most essential things." "If someone is feeling bad there's a canopy and chairs and they can sit there, drink some water, and if they feel worse [not] go back to work." "In other companies you need to buy your own gloves, your own shears, and here they give you everything."
Health and safety training satisfactory	"In everything, in everything they train us." "Every year when we start work, they give us information on everything that is safety in this company . . . every 6 months also they give us safety points." "Every year they do a review."
Pay	
Pay scales should reward seniority and represent significant increases	"There are people who have . . . here 10, 15, 20 years. Someone new arrives and earns \$17 and the only difference is earning 25 cents." "What I'm saying about those who have worked here longer, if one is earning \$17.25, and they're paying \$17 to new workers. That does not work for me." "There should be seniority, that's what we mean." "And there are people that don't know how to do the work . . . why are they paying us the same? Because they don't know how to do much." "When we become permanent the wage goes up, [but] there are people here that have worked here for years and they still don't make as much as if they were permanent."
Communication	
Uninformed about certain topics	"Yes. Like they didn't tell us what it was about or anything, just go to the office." "But that's your supervisor because I was told last week. . . ." [about pending changes in pay] "Nobody told us anything." [about pending changes in pay] "It's something they say, but the boss has not told us exactly if it's true." [about changes in overtime laws] "No one has talked to us about that yet." [about changes in overtime laws] "We heard about it, but no one in the company has talked about what is going to change." [about changes in overtime laws] "I haven't heard anything here yet, from the managers . . . no. You just hear rumors."

Continued next page

TABLE 2 (*continued*). Summary of key themes for 22 permanent workers interviewed

Theme	Example
Communication (*continued*)	
Respectful treatment	"Right now there are people . . . they do not do good work, they mistreat, they shout, they do what they want, and then they are given seniority and no one tells them anything, nothing." "They [management] need to be harsher with the crew leaders here." "I think that the crew leaders, for example, those who are new, must be given many classes and first of all on how to treat people." "[When] they were told here that they are crew leaders, they will treat you badly." "Here people don't use insults or anything, everything is very nice." "Even if there are women and men together, there it's . . . respect everything, lots of respect."
Grievance procedures	Do you feel that you can't report a crew leader if you have an issue? "Yes, you can report. But it should be confidential [implied it was not usually]." "You can report but you do not see any change." "I've seen many things that supervisors do that are not okay and do not get in trouble — people chicken out [on reporting them]."
Nature of agricultural work	
Humane pace of work	"There are companies that . . . They say 'here we want 40 plants per hour per person.' And so we start working and we come out with 30 or 35 plants and they say you're coming out short . . .. In this company no, you just start working and they're not asking you for a number of plants." "It's very good because . . . people go at their own pace." "This company is very good because they give [people] work when they are older . . .. In other companies if they seem older, they don't want them. It's hard to find work. . .. Here for older people working is much more relaxed . . .. In other companies they make you move real fast . . . to make them [older people] leave."

job satisfaction categories. Interview transcripts were translated into English and the conversations sorted into key themes (table 2), which we used to illustrate our conclusions. Twenty-two permanent workers (18 laborers, two tractor drivers, two irrigators; 16 were female) at three companies participated in the interviews. The survey questionnaire was composed of items from multiple tools as outlined below.

Demographics

Key demographic variables were recorded from each worker: age, gender, employment status (seasonal or permanent) and zipcode of residence. Employers provided details on the pay and benefits workers received.

Job satisfaction

A modified and expanded version of the job satisfaction survey (JSS; Spector 1994), a general tool broadly applicable to most occupations, was employed. The JSS requires participants to rate their agreement on a 0–5 scale ("completely disagree" to "completely agree") for a series of statements relating to several categories of job satisfaction. We modified and expanded the JSS by adding our own statements pertaining to salient issues for California agricultural workers and Napa vineyards. Using factor analysis, we derived a final set of 45 statements (from an original 60), relating to 11 categories of job satisfaction (table 3). We refer to this final version as the agricultural job satisfaction survey (AJSS). From it, we derived numerical scores for each satisfaction category and an overall score for job satisfaction.

Turnover

We measured turnover using a turnover intentions scale (Abbas et al. 2012), a known antecedent of actual

TABLE 3. Categories of satisfaction and Cronbach's Alpha* reliability values for agricultural job satisfaction survey (AJSS) measures

Category†	Description	Alpha‡
Pay	Pay level and raises	**0.73**
Promotion	Promotion opportunities (including change in employment status)	0.52
Fringe benefits	Nonwage benefits, e.g., bonuses, health care, pension	**0.61**
Contingent rewards	Appreciation, recognition and rewards for good work	**0.64**
Supervision (crew only)	Competency, fairness and consideration of immediate supervisor	**0.67**
Communication	Communication within the organization	**0.62**
Co-workers	Interactions with others in your job role (crew members or supervisors)	0.50
Nature of agricultural work	Work tasks and general agricultural work environment	**0.70**
Family commitments	Work schedule and convenience with family commitments	0.59
Health consequences	Health consequences of agricultural work	**0.60**
Commuting	Distance and quality of journey to work	0.49
Crew (supervisors only)	Motivating and guiding crew; personal (dis)like of crew members	**0.62**
OVERALL SATISFACTION	**Sum of scores of all categories**	**0.89/0.91**§
Turnover intentions scale		**0.73**

* Cronbach's Alpha tests how well each set of questions measures what was intended when the statements were developed.

† Categories listed in bold type indicate those that were drawn from the job satisfaction survey (Spector 1994). Statements for the other categories were developed by the research team.

‡ Reliability for the AJSS categories was largely commensurate with the job satisfaction survey reliability data, which are cited between 0.62 and 0.82 (Spector 1994). Values indicated in bold type fall within or near this range; lower values indicate these results should be treated with caution and require future study.

§ Overall survey reliability for crew version/supervisor version. The survey differed for crew and supervisors on one category: "supervision" for crew members, "crew" for supervisors, to reflect their different roles.

turnover (Wood et al. 2011). This is a three-item tool that quantifies the thoughts and plans an employee has about quitting a job.

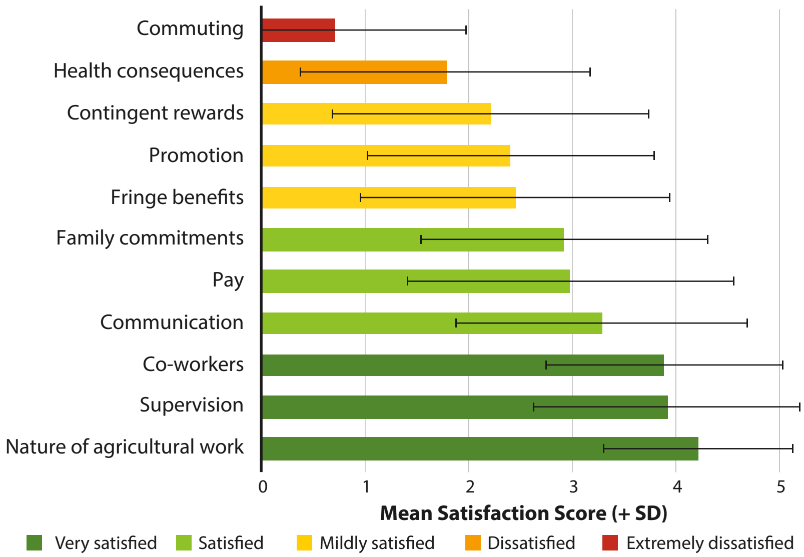


FIG. 1. Mean (+ SD) job satisfaction scores for 611 crew members who participated in the 2018 survey.

Worker satisfaction varied across categories

Participating workers were "very satisfied" or "satisfied" with six of the measured categories and "mildly dissatisfied" to "extremely dissatisfied" with five categories (fig. 1), albeit with variation between individuals as indicated by the standard deviations. Workers were "very satisfied" with the nature of agricultural work, their supervisors and co-workers. Satisfaction levels were relatively high for internal communication, pay and family commitments. Workers were "extremely dissatisfied" with their commute to work and "dissatisfied" with the health consequences of vineyard work (see sidebars, pages 35 and 37). They were "mildly dissatisfied" with the fringe benefits offered, promotional opportunities and contingent rewards.

Seasonal and permanent workers, and male and female workers, did not differ ($ps > 0.05$) on overall satisfaction scores. However, seasonal workers were significantly more dissatisfied with the nature of agricultural work ($p < 0.00$), and men more dissatisfied with supervision ($p < 0.00$). We also found that the age of workers was positively correlated with the nature of agricultural work ($r = 0.16$), health consequences ($r = 0.12$) and promotion ($r = 0.10$).

Supervisors have higher job satisfaction

We analyzed the data for the 54 supervisors separately. Terminology differs among employers, but most participants were crew leaders — that is, they were responsible for supervising a single crew. A few participants (typically in the smaller companies) also fulfilled higher supervisory roles, under the title field supervisor.

Overall, supervisors had greater job satisfaction than the workers they managed, expressing dissatisfaction on average with just two categories: commuting and health consequences (fig. 2). Despite expressing dissatisfaction with commuting, the average commuting score was considerably higher than laborers' commuting score (and with widespread variation), reflecting supervisors' closer proximity to their place of work (see sidebar, page 35). As with laborers, the supervisors were "very satisfied" with the nature of agricultural work and co-workers. Supervisors were also "very satisfied" with their pay, which ranged between \$19.00 and \$29.00 per hour when they were strictly crew leaders, and up to \$34.00 when they also fulfilled other supervisory duties.

As with the crew members, overall job satisfaction was negatively correlated with turnover intentions ($r = 0.65$), illustrating the importance of job satisfaction for retaining supervisory-level employees. The lower sample size precluded regression analysis, but we did note that correlations with turnover intentions were strongest between family commitments ($r = 0.69$) and communication ($r = 0.54$), suggesting that supervisor turnover may be driven by issues similar to the ones affecting crew member turnover.

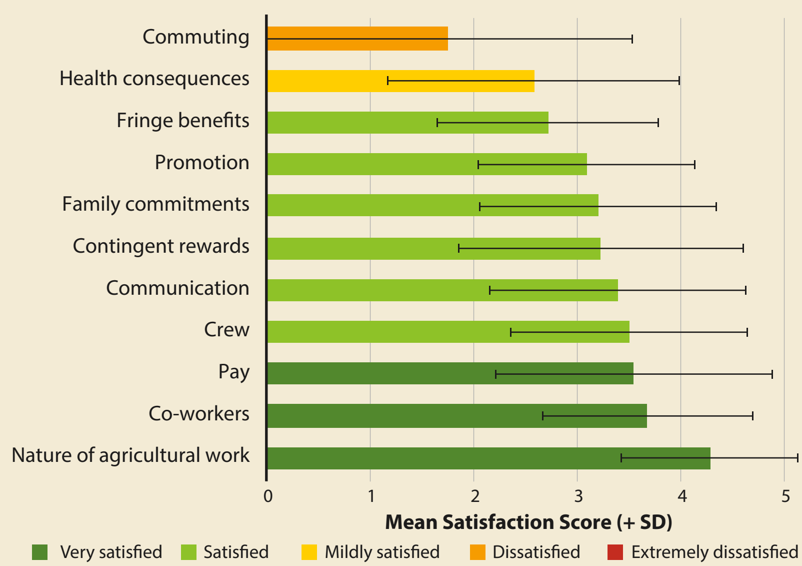


FIG. 2. Mean (+ SD) job satisfaction scores for 54 supervisors/crew leaders who participated in the 2018 study.

Commuting: Where do Napa workers live?

Supervisors tended to reside in or close to Napa, within a radius of 20 to 30 miles, with the farthest living in Fairfield (fig. 3). Of the permanent workers, 35% lived in Napa County, with the remainder primarily commuting from Solano (30%; 15 to 30 miles) and smaller proportions living in San Joaquin, Sonoma, Yuba and Lake counties. A small number of seasonal workers (14%) lived in Napa, but most commuted from Solano (23%) and San Joaquin (30%) counties, with a significant number travelling extraordinary distances, to a radius of 226 miles: notably Yuba City (100 miles), Madera (185 miles), and Parlier (226 miles). Thus, the majority of permanent and seasonal laborers in this sample faced long and exhausting commutes from outside Napa County, reflected in the "extremely dissatisfied" rating for commuting (fig. 1; table 2). Travel times even for workers closest to Napa (e.g., Vallejo, Fairfield) can be lengthy at busy times of the day on roads that are frequently gridlocked with traffic.

In Napa County, a chronic housing shortage has forced farmworkers to reside outside the county (Strochlic et al. 2007). Supervisors and permanent workers earning a higher wage can more easily live near their place of work, but there is insufficient affordable accommodation for the seasonal labor force. Online real estate searches (e.g., rentjungle.com) show that in the time period we conducted this study residential property rent in Napa averaged \$2,500 per month, compared to \$1,800 in Fairfield, \$1,100 in Stockton and \$700 in Yuba City.

The inability to house sufficient workers in Napa has produced higher wages than in surrounding counties (FELS 2010; Martin et al. 2018), as companies must attract workers from farther afield. Our data indicate that this approach is broadly successful, if not a complete solution: pay was a predictor of turnover, but commuting was not. Farmworkers come to work in Napa vineyards for higher pay despite punishing commutes. However, long commutes have negative impacts on safety (Milia et al. 2012), health (Stutzer and Frey 2008), work performance/productivity and relationships with other employees (Michie 2002) and family (Sandow 2010).

Housing problems can be addressed by government authorities and private industry. The best solution may be to build more affordable farmworker housing; although expensive in the short term, this may have long-term benefits, particularly if employers can no longer afford competitively high wages necessary to draw in workers. Napa County has three efficiently run farmworker housing centers for 180 workers (Eberling 2018), which may partially account for the populations of workers we found living in Napa. The county also offers rental assistance to low-income households (Watt 2010). Companies can also opt to provide housing for workers. This would help them take advantage of the H2-A program, although they may be unwilling to take on the cost and management burdens or to be as challenged as the government is to find sites for affordable housing.

Commute and housing issues can also be partially addressed by improving transport networks to make commutes more efficient and less stressful. Most workers travelled to work in their own cars or in private ride shares. Unfortunately, shared transport, vanpool programs (Strochlic 2009) and public transit are likely to face resistance from workers, who, although generally supportive, were blunt about preferring their own transport. Company-owned vans are also costly, and many managers would prefer to know workers will use them before justifying such investment.

Despite spending large portions of their wages on gas (table 2), these workers valued the flexibility of their own vehicle, so fuel allowances for workers may be the lowest-cost option for companies to help workers. Workers in this study employed by management companies did also suggest a low-cost strategy could be to rotate crews to different vineyards to shorten their commutes for at least part of the season, although this is only an option for a company that works in multiple vineyard sites.

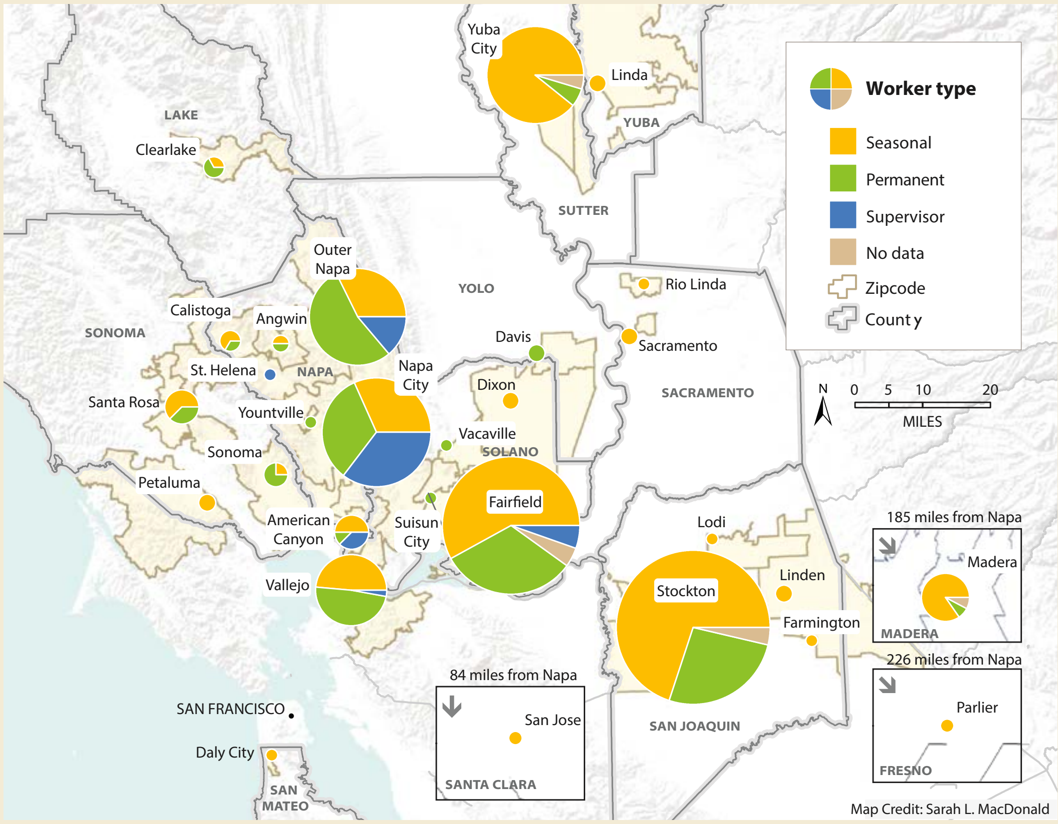


FIG. 3. Zipcodes of residence for Napa County vineyard workers. Permanent and seasonal workers and supervisors provided their home zipcodes. Size of pie is representative of number of workers in that area, with the smallest pie (St. Helena) = 1 participant and the largest pie (Stockton) = 138 participants.

TABLE 4. Summary of regression analysis

Variable	β (standardized)	Hayes adjusted standard errors	Zero order correlations with turnover intentions
Pay	0.20**	0.042	0.41
Promotion	0.02	0.052	0.27
Fringe benefits	0.09	0.047	0.25
Contingent rewards	0.02	0.048	0.37
Supervision	0.02	0.047	0.35
Communication	0.23**	0.054	0.49
Co-workers	0.07	0.053	0.31
Nature of agricultural work	0.19**	0.040	0.42
Family commitments	0.19**	0.041	0.47
Health consequences	0.08*	0.048	0.39
Commuting	0.04	0.100	0.06
R^2	0.46		
F	23.0**		
Valid responses	402		

* $p < 0.05$, ** $p < 0.01$. The assumptions of regression were checked using p-p plots to assess normality, scatterplots of predicted values and residuals to assess homoscedasticity, and VIF values (< 5) to assess multicollinearity. Participant responses were nested at a higher level within 14 companies, so heteroscedasticity-consistent adjusted standard errors were used when testing for significance (Darlington and Hayes 2017).

Four categories predicted turnover

Overall job satisfaction had a moderate negative correlation ($r = 0.59$) with turnover intentions, indicating that dissatisfaction was associated with an increased intent to quit a company. We used regression to explore the specific satisfaction categories that predicted turnover intentions, with age, gender and employment status as control variables, and the 11 satisfaction categories as predictors of the turnover intentions measure.

Four satisfaction categories significantly predicted turnover intentions, with a negative relationship in each case, and explained 46% of the variance in turnover intentions (table 4). Communication had the greatest influence (0.23), closely followed by pay (0.20), family commitments (0.19) and nature of agricultural work (0.19). The remaining categories did not significantly predict turnover intentions, although fringe benefits ($p = 0.08$) and health consequences ($p = 0.09$) were close to significance.

Although important, raising pay is not the only avenue to address worker retention, and employers can be proactive in implementing low-cost strategies to reduce turnover with limited resources.

This study accounted for 46% of the variance of turnover intentions, leaving 64% unaccounted for by variables we did not measure. These could include reunification with family from home country (Gonzalez-Barrera 2015), workplace sexual harassment (Hobbs et al., unpublished data; Prado et al. 2018) and employment security (Strochlic and Hammerschlag 2006). Although we attempted to measure the latter, our statements failed as a reliable measure and we ejected them from the results. However, we acknowledge the importance of addressing other potential factors in future studies.

Strategies to boost worker retention

In our study population, vineyard worker turnover was explained by four categories of job satisfaction. Although this regression analysis cannot determine causation, our results suggest that Napa vineyard companies can best boost worker retention and alleviate labor shortages by focusing resources on strategies to improve these aspects of the work environment. It should also be evident that, although important, raising pay is not the only avenue to address worker retention and that employers can be proactive in implementing low-cost strategies to reduce turnover with limited resources. Additionally, employers who are already offering competitive pay rates can address worker retention using the other strategies. The interviews (table 2) and Strochlic and Hammerschlag (2006) provided further detail on these strategies.

Effective communication (low-cost strategy)

The importance of communication likely lies in its ability to signal respectful treatment, and, when it's poor, to exacerbate other problems, making them hard to resolve. Respectful treatment is very important for workers who have been abused and exploited on farms (Strochlic and Hammerschlag 2006). Strategies to improve communication include respectful communication styles (e.g., "no yell" policies), direct grower-worker communication channels, decision-making structures that recognize the contribution of individual workers, training of supervisors, and specific company policies as to how workers should be treated.

The workers we interviewed did not raise many concerns about being disrespected, but some expressed concern about grievance procedures for reporting supervisors, gave mixed reports on the quality of communication and repeatedly claimed they did not feel well informed about some topics (e.g., pending changes to pay, why another worker got promoted over them). Companies should prioritize improving internal communication, given its role as the best predictor of turnover, and the strategies noted here are of very low cost in comparison with strategies for the second most important predictor of worker turnover: pay.

Improve pay (high-cost strategy)

Workers in Napa were generally happy with their pay rates, but responses varied considerably among workers. All workers in the sample received hourly pay (rather than piece rate), which ranged from $15.50 to more than $20.00. Satisfaction depended in part on whether a worker perceived their wage to be commensurate with what competitors were offering. A primary strategy to stabilize worker retention is to match average regional wages. Tracking changes in average wages can be difficult, especially currently, as new regulations are being phased in (Isom 2019). However, regional organizations and collaborations can generate comparisons and advice on setting appropriate wage levels.

Worker retention may also be improved by paying wages higher than the regional average to draw in workers from farther away. This tactic has been used in Napa County, which has the advantage of an industry that can support higher wages — at least over the short term. It has been somewhat useful in offsetting worker housing shortages (see sidebar, page 35); however, it can result in health consequences to the employee related to longer commute times. Above-average wages are a high cost to an employer, but lower-cost pay-related strategies are available. For example, as we learned during the interviews, structured pay scales that fairly reflect experience, seniority and company loyalty are important to workers. Pay rates that did not reflect company tenure/experience were unpopular, as were pay scales that delivered meager increases for seniority.

Help workers fulfill family commitments (medium-cost strategy)

Long work hours, unconventional work schedules that vary seasonally and frequently entail early start times, and the often insecure nature of agricultural employment make it challenging for workers to honor family commitments. Additionally, the agricultural workforce has become increasingly populated by individuals with greater family commitments (Fan et al. 2015). Agricultural work is typically more demanding in summer and less demanding in winter, but family commitments may be greater in summer months, when school is not in session, creating a conflict with agricultural work.

Also, seasonal workers in our study tended to commute greater distances than permanent workers (see sidebar, page 35). This is a challenge for seasonal workers not only because of the added travel time but working far from home can make it difficult to leave work in the middle of the day for family commitments or appointments. Additionally, seasonal workers tended to carpool, and the lack of a personal vehicle complicates the logistics of fulfilling family commitments.

Potential strategies include offering a reasonable number of vacation days for workers to rest and take care of family business, logistical flexibility where possible, a degree of personal freedom at work to take care of personal needs, and child care subsidies or the support of local initiatives for child care provision.

Consider nature of work (low-cost strategy)

The types of tasks performed and the general vineyard work environment (e.g., working outside) were an

Overall, seasonal workers who responded to the survey reported greater dissatisfaction with their jobs than permanent workers.

Health consequences: What health-related issues are workers concerned about?

Health consequences was the second lowest ranking satisfaction category and has been found to be important in other studies (Nather et al. 2015). Agricultural workers face numerous workplace health risks including heat illness (Stoecklin-Marios et al. 2013), pesticide exposure (Flocks et al. 2011), musculoskeletal problems (Osborne et al. 2012) and workplace accidents (McCurdy and Carroll 2000). Tackling such issues contributes to a healthier, more productive and sustainable workforce.

The permanent vineyard workers interviewed in this study (table 2) indicated they were satisfied with general health and safety practices of their employers, but some wanted greater provision of basic equipment (e.g., boots, gloves). There was also widespread concern about pesticide exposure and risk of chemical drift from neighboring vineyards. Given the substantial public investment in worker protection, future studies should further explore the risk, worker perceptions and possible synergies with improved communication around worker health and safety.

Employers can demonstrate a high regard for worker safety using low-cost methods such as providing essential equipment and effective health and safety education, training, equipment and protocols. They can also limit time spent on repetitive tasks where injuries are likely and ensure prompt medical attention in the case of serious injuries (Strochlic and Hammerschlag 2006). Higher-cost strategies include time off to recover from injuries or accidents followed by "light duty" (Strochlic and Hammerschlag 2006) and company-subsidized health coverage for workers.

Malcolm Hobbs

The authors suggest that companies can increase worker retention by adopting strategies to improve communication and pay, help workers fulfill family commitments, and provide a greater diversity of tasks.

important influence on turnover. Our study population was "very satisfied" with the nature of agricultural work, as has been reported in other California regions (Billikopf 1999), suggesting that workers who lack an affinity for agricultural work are weeded out quickly, leaving those who feel more positive about the work environment.

In our study, seasonal workers reported greater dissatisfaction than permanent workers. Seasonal work is the entry position into agricultural labor, and workers new to the vineyard environment may take time to adjust. Lacking experience, they may also have less responsibility and variety in tasks to perform. Although this category is largely beyond the control of a company, providing a greater diversity of tasks for workers could address some concerns (Strochlic and Hammerschlag 2006). Workers also appreciated a humane pace of work (table 2). This could be an especially important strategy for retaining older workers, who feel pressured by companies demanding strict time-based outputs.

Expanding job satisfaction surveys to other agricultural regions and commodities

The sample in this study was restricted to vineyard workers in Napa County. Although the levels of job satisfaction (fig. 1) are specific for this population and cannot be generalized to other agricultural worker populations, the AJSS could be utilized in other regions to assess local conditions and develop remediation strategies. The four categories of satisfaction that predicted turnover in Napa vineyard workers may be important in other regions and agricultural industries. For example, crop and dairy workers ranked fair pay and family issues as the top reasons for seeking other employment (Billikopf 1984, 1999), and communication was the attribute workers most valued in their supervisors (Billikopf 1999).

There are also indications that some of the categories important for turnover might extend to employees in supervisory jobs (see sidebar, page 34). However, replicated studies in other regions with workers of different demographic circumstances are required to fully determine how far these results can be generalized. The original survey (JSS), of which the AJSS is a modified form, is a general tool designed to be used across occupations, and the AJSS retains this broad approach. In summary, the AJSS is a tool to study any population of workers within the agricultural industry to understand their job satisfaction and to develop strategies to promote job satisfaction.

Employers can be proactive

Our work highlights that agricultural employers can be proactive in retaining employees to offset labor shortages using cost-efficient methods. Although it is critical to offer wages commensurate with the regional average, a combination of improvements in communication, diversity of work tasks and consideration for family commitments can influence turnover to a greater degree than further increases in pay alone.

We captured a snapshot of vineyard worker satisfaction in 2018; some employers had already adopted strategies to improve job satisfaction and some had not, which may account for some of the variability in the levels of satisfaction among workers. Future studies may seek to evaluate which strategies are most effective by assessing changes in worker perceptions before and after the introduction of new practices, using tools such as the AJSS.

In addition to reducing turnover, improving job satisfaction can also increase work performance and worker health outcomes. Therefore, the satisfaction categories that did not predict turnover should not be dismissed, as dissatisfaction in these areas can contribute to other negative consequences.

The AJSS tool overall proved reliable, but it contains four categories with low reliability (< 0.60, table 3) that require further adjustment and retesting in future studies. In the long term, we are confident that adoption of this tool by the industry could support improvements in productivity, worker health and happiness, and promote the sustainability of the agricultural workforce. CA

M. Hobbs is Staff Research Associate and M. Cooper is Farm Advisor, UC Cooperative Extension Napa County; and E. Klachky is Technical Coordinator, Food and Agriculture Division, SCS Global Services.

This study was partially funded by the Western Center for Agricultural Health and Safety, NIOSH #2U54OH007550, and by private donations (solicited through experiment.com). We gratefully acknowledge the participation of workers and the willingness of their employers to facilitate that.

References

Abbas M, Raja U, Darr W, Bouckenooghe D. 2012. Combined effects of perceived politics and psychological capital on job satisfaction, turnover intentions, and performance. J Manag 40(7):1813–30. doi:10.1177/0149206312455243

Billikopf G. 1984. Why workers leave dairies. Calif Agr 38(9):26–8.

Billikopf G. 1999. Farmworkers positive about their jobs, but suggest improvements. Calif Agr 53(1):33–6.

Charlton D, Taylor E. 2013. Mexicans are leaving farm work: What does it mean for U.S. agriculture and immigration policy? ARE Update 16:1–4.

Darlington RB, Hayes AF. 2017. *Regression Analysis and Linear Models: Concepts, Applications, and Implementation*. New York: Guilford Press.

Downing J. 2018. Next generation mechanization: New advances in image-recognition technology and robotics are reducing the need for manual labor — and potentially herbicides as well. Calif Agr 72(2):102–4.

Eberling B. 2018. Napa County prepares to raise vineyard assessment for farmworker housing. *Napa Valley Register*, June 5.

Erdogan B, Bauer T, Truxillo D, Mansfield L. 2012. Whistle while you work: A review of the life satisfaction literature. J Manag 38(4):1038–83.

Fan M, Gabbard S, Alves-Pena A, Perloff J. 2015. Why do fewer agricultural workers migrate now? Am J Agr Econ 97(3):665–79.

Faragher E, Cass M, Cooper C. 2005. The relationship between job satisfaction and health: A meta-analysis. Occup Environ Med 62:105–12.

[FELS] Farm Employers Labor Service. 2010. Agricultural Wage and Benefit Survey. California Assoc. of Winegrape Growers. www.cawg.org

Flocks J, Kelley M, Economos J, McCauley L. 2011. Female farmworkers' perceptions of pesticide exposure and pregnancy health. J Immigr Minor Health 14(4):626–32.

Gonzalez-Barrera A. 2015. More Mexicans leaving than coming to the U.S. Pew Research Center, Washington DC, November.

Griffeth R, Hom P, Gaertner S. 2000. A meta-analysis of antecedents and correlates of employee turnover: Update, moderator tests, and research implications for the next millennium. J Manag 26(3):463–88.

Hertz T, Zahniser S. 2013. Is there a farm labor shortage? Am J Agr Econ 95(2):476–81.

Hobbs M, Cooper M. 2017. Changing gender diversity of the California vineyard labor force and implications for grape production. Catalyst: Discovery into Practice 1:99–102. doi:10.5344/catalyst.2017.17008

Isom R. 2019. New and changing labor laws go into effect on January 1st. West Coast Nut, February.

Judge T, Thoresen C, Bono J, Patton G. 2001. The job satisfaction-job performance relationship: A qualitative and quantitative review. Psychol Bull 127(3):376–407.

Lambert E, Hogan N, Barton S. 2001. The impact of job satisfaction on turnover intent: A test of a structural measurement model using a national sample of workers. Soc Sci J 38(2):233–50.

Locke E. 1976. The nature and consequences of job satisfaction. In: *Handbook of Industrial and Organizational Psychology*. Dunnette MD (ed.). Chicago: Rand-McNally. p 1297–349.

Martin P, Cheung F, Knowles M, et al. 2011. *IAAP Handbook of Applied Psychology*. Chichester, UK: Wiley-Blackwell.

Martin P. 2018. The race in the fields: Imports, machines and migrants. Calif Agr 72(2):100–1.

Martin P, Hooker B, Stockton M. 2018. Employment and earnings of California farmworkers 2015. Calif Agr 72(2):107–13.

McCurdy S, Carroll D. 2000. Agricultural injury. Am J Ind Med 38(4):463–80.

Michie S. 2002. Causes and management of stress at work. Occup Environ Med 59:67–72.

Milia L, Rogers N, Akerstedt T. 2012. Sleepiness, long distance commuting and night work as predictors of driving performance. PLOS ONE. doi.org/10.1371/journal.pone.0045856

Nather M, Stratmann C, Bendfelt C, Theuvsen L. 2015. Which factors influence the job satisfaction of agricultural employees? In: Proc XXVI Eur Soc Rural Sociol Congress, Aug. 18–21. Aberdeen, Scotland.

Osborne A, Blake C, Fullen B, et al. 2012. Risk factors for musculoskeletal disorders among farm owners and farm workers: A systematic review. Am J Ind Med 55:376–89.

Peri G. 2018. Napa Valley Wages & Benefits Survey Results. The Business of Vineyards — Part II: Labor & the Napa Valley Workforce. Napa Valley Grapegrowers Seminar, May.

Prado K, Martinez-Servin L, Guzman-Carillo K, et al. 2018. Workplace sexual harassment (WSH) in agriculture: Experiences, perspectives, attitudes, and beliefs among men and women farmworkers in California, USA and Michoacan, MX. In: Proc 13th Summer Institute on Migration and Global Health, Jun. 18. Oakland, California.

Sandow E. 2010. Till work do us part — The social fallacy of long-distance commuting. In: Proc 50th Congress of the European Regional Science Association: "Sustainable Regional Growth in the Creative Knowledge Economy", Aug. 19-23 Jönköping, Sweden.

Singh P, Loncar N. 2010. Pay satisfaction, job satisfaction and turnover intent. Ind Relat 65(3):470–90.

Spector PE. 1994. Job Satisfaction Survey. University of South Florida, Tampa, FL. www.statisticssolutions.com/job-satisfaction-survey-jss/

Stoecklin-Marios M, Hennessey-Burt T, Mitchell D, Schenker M. 2013. Heat-related illness knowledge and practices among California hired farm workers in MICASA study. Ind Health 51:47–55.

Strochlic R. 2009. An Assessment of the Demand for a Vanpool Program Serving Agricultural Workers in Napa County. California Institute for Rural Studies, Davis, CA.

Strochlic R, Hammerschlag K. 2006. Best Labor Practices on Twelve California Farms: Towards a More Sustainable Food System. California Institute for Rural Studies, Davis, CA, January.

Strochlic R, Villarejo D, Nichols S, et al. 2007. An Assessment of the Demand for Farm Worker Housing in Napa County. California Institute for Rural Studies, Davis, CA.

Stutzer A, Frey B. 2008. Stress that doesn't pay: The commuting paradox. Scand J Econ 110(2):339–66.

Tnay E, Othman E, Siong H, Lim S. 2013. The influences of job satisfaction and organizational commitment on turnover intention. Procedia Soc Behav Sci 97: 201–8.

Watt N. 2010. Affordable Housing Trust Fund: Notice of Funding Availability for Development of Affordable Rental Housing. County Executive Office, Napa, June.

Wegge J, Schmidt K, Parkes C, Dick R. 2007. 'Taking a sickie': Job satisfaction and job involvement as interactive predictors of absenteeism in a public organization. J Occup Organ Psychol 80:77–89.

Wood R, Roberts V, Whelan J. 2011. Organizational psychology. In: *IAAP Handbook of Applied Psychology*. Martin P, Cheung F, Knowles M, et al. (eds.). Chichester, UK: Wiley-Blackwell. p 233–68.

RESEARCH ARTICLE

Youth in 4-H Latino Initiative programs achieve similar outcomes to youth in 4-H community clubs

Results from a pilot study suggest that adaptations to strengthen the cultural relevance of 4-H programs increase the number of Latino youth while realizing similar youth development outcomes.

By Steven Worker, Maria Fábregas Janeiro and Kendra Lewis

Abstract

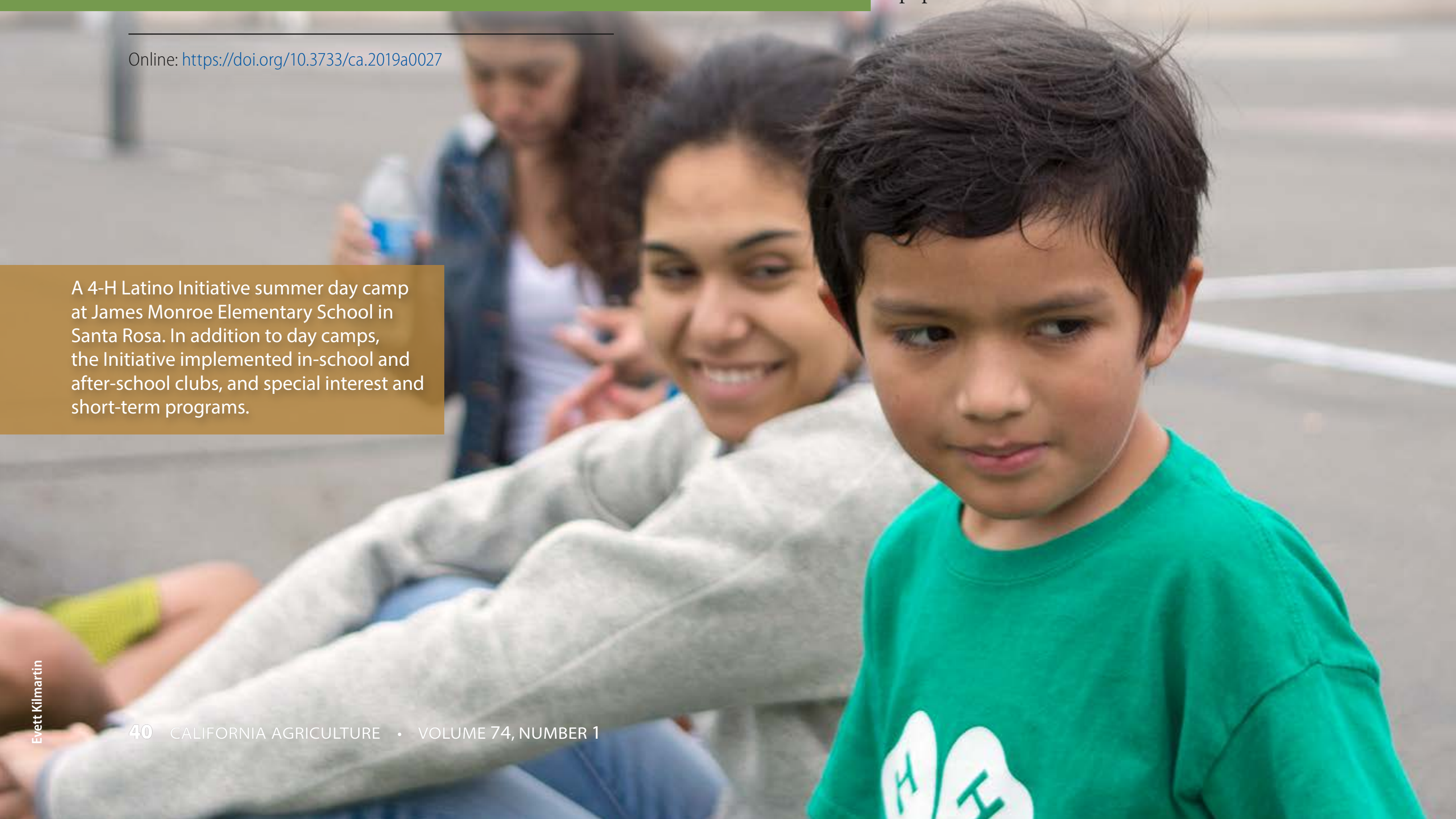
Until recently, California 4-H programs did not represent the ethnic diversity found in California's population of young people. To close the gap in representation — particularly with Latino youth — UC ANR began the 4-H Latino Initiative, an effort to pilot adapted programs that would target the engagement of Latino youth and families. In this paper, we explore and compare young people's program experience and youth development outcomes between 4-H community clubs and 4-H Latino Initiative programs. We employed comparative post-test survey methodology with two treatment groups (community clubs versus 4-H Latino Initiative programs). The findings provide encouraging evidence that young people experienced positive outcomes from participating in 4-H programs, inclusive of both 4-H community clubs and 4-H Latino Initiative programs. Additionally, we found that the program experience — including relationship building and youth engagement — were similar across community clubs and 4-H Latino Initiative programs.

Online: https://doi.org/10.3733/ca.2019a0027

The U.S. population is now 327 million people, up from 76 million in 1902, when 4-H was founded (US Census Bureau 1901, 2018). By 2020, more than half of U.S. children will be from a race or ethnic group other than non-Hispanic white (Chappell 2015). In California, over 54% of the K–12 student population identifies as Hispanic or Latino (Ed-Data 2018). However, until recently, California 4-H programs did not represent this population well. For example, in the 2014–2015 school year, California 4-H served 73,246 youth, with only 24,042 youth (33%) identifying as Hispanic or Latino, a gap of more than 21 points.

Adapted programming to engage Latino youth

UC Agriculture and Natural Resources (UC ANR) is committed to reaching all segments of the state's population in order to contribute to an inclusive and



A 4-H Latino Initiative summer day camp at James Monroe Elementary School in Santa Rosa. In addition to day camps, the Initiative implemented in-school and after-school clubs, and special interest and short-term programs.

Evett Kilmartin

equitable society. Starting in the early 2010s, UC ANR Cooperative Extension advisors responsible for academic leadership of the 4-H Youth Development Program began to explore how 4-H could better serve Latino youth. The research base supported this transformation; other Cooperative Extension academics argued that 4-H must "become a more nimble organization, addressing the complex needs of young people from diverse backgrounds and settings" (Borden et al. 2014).

In 2015, UC ANR invested resources for a pilot effort, the 4-H Latino Initiative, focused on adapting programming to become culturally relevant and responsive to Latino youth — that is, programming that recognized effects of discrimination and economic poverty, tapped assets unique to local Latino youth (such as experience navigating two cultures), engaged Latino families and communities, and encouraged positive ethnic identity (Erbstein and Fabionar 2014). While the 4-H Latino Initiative focused on Latino youth, the hope was that adapted programming would emerge to help UC ANR better serve all youth of color.

The 4-H Latino Initiative

The 4-H Latino Initiative was piloted in seven counties. Full-time bilingual 4-H staff were hired in each county to assess interests of the Latino community, market 4-H to Latino families and communities and implement culturally responsive 4-H programs. The 4-H Latino Initiative permitted flexibility in program models, structure and curriculum, within existing 4-H delivery modes (i.e., pre-defined program categories consisting of community clubs, special interest programs, short-term programs, day camps, after-school and in-school clubs, and school enrichment), adapted to be culturally responsive for Latino youth and families. One significant factor was identifying how to adapt programming to engage Latino youth, be inclusive and accessible, and that offered similar high-quality youth development achieved by 4-H community clubs. While Cooperative Extension has used an array of 4-H delivery modes other than 4-H community clubs for decades, this paper reports on data from the second year of a 3-year initiative to adapt programming to become more culturally relevant for Latino youth.

Efforts to be culturally relevant and responsive were built on work from Gay (2010) and Ladson-Billings (2014). Culturally responsive programs involve building and sustaining the engagement of Latino youth and families, which require that staff have intercultural skills, rethink recruiting processes and approach communities with a holistic cultural perspective (Fábregas Janeiro and Bird 2018; Fábregas Janeiro and Horrillo 2017). The 4-H Latino Initiative program adaptations included employing bilingual and bicultural staff and bilingual volunteer leaders, recruiting local Latino teenage mentors, providing opportunities for family involvement, choosing locations likely to target engagement of Latino youth and families, and including relevant curriculum selected by youth and families.

By the end of the second year of the 4-H Latino Initiative, all seven counties demonstrated an increase in Latino youth involvement and an increase in the proportion of Latino 4-H youth. Over the first 2 years of the Initiative, the seven counties reached an additional 10,000 Latino youth.

4-H community club legacy

The 4-H community club delivery mode began with the origins of the 4-H program in 1902 (Howe 1911; Wessel and Wessel 1982). The community club model quickly became the prevalent program model, a legacy that continues to the present day. Community clubs have been shown to support youth leadership, community service and project-based learning (Forero et al. 2009). However, as scholars have pointed out, many youth programs that formed at the turn of the 20th century have primarily served youth from dominant social groups and been less successful serving marginalized youth, youth of color, or youth from non-dominant social groups (Russell and Van Campen 2011).

Although the community club delivery mode was explored initially, community clubs were not heavily utilized in the 4-H Latino Initiative. The 4-H Latino Initiative programming primarily targeted new communities with no awareness or investment in 4-H, and thus, new bilingual 4-H staff experienced difficulties recruiting adult volunteers for long-term volunteer commitments with heavy administrative overhead. Additionally, staff encountered challenges working with existing community clubs to make adaptations to better reach Latino youth (Worker et al. 2019). Instead of utilizing the community club delivery mode, 4-H staff in the seven counties implemented programming using other 4-H delivery modules

Steven Worker

An elementary school student learns engineering design principles using building blocks in a 4-H after-school club. In its first 2 years, the 4-H Latino Initiative reached an additional 10,000 Latino youth in California.

TABLE 1. 4-H Latino Initiative programs

County	Delivery mode	No. of sessions	Session length	Age range	Approx. no. of participants	Direct delivery educator
			hours	*years*		
Kern	Special interest*	6	2.0	5–18	Age 5–8: 11 Age 9–18: 17	UC Cooperative Extension (UCCE) staff, partner organization staff, 4-H volunteers (teenagers), 4-H volunteers (adults)
Merced	Day camp†	12	2.0	14–18	Age 14–18: 18	UCCE staff, 4-H volunteers (adults)
Merced	Short-term*	6	2.5	14–18	Age 14–18: 11	UCCE staff, partner organization staff
Monterey	4-H after-school club	18	3.0	5–10	Age 5–8: 10 Age 9–18: 7	Partner organization staff
Orange	Special interest*	10	2.0	5–10 14–18	Age 5–8: 10 Age 9–18: 15	UCCE staff
Riverside	Special interest*	6	1.0	5–13	Age 5–8: 50 Age 9–18: 20	UCCE staff
Santa Barbara	4-H in-school club	30	1.0	11–13	Age 5–8: 71	UCCE staff
Sonoma	4-H after-school club	30	2.0	5–10 14–18	Age 5–8: 34 Age 9–18: 39	UCCE staff, 4-H volunteers (teenagers), 4-H volunteers (adults)

* Special interest and short-term are learning experiences not part of a club or school. Both must meet a minimum of 6 hours; short-term is no more than 6 weeks.

† Day camp is a planned educational experience where youth return home each evening.

TABLE 2. Demographics of older youth (age 9 to 18)

Demographic variable	4-H community clubs (*n* = 495)	4-H Latino Initiative programs (*n* = 131)
	%	%
Gender		
Female	64.6	45.5
Male	35.4	54.5
Ethnicity		
Non-Hispanic or Latino	83.2	23.1
Hispanic or Latino	16.8	76.9
Race		
White	82.7	65.1
Black or African-American	0.4	20.6
Asian	3.2	3.2
American Indian or Alaska Native	2.8	3.2
Native Hawaiian or other Pacific Islander	0.0	1.6
Multiple races	6.3	6.3
Undetermined	4.5	0.0
Residence		
Farm	20.6	3.2
Town (nonfarm, rural, population < 10,000)	20.2	4.8
Town or city (population 10,000–50,000)	23.0	42.7
Suburb of city (population > 50,000)	25.5	8.1
Central city (population > 50,000)	10.7	41.1
	Mean (SD)	*Mean (SD)*
Age	12.46 (2.31)	12.12 (2.56)
Years in 4-H	4.25 (2.63)	1.73 (0.82)

Note: Percentage is based on valid percent; that is, based on those who answered the question.

(including day camps, special interest, short-term, in-school and after-school clubs).

Surveys of youth in 4-H community clubs and 4-H Latino Initiative programs

We sought to compare young people's outcomes and experience in 4-H community clubs with young people's outcomes and experience in 4-H Latino Initiative programs to determine whether the 4-H Latino Initiative programs offered similar experiences and outcomes to 4-H youth. We employed post-test survey methodology using the same measures with two treatment groups to compare their means (Rea and Parker 2005). Our hypothesis was that there would be no statistical differences in the means on all measures. California youth (aged 5 to 18) participated in either a 4-H community club or 4-H Latino Initiative program during the 2017–2018 program year. Data was collected from youth as their respective programs neared conclusion. Table 1 summarizes eight 4-H Latino Initiative programs included in this study (note: more than eight programs were implemented but youth surveys were only administered in these eight), and their core components. Community club youth, aged 9 to 18, completed surveys online using the Online Record Book (ORB) (for an explanation of ORB, see Lewis and Worker 2016), Qualtrics, or paper and pencil. Younger youth, aged 5 to 8, completed surveys at state events near the end of the program year. 4-H Latino Initiative program youth, aged 5 to 18, completed the surveys using paper and pencil near the end of their respective program. We used a convenience sampling method. Youth demographics are presented in tables 2 and 3. Ethnicity and residence information was not collected for youth aged 5 to 8. Demographics for youth in the community club program were pulled from the 4HOnline enrollment system. Demographics for youth in 4-H Latino Initiative programs were collected on the last page of their survey. Youth self-identified their race and ethnicity using the options in table 2.

We employed two survey instruments, one for youth aged 9 to 18 and another for younger youth, aged 5 to 8. Both survey instruments assessed youth development outcomes and program experience.

To assess program outcomes of older youth, aged 9 to 18, we used the National 4-H Common Measures 2.0 universal measure, which assesses social, emotional, character and leadership skills necessary for academic or workplace success (Hawley n.d.). The measure consists of 23 items; 10 items assess personal mindset (social and emotional skills; e.g., character, growth mindset and decision-making), 10 items assess social skills (social and leadership skills; e.g., ability to communicate, value and respect for other cultures) and three items are negatively worded to encourage deeper processing and are not included in the analyses. All personal mindset and social skills items provide four-point response options, coded such that No = 1, Not really = 2, Usually = 3 and Yes = 4. The National 4-H Common Measures 2.0 universal measure scale Cronbach alpha reliability was reported as 0.84 (Hawley n.d.). In the current study, both the personal mindset and social skills scales showed excellent Cronbach alpha reliability in community clubs (0.80 and 0.78, respectively) and in 4-H Latino Initiative programs (0.80 and 0.83, respectively).

The older youth's program experience was assessed using a measure with items developed by academic coordinators and Cooperative Extension specialists; the Thrive Foundation for Youth, YMCA and Camp Fire; and Zeldin et al. (2014). Four items assess relationship building (e.g., "I feel like I belong in 4-H" and "Adults in 4-H support me when I try something new") and 12 items assess youth engagement (e.g., "I think youth and adults learn a lot from working together in 4-H", "I have a say in planning the activities in 4-H" and "I think youth in 4-H have opportunities to lead an activity"). Items provide five-point response options, coded as Strongly disagree = 1 to Strongly agree = 5, or Never = 1 to Most of the time = 5. Both the relationship building and youth engagement scales showed excellent reliability in community clubs (0.77 and 0.92, respectively) and in 4-H Latino Initiative programs (0.83 and 0.89, respectively).

The survey for the younger youth, aged 5 to 8, consisted of 10 items developed by academic coordinators. Six items assess outcomes and four items measure program experience. All items are on a five-point scale. We adapted the Wong-Baker Faces pain rating scale (Wong and Baker 2000) so the saddest face matches to Disagree and the happiest face matches to Agree; the middle three faces do not have a written anchor.

To analyze the older youth survey, we first created scales that represent the mean score for each set of questions (i.e., personal mindset, social skills, relationship building, youth engagement). Difference in these mean scores and items was tested using independent samples *t*-tests. Significance level was set at $p < 0.05$. Younger youth survey items were analyzed individually; no scales were created. Sample size for each analysis varied based on missing data; numbers (*n*) are noted in the figures. Cohen's *d* (Cohen 1988) effect sizes were calculated and are presented for significant effects; an effect size of 0.20 is small and 0.50 is medium.

Outcomes and experience of older youth

In terms of outcomes among the older youth (9 to 18), the means were higher for community clubs than for 4-H Latino Initiative programs on both scales. We calculated independent samples *t*-tests to compare the means. There was not a statistically significant difference between groups on personal mindset, but there was a statistically significant difference for social skills; $t(178) = 2.48$, $p < 0.05$, effect size = 0.26; although the practical significance (effect size) was small (fig. 1).

In terms of program experience, the means were higher for community clubs than for 4-H Latino Initiative programs on relationship building, but were the same for youth engagement. An independent

TABLE 3. Demographics of younger youth (age 5 to 8)

Demographic variable	4-H community clubs (*n* = 149)	4-H Latino Initiative programs (*n* = 124)
	%	%
Gender		
Female	52.2	48.0
Male	47.8	52.0
	Mean (SD)	*Mean (SD)*
Age	7.08 (1.15)	7.06 (0.91)
Years in 4-H	1.87 (1.15)	1.17 (0.38)

Note: Percentage is based on valid percent; that is, based on those who answered the question.

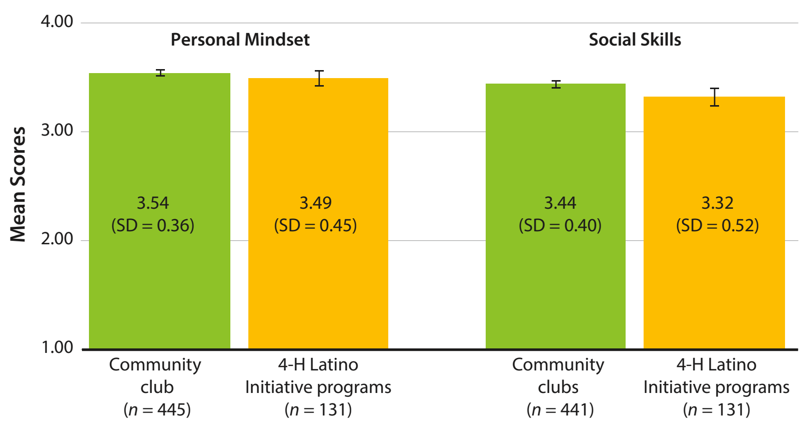


FIG. 1. Descriptive statistics for the personal mindset and social skills of the older youth (age 9 to 18), in community club and 4-H Latino Initiative programs. SD = standard deviation. Error bars are two times the standard error.

samples t-test revealed a significant difference between groups on relationship building; $t(329) = 2.06$, $p < 0.05$, effect size = 0.22. The practical significance between the means on relationship building was small (fig. 2).

Outcomes and experience of younger youth

In terms of outcomes among the younger youth (5 to 8), the means were higher for community clubs than for 4-H Latino Initiative on all six items. We calculated independent samples t-tests between the means. The only statistically significant result was a difference between the means on the item "It is important to make good choices"; $t(182) = 2.00$, $p < 0.05$, effect size = 0.24 (table 4).

In terms of program experience, the means were higher for community clubs than for 4-H Latino Initiative programs on all four items; however, independent samples t-tests revealed no significant differences on all items (table 5).

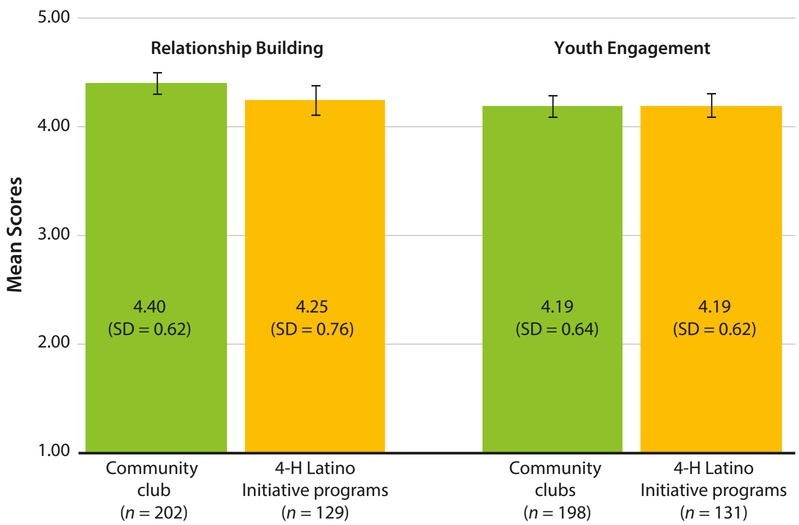


FIG. 2. Descriptive statistics for the relationship building and youth engagement of the older youth (age 9 to 18), in community club and 4-H Latino Initiative programs.

TABLE 4. Descriptive statistics for six outcome items on the younger youth survey (age 5 to 8)

Item	4-H community club (n = 149)	4-H Latino Initiative programs (n = 124)
I can learn something even if it is hard	4.52 (0.81)	4.32 (1.05)
I can set a goal	4.49 (0.88)	4.34 (1.02)
I feel good about myself	4.71 (0.66)	4.66 (0.69)
It is important to make good choices	4.90 (0.32)*	4.79 (0.58)*
I can help someone if they need me	4.68 (0.71)	4.60 (0.89)
I have people in my life that care about me	4.89 (0.48)	4.76 (0.77)

* $t(182) = 2.00$, $p < 0.05$. Levene's test for equality of variances indicated variances were not equal; therefore we used results that adjust the standard error and degrees of freedom.

TABLE 5. Descriptive statistics for four program experience items on the younger youth survey (age 5 to 8)

Item	4-H community club (n = 149)	4-H Latino Initiative programs (n = 124)
I made a friend in 4-H	4.61 (1.00)	4.53 (0.94)
The place where 4-H meets is safe	4.74 (0.60)	4.59 (0.85)
I think youth in 4-H are nice to each other	4.65 (0.71)	4.50 (0.93)
I think adults in 4-H are nice to youth	4.81 (0.52)	4.72 (0.68)

Results similar in community clubs and 4-H Latino Initiative programs

Our findings provided encouraging indications that young people experienced positive outcomes from participating in 4-H programs, including 4-H community clubs and other programs adapted for the 4-H Latino Initiative. Additionally, the findings demonstrated that 4-H program experience — particularly relationship building and youth engagement — was similar across community clubs and 4-H Latino Initiative programs.

For older youth, findings showed significant differences for one outcome (social skills) and one program experience assessment (relationship building), although the practical significance (effect size) was small. Social aspects might be improved in the 4-H Latino Initiative programs. These programs tended to be shorter in duration than the community club programs, and the time youth stayed in them was shorter (average = 1.7 years) compared to the time youth stayed in community clubs (average = 4.3 years) (table 2). Youth in 4-H Latino Initiative programs may have needed more time in the program to build relationships with peers and adults; and future programming may want to increase the amount of time youth may participate; for example, by offering short-term programs multiple times so youth can continue participating.

The youth in this study differed not only in the delivery modes, but in their demographics. Youth from the community clubs tended to be from rural areas and identify as non-Hispanic white, while youth in 4-H Latino Initiative programs tended to be from urban areas and identify as Hispanic white. These differences, paired with the mostly non-significant differences—or at least, small practical significance — in youth development outcomes and program experience, provide encouragement for 4-H professionals to continue developing and implementing delivery modes attractive to Latino youth. In other words, 4-H Latino Initiative programs may provide similar youth development outcomes and program experiences, regardless of ethnicity or residence.

The 4-H Latino Initiative programs were adapted specifically to improve UC ANR's reach with Latino youth. Our findings provided promising evidence that the adaptions we made to improve the cultural relevance of 4-H programs for Latino youth not only increased the numbers of Latino youth participants,

At a 4-H in-school club at an elementary school, youth learn about healthy foods through gardening. The authors' findings indicate that youth development outcomes and program experience were similar across 4-H community clubs and 4-H Latino Initiative programs.

but also realized similar youth development outcomes to the community club model. The results of our study point toward the effectiveness of our approach in moving toward two goals: the UC ANR 2016-2020 Strategic Plan objective to provide programming to at least 3% of California's youth; and California 4-H Youth Development Program's goal to realize high-quality youth development outcomes for all youth participating in 4-H programs.

We note a few limitations of this study. First, sample sizes were dissimilar for the community club and 4-H Latino Initiative program groups in older youth, although nearly equal for the younger youth. Second, our samples for both age groups were convenience samples. Additionally, there was not random assignment; thus, we could not test for differences in an experimental model. Third, the measure for younger youth (aged 5 to 8) is not validated measure. We recognized that our methodology would not enable casual inferences or reveal growth over time within each group, and that it would suffer from selection bias; however, practical necessities and logistical constraints were paramount. Despite these limitations, the study showed preliminary supportive evidence for adapting programming.

With some additional attention to social and relationship building aspects of adapted programs, we would expect there to be no significant difference between community clubs and 4-H Latino Initiative programs. These results should encourage 4-H professionals to engage in outreach efforts with underserved audiences and use adapted programs when these better meet the needs of the target audience. The future of 4-H will partly depend on 4-H professionals' abilities to approach new audiences and deliver programs using culturally relevant methods. CA

S. Worker is UC 4-H Youth Development Advisor, Marin, Napa and Sonoma counties; M. Fábregas Janeiro is Director, 4-H Center for Youth Development, University of Missouri, and was previously UC Assistant Director for 4-H Diversity and Expansion; and K. Lewis is University of New Hampshire State Specialist for Youth and Family Resiliency, and was previously UC 4-H Academic Coordinator for Evaluation.

We acknowledge John Borba, Claudia Diaz Carrasco, Maria de la Fuente, Russell Hill, Lynn Schmitt-McQuitty and Katherine Soule for their contributions conducting this research.

References

Borden LM, Perkins DF, Hawkey K. 2014. 4-H youth development: The past, the present, and the future. J Extension 52(4). https://joe.org/joe/2014august/comm1.php

Chappell B. 2015. For U.S. children, minorities will be the majority by 2020, census says. The Two-Way, Mar 4. National Public Radio. www.npr.org/sections/thetwo-way/2015/03/04/390672196/for-u-s-children-minorities-will-be-the-majority-by-2020-census-says

Cohen J. 1988. *Statistical Power Analysis for the Behavioral Sciences* (2nd ed.). Lawrence Erlbaum Assoc.

Ed-Data. 2018. California Public Schools. Ed-Data partnership of the California Department of Education (CDE), EdSource and Fiscal Crisis & Management Assistance Team (FCMAT). www.ed-data.org/

Erbstein N, Fabionar J. 2014. Latin@ Youth Participation in Youth Development Programs. Internal white paper for review by the UCANR Diversity in Youth Development Workgroup. http://cesantaclara.ucanr.edu/files/261436.pdf

Fábregas Janeiro MG, Bird M. 2018. 4-H community clubs and the challenge of inclusion: The Isleton experience. J Extension 56(6). www.joe.org/joe/2018october/iw4.php

Fábregas Janeiro MG, Horrillo S. 2017. Welcoming youth Latinos to California 4-H! In: 15th Ann Conf Cambio de Colores Proc, June 8–10, 2016, Columbia, MO.

Forero L, Heck KE, Weliver P, et al. 2009. Member record books are useful tools for revaluating 4-H club programs. Calif Agr 63:215–9. https://doi.org/10.3733/ca.v063n04p215

Gay G. 2010. *Culturally Responsive Teaching: Theory, Research, and Practice* (2nd ed.). New York, NY: Teachers College Press.

Hawley LR. n.d. 4-H Common Measures 2.0: General User's Guide and Protocol. Univ. Nebraska-Lincoln. https://4-h.org/wp-content/uploads/2018/08/Common-Measures-2.0-Protocol.pdf

Howe FW. 1911. Rural-school extension through boys' and girls' agricultural clubs. In *The Tenth Yearbook of the National Society for the Study of Education*. B. Crocheron et al. (eds.). Bloomington, IL: Public School Publishing Co. p 20–8.

Ladson-Billings G. 2014. Culturally relevant pedagogy 2.0: a.k.a. the remix. Harvard Educ Rev 84:74–84.

Lewis KM, Worker SM. 2016. Youth and adult perceptions of a new technology in California 4-H: The online record book. J Youth Dev 11(2). https://doi.org/10.5195/jyd.2016.447

Rea LM, Parker RA. 2005. *Designing & Conducting Survey Research: A Comprehensive Guide* (3rd ed.). San Francisco, CA: Jossey-Bass.

Russell ST, Van Campen K. 2011. Diversity and inclusion in youth development: What we can learn from marginalized young people. J Youth Dev 6(3):95–108. https://doi.org/10.5195/jyd.2011.177

US Census Bureau. 1901. Statistical abstract of the United States:1900. www.census.gov/library/publications/1901/compendia/statab/23ed.html

US Census Bureau. 2018. Annual Estimates of the Resident Population: April 1, 2010 to July 1, 2018. https://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=PEP_2018_PEPANNRES&src=pt

Wessel T, Wessel M. 1982. *4-H: An American Idea 1900–1980: A History of 4-H*. Chevy Chase, MD: National 4-H Council.

Wong DL, Baker CM. 2000. *Reference Manual for the Wong-Baker Faces Pain Rating Scale*. Duarte, GA: City of Hope Pain/Palliative Care Resource Center. https://wongbakerfaces.org/

Worker SM, Fábregas Janeiro MG, Diaz Carrasco CP, Soule KE. 2019. University of California 4-H Latino Initiative: Experiences of bicultural and bilingual staff. J Youth Dev 14(3). https://doi.org/10.5195/jyd.2019.667. https://jyd.pitt.edu/ojs/jyd/article/view/19-14-03-FA-02/873

Zeldin S, Krauss SE, Collura J, et al. 2014. Conceptualizing and measuring youth–adult partnership in community programs: A cross national study. Am J Comm Psychol 54:337–47. https://doi.org/10.1007/s10464-014-9676-9

RESEARCH ARTICLE

Agricultural water use accounting provides path for surface water use solutions

A survey of Northern California wine grape, apple and pear growers found that increased knowledge of crop water needs and use of improved irrigation practices are supporting efficient use of water.

by Glenn McGourty, David Lewis, Josh Metz, John Harper, Rachel Elkins, Juliet Christian-Smith, Prahlada Papper, Larry Schwankl and Terry Prichard

Online: https://doi.org/10.3733/ca.2020a0003

Abstract

Agricultural water demands can conflict with habitat needs in many North Coast watersheds. Understanding different water use patterns can help reduce conflict over limited supplies. We measured on-farm crop water use and conducted grower interviews to estimate the agricultural water demand in the upper Russian River and Navarro River watersheds. Annual agricultural water demand was less than 11% in the Russian River, and 2% in Navarro River, of the total annual discharge in each watershed. However, because demands are concentrated in the dry season when instream flows are at a minimum, these relatively small amounts can represent a significant constraint to stream habitat conditions. We have shared our study results in broad basin and community water resource planning efforts, including flow management of the Russian and Navarro rivers and implementation of the Sustainable Groundwater Management Act in the Ukiah Basin. Findings and recommendations from this study have influenced on-the-ground solutions to meet water demand in these watersheds, including construction of off-stream wintertime storage capacity to replace summertime stream diversions, and use of a municipal recycled water conveyance system as a replacement for summer diversions.

Satisfying water demands for multiple uses in California is an increasingly acute and difficult issue. High interannual climate variation characterized by successive drought and flood years introduces extreme uncertainty into water allocation decisions. During drought, allocations for agricultural use have been curtailed and environmental flows reduced to perilous levels for endangered and threatened wildlife (NOAA 2005). The Russian River Basin exemplifies the challenges of managing water for agriculture and the environment and has become the focus of recent state regulations (2015-2016 Russian River Tributaries Emergency Regulation Information Order) to more accurately account for water demands within tributary streams that support critical habitat for coho and steelhead trout.

Another significant policy enacted to address competing demands in the Russian River is the 2013 California State Water Resources Control Board (SWRCB) Policy for Maintaining Instream Flows in Northern California Coastal Streams (SWRCB 2013; SWRCB 2014). The purpose of this policy is to develop a streamlined process for reviewing and approving pending water rights applications, which in some cases have been delayed for decades by the SWRCB Division of Water Rights. The policy requires water rights applicants to meet stringent minimum instream bypass flow requirements and to consider alternatives for meeting their respective water needs, including water conservation and use of alternative sources.

Results from a UC Cooperative Extension study of the upper Russian River and Navarro River watersheds indicate that, on an annual basis, the amount of water used for crop production in both watersheds is small relative to total annual discharge.

Glenn McGourty

To avoid impacts to the environment, more research is needed to better understand and manage agricultural water demands. Completed and ongoing studies in the Russian River watershed are generating water budgets and insight into the relationships between water use and stream flows. There are differing indications that subsurface and groundwater stores have been impacted over the last two decades in both mainstem reaches of the Russian River (Constantz et al. 2003; Marquez et al. 2016) and tributary watersheds like Alexander Valley (Metzger et al. 2006). Deitch (2006) correlated changes in stream flow to daily agricultural water use patterns and found evidence of direct steam flow reductions during irrigation periods. These and other investigations point to knowledge gaps about the timing and volume for water uses like agriculture that can support development of solutions to reduce impacts to the environment and competition for limited water supplies.

Our premise is that the best opportunity to relieve competition for water involves working with local agriculture to generate an accurate accounting of current and future water demand, including location and timing of use, and evaluate existing and potential options for meeting this demand. To serve that purpose, the primary objective of this study was to calculate agricultural water demand in the Mendocino County portion of the Russian River and Anderson Valley portion of the Navarro River watersheds (fig. 1). This includes the volume and timing, or seasonality of use, that could then be compared to annual and seasonal fluctuations in stream flow volumes and environmental flow demands.

Our second objective was to assess needs and opportunities for innovations, including grower motivations, in irrigation technology, practices and water sources. Findings from this research have already improved agricultural water demand knowledge and facilitated feasible and sustainable agricultural water use in the study area (see sidebar, next page). This on-the-ground and with-the-users approach to water use accounting and the application of the results for solutions to meeting multiple water demands provides a useful model for relieving competition for water use in other watersheds.

Site description

The Navarro River, flowing east to west, is the largest coastal watershed in Mendocino County, covering approximately 315 square miles. The portion of the Russian River within Mendocino County is approximately 362 square miles and flows north to south. The Navarro is a natural river with no dams or other obstructions on its mainstem, whereas the Russian River is regulated by the Coyote Valley Dam, which creates a maximum 110,000 acre-feet of storage in Lake Mendocino. Additionally, inter-basin transfers are made from the Eel River to the Russian River via the Potter Valley Project.

The climate of both watersheds is Mediterranean with most rainfall occurring in the winter months, followed by no rainfall from late May to late September. Because of the close proximity to the Pacific Ocean, there is a strong marine influence on the Navarro watershed, with fog occurring many late nights and mornings and cooling westerly winds during the day. This contrasts with the more inland position of the Russian River watershed in Mendocino County, which has relatively clearer skies and drier and warmer conditions. Rainfall in the Navarro River watershed averages 40.6 inches per year, whereas the city of Ukiah and the Russian River watershed average 36.6 inches per year (Bearden 1974). The Navarro is sparsely populated with approximately 3,200 people. The Russian River watershed in Mendocino County is also rural in comparison to other parts of California. However, Ukiah and other residential centers have a combined population of over 20,000 people. Both watersheds experience the economic activities of agriculture (vineyards, orchards, livestock, small-scale mixed horticultural enterprises and commercial softwood production), beverage production (wine and beer) and tourism.

Study design and methods

We completed this study in 2007 in the Russian River and in 2009 in the Navarro River watersheds, using the same study design and approach comprised of three elements for water use accounting.

1. We quantified the current acreage and crop designations using available agricultural statistics, aerial photograph interpretations and field visits to validate crop type and extent determinations. This included comparisons with past irrigated agriculture acreage and estimation of potential additional irrigated acreage; field evaluations were conducted of irrigation systems to quantify applied water for irrigation, heat protection, frost protection, and postharvest needs and irrigation distribution uniformity.
2. To estimate total annual agricultural water demand we summed the amounts of irrigation water, frost protection, heat protection,

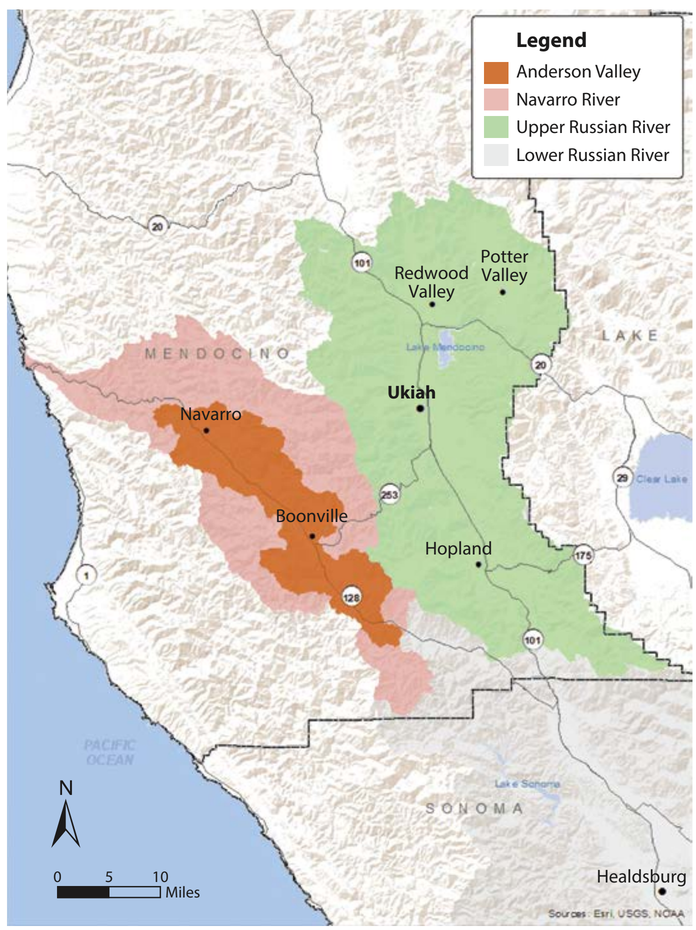


FIG. 1. Study location including the upper portion of the Russian River watershed and the Anderson Valley portion of the Navarro River watershed.

Mendocino County winegrowers and advocates find solutions for agricultural water use while protecting endangered species

This study was undertaken with the aspiration that it could lead to solutions relieving potential pressure on stream flows from agricultural diversions, including the feasibility for small-scale private winter flow storage and opportunities for water reuse. Our study quantifies the amount of water used by agriculture relative to the total flow of water in both watersheds. We noted while water diversions are a small percentage of total flow, agriculture diverts water at a time when flow rates are low, and the need of water for fisheries is critical. In our recommendations, we discussed the concept of off-stream water storage when water flow was more plentiful. We also discussed that growers were comfortable with using recycled water as a substitute for direct diversions from the Russian River.

Spring of 2008 was one of the most challenging frost protection seasons in the upper Russian River watershed in over 30 years. Many growers required up to 20 nights of frost protection in their vineyards and orchards. A combination of limited water releases from Lake Mendocino due to a very dry winter, and large diversion demands for sprinkler frost protection from vineyards and orchards, greatly reduced flow in the main stem of the Russian River. In a normal rainfall year, instream flows during frost season range from 200 to 600 cubic feet per second (cfs) as recorded at the USGS water gauge in Hopland. In 2008, instream flows averaged 175 cfs. On April 20, 2008, a very cold advective freeze event occurred, creating an instantaneous drawdown of 83 cfs when nearly every agricultural water diverter turned on their frost protection systems. This drawdown resulted in a 2-inch drop in river stage and caused the stranding and mortality of hundreds to thousands of juvenile coho and steelhead trout, endangered and threatened species, which the National Marine Fisheries Service (NMFS) considered a "take" under the Endangered Species Act. As a result, in April 2009, NMFS requested that the California State Water Resources Control Board place a moratorium on the use of river water for frost protection. Honoring this request would have made it impossible in many years to grow wine grapes in the region, resulting in large employment and economic losses (estimated at up to $235 million).

In response, the Upper Russian River Stewardship Alliance was formed by the Mendocino County Farm Bureau, the Mendocino Wine Grape Commission, the Upper Russian River Flood Control District, the California Land Stewardship Institute, the Redwood Valley County Water District and local NRCS and UCCE offices to work with resource agencies and to find more reasonable approaches to solving the problem of river drawdown that could potentially strand young salmonid fish.

The group met regularly and developed The Upper Russian River Frost Protection Pumping Coordination Protocol. This coordinated effort improved frost forecasting precision by making more private weather stations available to frost forecasters. When frost events are likely to happen, growers call the Sonoma County Water Agency, controller of water releases from Lake Mendocino, so that river flows can be increased during frost events. Additionally, a new USGS water gauge was installed closer to Lake Mendocino to more accurately measure flow.

The California Land Stewardship Institute and the NRCS worked together to apply for $5.7 million in grants for water management infrastructure to prevent another fish stranding like that on April 20, 2008. The grant funds focused on creating off-stream ponds to store water to be used during frost events so that instantaneous drawdown would be reduced. Twenty ponds were built, with a combined water storage of 435 acre-feet. These ponds are filled with water under appropriated water rights (water stored from behind the Coyote Dam at Lake Mendocino). Growers have the capacity to pump as much as 145 cfs during a frost event from their ponds, replacing Russian River diversions that could imperil juvenile salmonids. After frost events, ponds are scheduled for recharge at more gradual rates to maintain adequate flows and water levels for fish.

To further improve the water supply situation, the city of Ukiah received $45 million in grants and low interest loans and is constructing a pressurized "Purple Pipe" system for agricultural and landscape water use. The Ukiah Municipal Wastewater Treatment Plant treats wastewater to California's Title 22 water reuse standards, with capacity to provide almost 4,000 acre-feet of water for use on farmland, parks, cemeteries and school grounds in Ukiah environs. Previously, this water was returned to the Russian River after treatment. This will reduce the demand for Russian River diversions, increase water security for the upper Russian River watershed, and reduce the costs associated with wastewater discharge management.

In Anderson Valley, The Nature Conservancy (TNC), who partially funded the Navarro River watershed portion of this study, very quickly teamed with the UCCE Mendocino County Office, as well as the Anderson Valley Winegrowers Association and the Mendocino County Resource Conservation District, to address some of the issues raised in our study.

The first major initiative was to install 16 new stream gauges in various smaller tributaries to augment the single USGS gauge near Philo, as the single gauge in the Navarro River watershed was inadequate for real-time irrigation management and better understanding impacts of dry season diversions on stream flows. The new gauges also help to inform conservation planning and identify areas that would benefit from additional water storage. Some of the gauges funded and installed by TNC are connected to cell phone interfaces so that a grower can accurately monitor the effects of diversions as they occur.

TNC is working with growers and the California State Water Resources Control Board to change their water rights to forbear summer diversions when flow rates in the watershed are very low and to allow for off-stream storage earlier in the year when flow rates are high, above critical levels for fish migration, spawning and juvenile survival. TNC also identified cost share funding for pond construction for water storage, working with the local USDA NRCS office and Mendocino County Resource Conservation District.

These examples of solving environmental problems proactively and locally through cooperative, thoughtful planning and execution resulted in much more positive outcomes and responded to real concerns for the impacts on people, their property and community in proposed regulations from agencies external to the region. Compiling and analyzing on-the-ground water use data, and applying that science through local associations and organizations, demonstrates how public and private partnerships can be successful for all concerned stakeholders.

and postharvest volumes multiplied by the extent of existing and potential irrigated agriculture in the two watersheds. As part of this calculation, we compared the volume and timing of the total agricultural water demand to instream flow volumes. Instream flow volumes or daily discharge (cubic feet per second) were determined using stream flow measurements from U.S. Geological Survey (USGS) gauging stations.

3. To assess the needs and opportunities in water use innovations, we conducted grower surveys on existing irrigation system infrastructure and irrigation management decisions. A 25-question survey (available as supplemental information online) was administered to further inform water amounts used, water conserving irrigation system technologies adopted, and other background information needed to explore options and drivers to meet water demand and conservation goals.

Estimated irrigated agriculture extent

We mapped irrigated agricultural acreage in the Russian River watershed (fig. 1) using aerial photographs taken between August and September 2004 (AirPhoto USA). Late summer and early fall images provided a stark contrast between green irrigated crops and golden-yellow dry grasses. We visually assigned acreage into five crop designations: grapes, orchards, row crops, pasture and unknown. We estimated potentially irrigable lands based upon slope and landscape position to evaluate potential future water demand. Crop acreage classifications were validated through systematic field visits.

We obtained agricultural acreage statistics for the Navarro River watershed from Mendocino County Department of Agriculture Annual Crop Reports (Linegar 2008), the California Department of Water Resources (CDWR 1964, 1979, 1989) and the California Department of Food and Agriculture (CDFA 1968, 1976, 2006, 2009). Additionally, we mapped irrigated agriculture spatial extent in a geographic information system (GIS) using U.S. Department of Agriculture (USDA) National Agriculture Imagery Program (NAIP) photographs (NAIP 2009). Data were summarized to provide a picture of historical and current irrigated agriculture extent in the study area. While the Navarro River extends beyond the study area, our analysis was constrained to portions of the Navarro River watershed with active agricultural operations, namely Anderson Valley (fig. 1).

We estimated future irrigated agriculture in the Russian River watershed by visually determining potentially irrigable lands not currently in production based upon the slope and landscape position. In the Anderson Valley, we used aerial imagery from the 2009 USDA NAIP aerial mapping program to develop a land cover classification for the Anderson Valley watershed. Sample points from forest and non-forest land cover types were identified in the 2009 aerial images and used to inform an image classification procedure. Maximum Likelihood Classification (Nagi 2011) was used to generate the land cover classes with a 10-m pixel resolution.

National elevation data at 10-m resolution was used to derive topographic slope for the Anderson Valley. The National Elevation Dataset provides uniform topographic data across the United States and allows for explicit consideration of topography in geographic analysis and modeling (State Water Commission and USGS 2017). Slope classes of < 10% and < 20% were created to discriminate vineyard potential under different slope thresholds. In general, steeper slopes are more difficult and costly to farm. Vineyard land cover identified during air photo mapping was used to extract existing vineyard land cover from the model.

The Squawrock-Witherall soil complex, interspersed with Hopland and Yorkville soil series and known to be high in magnesium (Rittiman and Thorson 1993), was excluded from our final analysis due to its known impacts on vineyard performance including potassium deficiencies, potential toxicity from nickel, poor surface stability and high erosion potential. While there are some vineyards planted on these soils, low yields, soil instability when saturated, and high erosion make them difficult to manage. Generally, these sites are not recommended for agricultural enterprises.

Irrigation system evaluation

Our evaluation of existing irrigation systems and measurements of applied water volumes included field measurements and calculation of water used for irrigation, including distribution uniformity, frost protection, heat protection and postharvest applications.

Irrigation use and distribution uniformity

We conducted field evaluation and existing irrigation systems measurements on a subset of vineyards, apple and pear orchards, and irrigated pastures to understand irrigation use and system distribution uniformity (consistency in applied water volume and rate throughout an orchard or vineyard). Methods used to conduct these evaluations are described in Prichard et al. (2007), Schwankl (2007) and Schwankl and Smith (2004). Evaluations included field measurement of water application rates and irrigation system distribution uniformity on 33 vineyard blocks, seven orchard blocks and one irrigated pasture in the Russian River watershed, and 26 vineyard blocks and three orchard blocks in Anderson Valley.

Additionally, we conducted interviews with cooperating growers to document irrigation season duration and irrigation frequency. Measured application rate and grower interview information were combined to estimate total irrigation use. Reference evapotranspiration (ETo; reference rate at which water evaporates from the soil and transpires) data were obtained for 2007 from California Irrigation Management Information System (CIMIS) stations #106 Sanel Valley in Hopland, F90 4933-23 on the Light Ranch in Redwood Valley, and the U.S. Army Corps of Engineers Coyote Dam station in the Ukiah Valley. Anderson Valley values for ETo were obtained for the 2009 season from an AdCon (AdCon Telemetry, Austria) weather station at Roederer Estate in Philo. Russian River soils information and data were derived from the Mendocino County Soil Survey (Howard and Bowman 1991). Available water holding capacity data for dominant soil types within irrigated agricultural lands in Anderson Valley were obtained from Rittiman and Thorson (1993).

Grapevine water use and crop coefficient (Kc) are linear functions of shaded area beneath the canopy (Williams and Ayers 2005). To calculate specific crop coefficients for this study, we measured percent canopy area covering the vineyard floor. In the Russian River study area, site-specific crop coefficients were calculated in 19 wine grape blocks. Shaded area beneath the canopy at midday was assessed using photographs, digitizing dark and light areas beneath and between vine rows, and measuring actual shaded area (Prichard et al. 2007). In the Anderson Valley, we used the Paso Panel technique (Battany 2012) to directly measure canopy shaded area on representative sites and trellis designs. Field data were used to calculate grapevine crop coefficients according to methods outlined by Battany (2012). We took vine canopy field measurements at Roederer Estate Vineyards in Philo between 1200 and 1300 hours (solar noon) on September 28 and October 2, 2012. Vine canopies were healthy, green and fully expanded. A total of four sites planted to pinot noir and chardonnay were selected based on trellis type, vine vigor and row orientation; we recorded 40 observations from each site. Crop coefficients were calculated using the algorithm provided by Battany (2012). These values were used to produce an average Kc.

Frost protection calculations

Grower interviews, relevant production manuals (Snyder 2007), project team experience and study area knowledge were used to generate total frost protection water use estimates. The dominant frost protection method is overhead sprinkler water application, which maintains the plant material surface temperature above freezing. In general, frost protection is used on vineyards and orchards located below 700 feet elevation because radiant frost typically occurs below this elevation in the study area. Heavier cold air settles in lower parts of the landscape, which poses crop damage risk (when green tissue is present) under normal radiant frost conditions. The elevation break for frost damage in Redwood and Potter valleys is higher than in the Ukiah Valley, as the valley floors are 770 feet and 950 feet, respectively. It is important to note that infrequent advective frost events impact the entire study area regardless of elevation.

Frost protection application rate was assumed to be 50 gallons per minute per acre (gal/min/ac) for grapes, or 0.1 inches of water per hour. In orchards, one acre-inch is applied for each frost protection event (Elkins et al. 2006). If systems are not routinely maintained and repaired, these values can be as low as 35 to 40 gal/min/ac. Additional assumptions for frost protection duration (hours/frequency) and acreage for each sub-basin were made based upon grower interviews.

Heat protection calculations

Total water use for heat protection calculations relied on grower confirmation of heat protection methods, relevant production manuals, project team experience and study area knowledge. In general, the same sprinkler system used for frost protection in grapes is used for heat protection. Accordingly, we assumed the heat protection application rate was 50 gal/min/ac, keeping in mind variability can exist due to system maintenance and effectiveness. Not all farms have these systems or access to sufficient water for heat protection.

TABLE 1. Acreage of irrigated agriculture in the Mendocino County portion of the Russian River watershed by crop in 2007 and in 2009 in the Anderson Valley portion of the Navarro River watershed, Mendocino County

Crop type	Russian River		Anderson Valley	
	acres	*% of total*	*acres*	*% of total*
Grapes	15,539	75.3	2,790	90
Pasture	3,144	15.2	66	2
Orchard	1,845	9.2	218	7
Other	26	0.1	50	1
Unidentified	60	0.2	-	-
Totals	20,614	100	3,124	100
Potential	517		4,649*	

* 2,652 acres on lands with slopes < 10% and 4,649 acres for land < 20%.

Additional assumptions for duration (hours/frequency) and acreage in which heat protection were made also based upon cooperating grower responses.

Postharvest application

Total water use calculations for postharvest application in wine grapes relied on grower response data, project team experience and study area knowledge. In general, the same irrigation system used for frost and heat protection in grapes is used for postharvest irrigation. Accordingly, we assumed postharvest application rate was 50 gal/min/ac, keeping in mind variability can exist. Postharvest irrigation is used to germinate cover crop seed banks and enhance carbohydrate storage. The latter objective is most applicable for white varieties where growers strive for yields of 5 to 6 tons per acre. Postharvest application decisions also depend on water availability. Additional postharvest application assumptions for duration (hours/frequency) and acreage relied on grower responses.

In pear orchards, postharvest irrigation occurs in August and September while trees are actively growing. For this reason, postharvest irrigation was included in pear irrigation use calculations.

Total agricultural water demand

We calculated total agricultural water demand by summing water used for irrigation, frost protection, heat protection and postharvest application; volumes were informed by agricultural practice differences and access to water. Total (per acre) water use (and its ranges) were multiplied by both existing (mapped) and potential (modeled) irrigated agriculture to calculate total agricultural water demand. Total demand, including timing and volume, was then compared to annual stream discharge data. Data from the following USGS stream gauging stations were compiled and analyzed for the Russian River watershed: Russian River near Ukiah, station #11461000; east fork of Russian River near Ukiah, station #11462000; and Russian River near Hopland, station #11462500. Stream discharge measurements from USGS stream gauging station #11468000 near Navarro, Mendocino County, were compiled and analyzed for the Navarro River watershed.

Grower surveys

We administered surveys to wine grape and fruit tree growers in both watersheds through two focus groups; the surveys were designed to understand water use patterns and document water resource use and irrigation management practices. The 25 questions in the survey were developed to gather information on growers' water resource management history, including frost and heat protection, irrigation system technology change, conservation program participation, and opinions on alternative water sources. All focus group participants and survey respondents (a total of 15 Russian River and 14 Anderson Valley grape, pear and apple growers) completed appropriate human subjects releases required by the Office of Research Institutional Review Board Administration for the University of California, Davis.

Transitions in irrigated acreage

Based upon our team's land use mapping and modeling, irrigated agriculture in the Mendocino County portion of the Russian River watershed consists of 75% wine grapes, 15% irrigated pasture, 9% pears and less than 1% in other vegetable and unconfirmed crops (table 1). CDFA crop acreage statistics identified 14,212 acres in wine grape vineyards and 1,867 acres in pear orchards within the study area (Bengston 2008). These values are 9% less for grapes and 1% more for pear orchards compared with our values.

Irrigated agriculture acreage has increased in the Russian River area in the past 50 years. This resulted from conversion of dryland-farmed acreage to irrigated agriculture and the expansion of irrigated agriculture overall (fig. 2). Our 2007 estimate of irrigated acreage for Hopland and the Ukiah Valley area is 12,502 acres, roughly the same as the total agricultural acreage in 1957 (Carpenter 1958), but a 125% increase over 1957 irrigated acreage. Similarly, we estimated 16,661 acres of irrigated agriculture in the entire study area minus Potter Valley for 2007, or a 31% increase over the 1985 estimate (Sommarstrom 1986). And as of 2007, well over 95% of grape acreage was irrigated.

This increase in irrigated agricultural acreage corresponds with a shift in the crops being grown (fig. 2). Most prominent is a conversion of pasture, including alfalfa, and pear orchards to wine grape vineyards. Between 1957 and 2007 there was a 4.5-fold increase in grape acreage and an almost 19-fold decrease in pasture acreage for the Hopland and Ukiah valleys alone. When compared with our estimates, Sommarstrom's determinations for the entire study area, excluding Potter Valley, confirm a transition to grape production with a corresponding decrease in pear acreage over the same time period. Countywide, there has been a 35% decrease in pear acreage from a peak of 4,085 acres in 1974 (Elkins et al. 2007). Each sub-watershed has experienced slightly varying paths of crop conversion; for example, large acreage in irrigated pasture still exists in Potter Valley.

Irrigated agriculture acreage in Anderson Valley is 90% wine grape vineyards, followed by 7% orchards, 2% pastures and 1% other irrigated crops (table 1). There have been multiple transitions in agricultural production in the Anderson Valley, beginning with subsistence farms in the 1850s, followed by diversified production of agricultural and food products for logging camps, which remained active through the second half of the 19th century. Dried fruit production, principally apples, was next, until the market turned to fresh fruit for juice and canning in the 1950s. From that time on, there has been a major transformation and increase of crop types from orchards to vineyards (fig. 3). Wine grape acreage in 2009 totaled 2,790 acres, a 13-fold increase over the amount in 1966. For orchards, there were nearly 900 acres in production in 1966, and by 2009 there were only 218 acres remaining.

There are approximately 517 acres in the Russian River with the potential to be put into irrigated agricultural production, a potential increase of 2.6% within the study area (table 1). In Anderson Valley, there are 4,649 acres for potential irrigated agriculture expanse, a 148% increase in the study area. Of these, 1,997 acres are on slopes above 10%; such slopes are under stricter regulations to safeguard against erosion, which may deter growers from planting wine grapes or other crops.

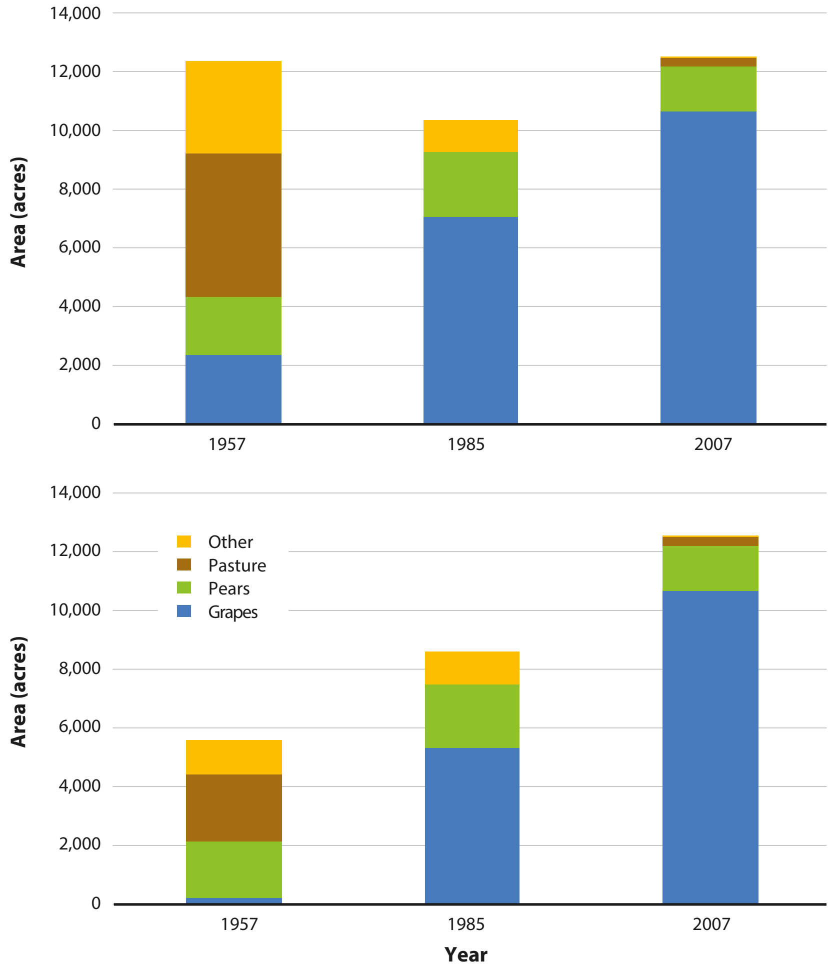


FIG. 2. Comparison of total (top) and irrigated (bottom) crop acreage in the Hopland and Ukiah valleys from 1957 (Carpenter 1958) to 1985 (Sommarstrom 1986), to 2007. "Other" in 1957 includes truck farms, prunes and small grains, and in 1985 combines pasture with crops other than apples, pears and grapes.

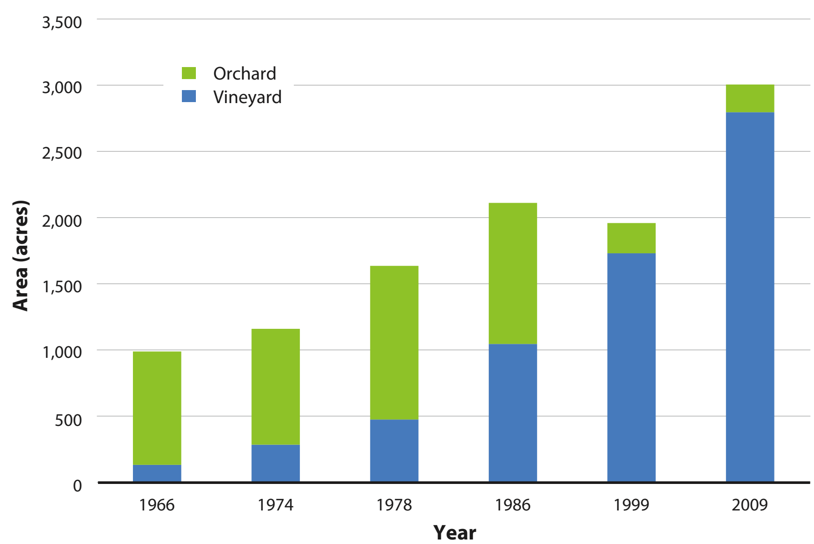


FIG. 3. Comparison of orchard and vineyard acreage from 1966 to 2009 in District 5 Reporting Region (Garcia River and Navarro River watersheds, and some portion of the Gualala River watershed). *Sources:* CDFA 1968, 1976, 2006, 2009; CDWR 1979, 1989.

Water used to meet crop needs

Calculated values for all water applied differed by crop in both the Russian River and Anderson Valley (table 2; values are derived from the field measurements of applied water, informed by the grower surveys, and then multiplied by the mapped and modeled irrigated agricultural extent). In general, grapes received less than 1 acre-foot per acre (afa) (fig. 4), while apples and pears received more than 2 afa (not shown). These values are lower than published agency amounts (CDWR 2010) of 0.79 afa for wine grapes and 2.39 afa for apples and pears for annual water use in Mendocino County.

All water applied for wine grapes and orchards in the Anderson Valley was 33% and 95% of the amount applied, respectively, in the Russian River watershed. This difference may be attributed to lower evapotranspiration rates and smaller canopy sizes in Anderson Valley compared to the Russian River Valley.

Applied irrigation water for irrigated pasture was 3.31 afa in the Russian River compared with 2 afa for the Anderson Valley pasture (not shown). This is consistent with estimated amounts needed for pasture irrigation in the Central Valley of California (Fulton et al. 2007) and less than the average use of 4.13 afa documented by the Potter Valley Irrigation District (Steve Elliot, Potter Valley Irrigation District Superintendent, personal communication).

Frost protection

Russian River growers said that frost protection was needed more in the 1970s and 1980s than during the last decade (n = 15). However, the threat still persists, with growers referencing 2001 as a dry, cold winter that required frost protection. The total number of frost days in a year and early bud break were identified as drivers that raise the risk of frost damage. This was demonstrated by the extreme conditions in March and April 2008, with over 20 frost days, which required growers to take corrective action.

The majority of focus group participants and survey respondents have transitioned from fans and smudge pots to sprinklers for frost protection. Dependability and effectiveness of sprinkler systems relative to these other methods is generally what motivated this transition. Growers are also using improved methods for frost protection, including late pruning to delay bud break, trellis and row design to influence temperature and dew point, and use of on-farm temperature monitoring and alarm systems and fruit frost forecasts to aid decisions about when to apply frost protection.

In the Russian River watershed, wine grape growers achieved frost protection though sprinkler irrigation on 5,263 acres, representing 36% of the total acreage in wine grapes and resulting in 2,955 acre-feet of calculated water use (table 2). Orchard acreage, in comparison, was 100% under frost protection with a combined use of 1,421 acre-feet of water.

Most (81%) of the Anderson Valley vineyards had an active frost protection system in place due to the high risk of frost in the Navarro River watershed. In contrast, only 42% of orchards had active frost protection. Most vineyards without frost protection are in higher elevation sites above settled cold air during the typical spring inversion and radiant freezes. Fans and microsprinklers are used in sites where there is limited water availability for site protection from freezing. Based on our survey results, 91% of frost-protected vineyard acreage in Anderson Valley is covered by water from off-stream storage. The remaining 9% of acreage is frost protected from direct diversion sources. In 2009,

TABLE 2. Water demand (acre-feet) for irrigated agriculture by crop in 2007 in the Mendocino County portion of the Russian River and in 2009 in the Anderson Valley portion of the Navarro River

Crop	Water use	Russian River	Anderson Valley
		acre-feet	
Grapes	Irrigation	9,479	558
	Frost protection	2,955	678
	Heat protection	515	0
	Postharvest	620	0
Orchards	Irrigation	4,263	457
	Frost protection	1,421	0
	Heat protection	nd	nd
	Postharvest*	—	—
Pasture	Irrigation	6,287	132
Other	Irrigation	39	—
Unidentified	Irrigation	90	—
	Totals	25,669	1,825

* Postharvest applications for apples and pears are combined in irrigation use.
nd, not determined.

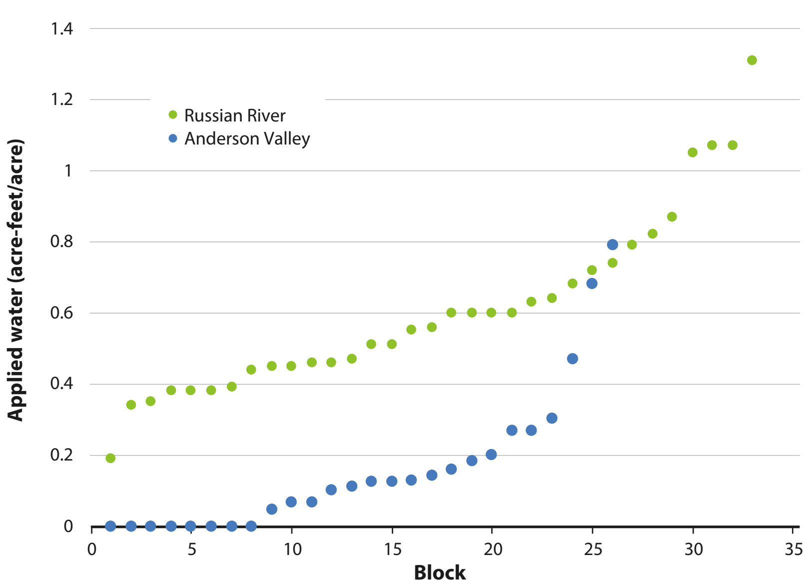


FIG. 4. Calculated water (acre-feet per acre) applied to meet irrigation use for Russian River and Anderson Valley vineyard blocks.

growers averaged about 40 hours of frost protection during five events, combining for an estimated total water used for frost protection of 678 acre-feet.

Heat protection

In general, heat protection is done where there is a sprinkler irrigation system and where the grower has access and rights to sufficient water. Russian River survey respondents consistently offered 2000 and 2007 as examples of years in which heat protection was needed. Interestingly, however, the number of "hot days" per year has decreased over the last five decades (Robinson 2007). The five grower respondents that conduct overhead sprinkler heat suppression explained that they have transitioned to pulsing to protect crops. In this approach, the irrigation system turns on for an hour and off for two hours, repeating this cycle two to three times during the span of the day when air temperatures are at or above 100°F. This method was accounted for in the estimates of water use for heat protection.

Additional comments shared by participants and respondents included energy costs as a disincentive to operate their irrigation systems for heat protection. Estimates of the water needed to provide for maximum heat protection in the Russian River watershed totaled 515 acre-feet. Only three Anderson Valley growers indicated that they provided heat protection with sprinklers. Since Anderson Valley is cooler due to its proximity to the Pacific Ocean, high temperature events are less common compared to the Russian River Valley area of interior Mendocino County. Also, growers often have limited water supplies, so they save available water for irrigation use.

Postharvest application

In general, postharvest application is done in vineyards with white fruit that has overhead sprinklers and that are cropped at 5 to 6 tons per acre, double the cropping level of red varieties. We estimate that 620 acre-feet of water is needed in the Russian River watershed to provide for postharvest applications in wine grapes. Postharvest application for pears is included in irrigation use because of the stage of growth the crop is at when these applications are made in August and September. Anderson Valley growers do not typically make postharvest irrigations to their vineyards in the fall because water availability is limited.

System distribution uniformity

System distribution uniformity field measurements in Russian River grape vineyards and pear orchards consistently averaged above 85% (table 3). In Anderson Valley the difference between the two crops was 18%, while in the Russian River it was less than 0.5%. These relatively high uniformity values indicate that growers are maintaining their irrigation systems. When coupled with grower survey results documenting vineyard and orchard transition to improved irrigation systems, the implication is that meeting agricultural water demand and minimizing instream flow impacts through irrigation systems innovations and management are already being realized. The mean crop coefficient for the wine grapes was 0.69 (SD = 0.16) in the Russian River watershed and 0.59 (SD = 0.07) for Anderson Valley. We did not measure system uniformity for pastures in either watershed.

Total water demand for agriculture

For the Russian River, the estimate of 25,669 acre-feet (table 2) represents a scenario that includes frost and heat protection for all crops and postharvest applications in grape vineyards. A year in which these protections and applications are not needed or made will experience a reduction in the use of water by irrigated agriculture to approximately 20,778 acre-feet. These amounts for total and irrigation use water demand were 11% and 9% of the 2007 total annual discharge in the Russian River near Hopland, and 5% and 4% of the total annual precipitation (UFD 2008). In high flow and wetter water years these percentages will be lower, and in low flow and drier water years they will be greater.

Calculated values for water applied to meet annual water demand in Anderson Valley differed by crop type (table 2). The total water used in Anderson Valley during 2009 (considered a low river flow year) for all irrigated agriculture was estimated to be 1,825 acre-feet. In the same year, total annual discharge measured on the Navarro River near Navarro was 107,000 acre-feet. Agricultural water use in the Navarro River watershed equaled 1.4% of this amount. In years such as 2006, when total flow at the same gauging station reached approximately 760,000 acre-feet, agricultural water use of 1,825 acre-feet would represent only 0.2% of river flow.

Growers' practices

Growers' individual experience in irrigated agriculture ranged from 10 to 70 years. Russian River respondents farmed a combined acreage of 6,415 acres, including 3,875 acres of grapes, 420 acres of pears, 128 acres of irrigated pasture, and 33 acres in other crops for a total of 4,456 acres of irrigated lands, or 22% of the irrigated agriculture acreage identified in the Russian River study area. Anderson Valley participants farmed 1,576

TABLE 3. Distribution uniformity in vineyard and orchard blocks in the Russian River watershed and in the Anderson Valley portion of the Navarro River

Crop	Mean	Standard deviation	Minimum	Maximum
Russian River				
Grapes ($n = 33$)	88.8	7.5	64.3	96.0
Pears ($n = 7$)	88.4	5.5	81.9	94.3
Anderson Valley				
Grapes ($n = 26$)	90.0	6.6	68.7	96.0
Apples ($n = 3$)	72.0	41.4	41.4	88.0

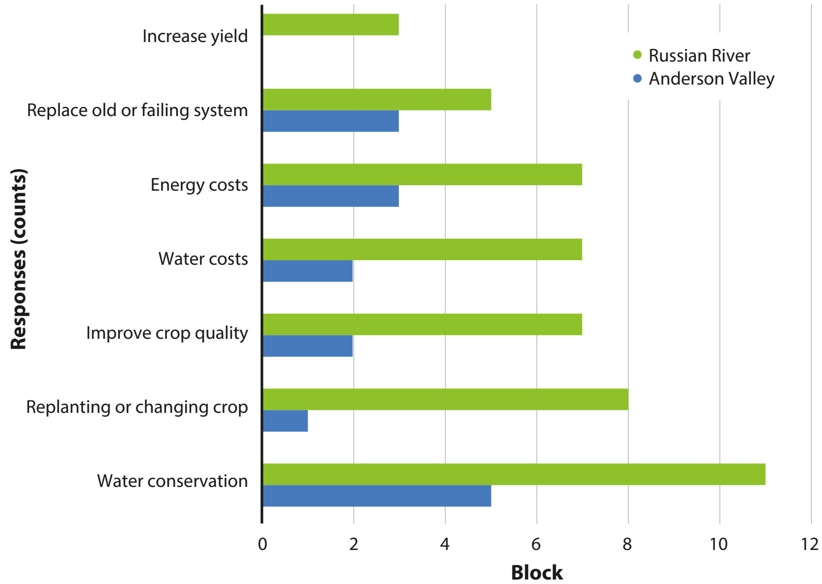


FIG. 5. Reasons identified by growers for conversion of irrigation systems to different technology. Growers could select any reason that applied to their respective decision.

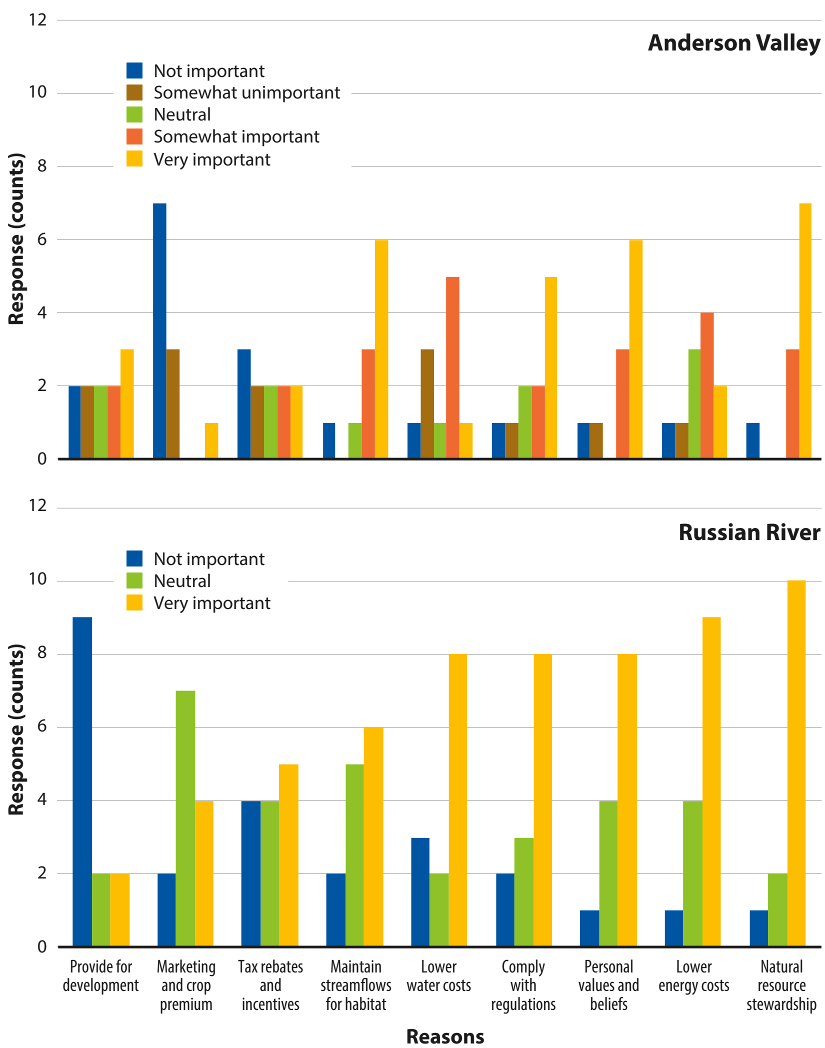


FIG. 6. Indication of importance of reasons growers would participate in on-farm water conservation in the Anderson Valley (top) and Russian River (bottom) watersheds.

acres, approximately 50% of the irrigated agriculture acreage identified in the study area, including 1,333 acres of grapes, 218 acres of apple orchards, 3 acres of irrigated pasture and 22 acres in other crops. Survey respondents used the farming practices (such as drip and under canopy irrigation systems) currently employed by growers within the two watersheds, thereby representing the current state of operation for irrigated agriculture in Mendocino County at the time of the study.

Russian River growers consistently identified 1977, 2002 and 2007 as years in which meeting crop irrigation needs was difficult. Comparatively, Anderson Valley growers cited 1976, 1977, 2000, 2008 and 2009 as challenging years. Low rainfall years, low stream flow, and low pond levels were the most frequently identified conditions that contributed to this problem among both groups. Paralleling this historical variability in water availability is documentation that growers converted from impact sprinklers or other systems to drip irrigation for grapes and below canopy sprinklers for apples and pears beginning in the 1970s, with near full conversion obtained by the 1990s. Thirteen of the 15 Russian River respondents cited multiple reasons for changing their irrigation systems, such as water costs, replanting crops, and improving crop quality (fig. 5). Of the Anderson Valley growers, eight of the 14 respondents had changed their irrigation systems, also citing multiple reasons for making these changes. The remaining six Anderson Valley growers said they did not change their irrigation systems, as they had originally installed them as high efficiency drip systems when their vineyards were planted. In both watersheds, the most commonly cited reason for system conversion was water conservation and the least identified reason was to increase stream yield.

Responses to our survey indicate that growers use a variety of information sources to make irrigation and water resource management decisions. Participation in one or more conservation programs was high for both groups, including the Natural Resources Conservation Service (NRCS) Environmental Quality Incentives Program (EQIP), UC Cooperative Extension (UCCE) Water Quality Planning, and California Land Stewardship Institute's Fish Friendly Farming program. Natural resource stewardship was the most frequently cited reason for participating in these programs (fig. 6). Other reasons growers in both watersheds shared for motivations to participate in conservation included personal values and beliefs (among the top three) and providing water for urban growth and development (in the bottom two).

Considerations for meeting water demands

The transition in both watersheds from dry farmed crops to irrigated agriculture took place prior to the

1980s, with the implication that the maximum water demand for agricultural use was largely established by then with few increases since.

On an annual basis, the amount of water used for crop production in both watersheds is small relative to total annual discharge. The calculation of annual agricultural water demand compared to total annual discharge is a starting point for resolving water use conflicts, as it provides stakeholders with the scale of the problem and therein the scale of the solution needed. The fact that growers, the agricultural water users, participated in the generation of these calculations, facilitates their support of the accuracy of the results and the use of the findings in plans and actions to resolve competition between uses.

The four primary water needs for irrigated agriculture generally occur at times when mean daily discharge is lowest (fig. 7). In drier water years, like 2007, the rates of daily use for irrigated agriculture can approach, equal, or potentially be greater than mean daily discharge rates. These findings suggest that irrigated agriculture requires additional assistance to reduce potential impacts to instream flows that result from water demand during the dry season.

Our results demonstrate that growers' water use decisions for irrigated agriculture are based upon a number of issues and factors. These include the cultural objectives for specific crops, soil and landscape position factors, the costs of energy and infrastructure to move and apply water, and resource stewardship considerations. In the case of wine grapes, growers generally seek to optimize fruit quality with less emphasis placed on yield. This can often result in reductions in the amount of water applied for irrigation use through regulated deficit irrigation. This is likely the reason that the calculated amount of water applied for irrigation in the evaluated wine grape blocks was consistently below net irrigation requirement.

Objectives for wine grape quality and yield depend on the varieties being grown — growers typically seek 5 to 6 tons per acre for white varieties compared with 2 to 3 tons per acre for red varieties. One way growers strive to maintain increased yield in white varieties is to make postharvest water applications. It is postulated that increased carbohydrate storage late in the season in the woody tissue of the plant improves growth and fruit set the following season. Several survey respondents identified this as the reason why they use postharvest applications. There is a need for research on this topic to help guide grower decision-making and water use.

Pear and apple agricultural objectives are orientated towards high yields because they are often sold as an unbranded commodity. The annual yield required for a grower to cover costs is 22 tons per acre. Obtaining such high yields requires a number of inputs, including 2 to 3 afa of water for irrigation use. Growers could take advantage of local weather data and well documented information on water needs for California orchards (Schwankl et al. 2007) to improve upon the timing and amount of water applied to meet crop needs.

In both evaluated wine grape blocks and apple and pear orchards, irrigation system distribution uniformity was good. In all three crops, there were isolated systems that had low values, which indicates system maintenance and upkeep were needed. However, averages above 88% in irrigation systems for both crops speak to efficient water use by these farmers to meet their respective agricultural objectives. This efficient use, combined with the documented transition to drip systems in grapes and under-canopy sprinkler systems in apples and pears through the last three decades, leaves little room for gains in conservation through irrigation system updates.

Although the need to protect crops from both frost and heat damage occurs on a limited amount of the total irrigated agriculture acreage in the study area, it still represents the next greatest need of water for irrigated agriculture. However, at the same time, it is imperative to find alternatives for this need in order to maintain stream flows at levels that support riparian wildlife and ecosystems.

The timing of water application for frost and heat events corresponds with critical salmon life stages and challenging stream conditions (fig. 7). Frost season, in March, April and even May of each year, is when young smolts migrate downstream to the ocean and young-of-the-year move downstream to large tributary streams. Heat events, which occur in July and August, match up with seasonal high stream water temperatures during critical rearing periods for young-of-the-year. In both cases, reductions in flows can prevent movement, increase stream temperatures and potentially result in increased mortality rates of these juvenile salmonids.

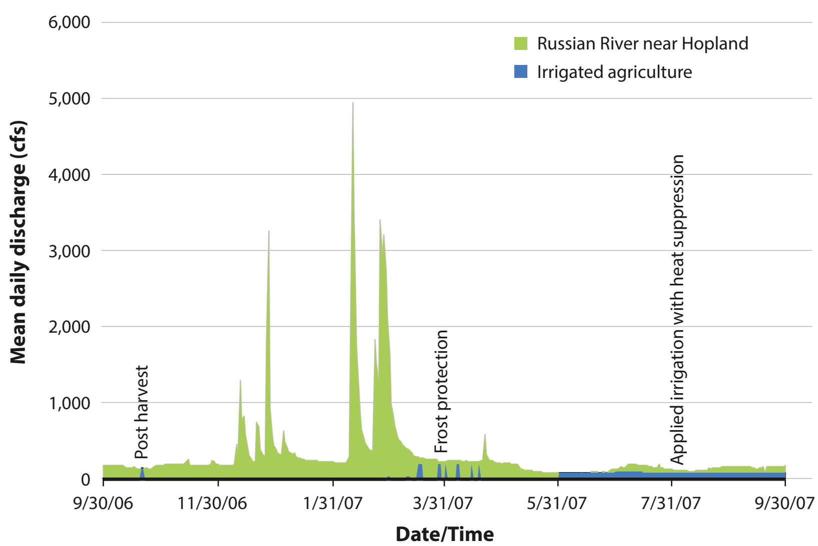


FIG. 7. Mean daily discharge (green) from Oct. 1, 2006, to Sept. 30, 2007, at USGS stream gauging station #11462500 near Hopland, California, and estimated daily rates of water applied (blue) to meet irrigated agriculture's water demand in the Mendocino County portion of the Russian River watershed.

In the case of grape production, grower survey responses indicated growers had transitioned to large volume solid set sprinkler systems for frost protection that deliver 50 gal/min/ac. This is because these systems are more reliable relative to other frost protection methods. It is possible to use low volume sprinkler systems that deliver 12 gal/min/ac, but the availability and durability of these systems are limited and they require innovation and improvement prior to grower adoption.

Grower survey responses indicate that they have evolved in their understanding of crop protection for frost and heat damage. This increase in knowledge has resulted in a reduction in the amount of water used during each threatening event. For frost, growers explained that they run their systems for shorter durations that closely match the timing of climatic threats for frost damage. They do this by intensively tracking dew point and ambient temperature through frost warning services and weather stations within specific vineyard blocks. Similarly, growers that protect against heat damage are switching from continual system operation when temperatures are at or above 100°F. They now pulse their systems, resulting in the system operating for 2 to 3 hours over the course of an event instead of a solid 6 to 12 hours. Facilitating these decisions with more local weather data, perhaps online decision support tools, and other varietal choices and planting approaches will contribute to water use efficiency for these purposes.

An interesting parallel to growers' increased knowledge and/or evolution in methods to protect crops from frost and heat damage is the documented change in the number of "cold" and "hot" days within the study area. In their survey responses, growers consistently explained there were fewer days now requiring frost and heat protection than in the past. This is consistent with documented trends in temperatures from 1955 to 2005 (Robinson 2007). These observations and trends suggest a reduction in the use of water for crop protection. However, as 2007 demonstrated for heat protection and 2008 demonstrated for frost protection, growers still need to be prepared to protect crops — both extremely hot and extremely cold conditions are never further than one season away, which was profoundly demonstrated in the extreme frosts of March and April 2008.

With regard to irrigated pasture, there is the potential to increase the consistency in the timing and amount of water applied to meet crop demand that will lead to greater efficiencies. Before discussing these opportunities, it is important to point out that irrigated pasture managers have also participated in USDA NRCS–sponsored programs to improve water delivery infrastructure since 1989. The result has been the conversion of over 80% of irrigated pasture from open-ditch to gravity type underground pipe and valve and sprinkler systems to reduce water loss and channel erosion. In looking for additional opportunities to improve irrigated pasture water use, recent research in other California irrigated pasture systems has identified high variability in the amount of water applied (Hanson et al. 2000). This included both over and under application of water to meet crop demand. Providing Mendocino County pasture managers with this information and facilitating their use of nearby measurements of evapotranspiration to estimate water needed to grow forage will contribute to their water resource management efforts. Additional steps could include on-farm measurements of soil moisture (Hanson et al. 2000) and forage production to generate more precise measurements and direction on water application rates and amounts.

A model for conservation

This collaborative field-based endeavor to understand and document agricultural water demand provides a successful model for resolving water use conflicts by generating credible water use numbers in the context of watershed specific-water availability. Meeting the agricultural, municipal, industrial and environmental water needs within the study area will require a combination of solutions and options for conserving and securing alternative sources of water. This will include continuation of on-farm conservation and water-use efficiency, connections between agriculture and recycled water, other potential policy changes, and more novel programs to afford winter storage for summer use by irrigated agriculture (see sidebar).

Survey responses about water conservation, coupled with the overall results for irrigation system efficiency, suggest that the participating growers are making efforts to be efficient water resource managers. Additional opportunities may exist to conserve agricultural water use through reductions in postharvest applications. The merits and benefits to achieving respective crops' agricultural objectives needs to be carefully evaluated for this water use. However, if this use does not provide a benefit, the savings in water used would be significant relative to the need for instream flows during the time of the year that postharvest applications are made.

One alternative with increasing potential is the use of recycled water. From 1997 to 2006, the city of Ukiah generated an average of 3,982 afa (minimum 3,755 and maximum 4,226) of water for residential and industrial uses (Burton 2007). The inference can be made that this generates approximately the same amount in wastewater that is currently treated at the Ukiah wastewater treatment facility. Dividing this volume by 1.25 afa, the average total annual water demand per acre of irrigated agriculture, indicates that water demand for approximately 3,185 acres of irrigated agriculture could be met with recycled water. The potential for use of this water by irrigated agriculture is initially dependent upon a reliable delivery system near acreage that can and is willing to use the water. Based on grower survey responses, there appears to be guarded willingness to use this water when the source is near irrigated acreage. Precedent for this type of use has already been set in other nearby regions both outside (Weber et al. 2014) and inside (Winzler & Kelly 2007) the Russian River watershed. Dialogue with Mendocino County growers on the concerns they have for using this water and exploration of infrastructure needs are moving this opportunity one step closer to fruition (see sidebar).

Another opportunity to meet agricultural and environmental water needs is strategic capture and storage of high winter flows. Using storage to match irrigated agricultural water demand with available water is an approach whose time has arrived — the storage structures and systems for water conveyance have already been put in place by growers and conservation organizations (see sidebar). This approach synchronizes water demand and availability and reduces water diversions during summer low flow conditions, maintaining flows and critical stream habitat requirements during dry periods of the year. CA

G. McGourty is UC Cooperative Extension (UCCE) Viticulture Advisor, Mendocino County; D. Lewis is UCCE Watershed Management Advisor, Marin and Napa counties; Josh Metz is GIS Analyst and Technical Writer, Monterey; J. Harper is UCCE Livestock and Natural Resources Advisor, Mendocino County; R. Elkins is UCCE Pomology Farm Advisor, Lake County; J. Christian-Smith is Senior Program Officer, Water Foundation, San Francisco; P. Papper is Ph.D. Candidate, Department of Environmental Science, *Policy, and Management, UC Berkeley; L. Schwankl is UCCE Irrigation Specialist Emeritus, Kearney Agricultural and Research Center; and T. Prichard is UCCE Irrigation Specialist, Department of Land, Air and Water Resources, UC Davis (retired).*

We want to thank cooperating growers for their contribution of time and for granting farm access to evaluate irrigation systems. We also want to recognize the Mendocino County Water Agency and The Nature Conservancy for funding this research. Jim Nosera and Sarah Baker provided significant contributions in the collection and compilation of field data, including GIS roles.

TABLE 4. Unit conversions

English	Metric equivalent
1 acre	0.405 hectares
1 short ton	0.907 metric tons
1 ton/acre	2.24 metric tons/hectare
1 gallon/minute/acre	9.35 L/minute/hectare
1 cubic foot per second	0.028 cubic meters per second
1 acre-foot	1,233.48 cubic meters

References

Battany M. 2012. Crop Coefficients – Paso Panel. UC Cooperative Extension San Luis Obispo County. http://cesanluisobispo.ucanr.edu/Viticulture/Paso_Panel/ (accessed Nov. 28, 2012).

Bearden B. 1974. The Climate of Mendocino County. UC Cooperative Extension, Mendocino County, Ukiah, California.

Bengston D. 2004. Mendocino County Crop Report. Mendocino County Agricultural Commissioner and California Department of Food and Agriculture. Ukiah, California. 17 p.

Burton BH. 2007. Drinking Water Adequacy Assessment. Ukiah Valley, Mendocino County. Department of Public Health, Drinking Water Field Operations Branch, Mendocino District. Ukiah, California. 75 p.

[CDFA] California Department of Food and Agriculture. 1968. Mendocino County fruit and nut acreage survey. California Department of Food and Agriculture.

CDFA. 1976. Mendocino County Fruit and Nut Acreage Survey. California Department of Food and Agriculture.

CDFA. 2006. Mendocino County Fruit and Nut Acreage Survey. California Department of Food and Agriculture.

CDFA. 2009. Mendocino County Fruit and Nut Acreage Survey. California Department of Food and Agriculture.

[CDWR] California Department of Water Resources. 1964. Land and Water Use in Mendocino Coast Hydrographic Unit. Bulletin 94-10. California Department of Water Resources. Sacramento, California. 86 p.

CDWR. 1979. Land Use Tables of Mendocino County – 1978. California Department of Water Resources. Sacramento, California. 38 p.

CDWR. 1989. Mendocino County 1986 Land Use Survey. Study No 88-60. California Department of Water Resources. Sacramento, California.

CDWR. 2010. Land and Water Use. California Department of Water Resources. https://water.ca.gov/Programs/Water-Use-And-Efficiency/Land-And-Water-Use/Agricultural-Land-And-Water-Use-Estimates

Carpenter EF. 1958. Water Use Survey on the Russian River in Southern Mendocino County. Prepared for the Mendocino County Board of Supervisors and the Mendocino County Russian River Flood Control and Water Conservation Improvement District. 51 p.

Constantz J, Jasperse J, Seymour D, Su GW. 2003. Heat tracing in streambed along the Russian River of northern California..In: Stonestrom DA, Constantz J. Heat as a Tool for Studying the Movement of Ground Water near Streams. U.S. Department of Interior and U.S. Geological Survey. Circular 1260. p 19–20. http://pubs.usgs.gov/circ/2003/circ1260/pdf/Circ1260.pdf

Deitch MJ. 2006. Scientific and institutional complexities of managing surface water for beneficial human and ecosystem uses under a seasonally variable flow regime in Mediterranean-Climate northern California. Ph.D. Dissertation. University of California, Berkeley. 323 p.

Elkins RB, Klonsky KM, De Moura RL. 2006. Sample costs to establish and produce pears. Green Bartlett. North Coast Region. Lake and Mendocino counties. University of California Cooperative Extension and UC Davis Department of Agriculture and Resource Economics. 26 p.

Elkins RB, Moratorio MS, McClain R, Siebert JB. 2007. History and overview of the California pear industry. In Mitcham EJ, Elkins RB (eds.). Pear Production and Handling Manual. University of California Agriculture and Natural Resources. Publication 3483. p 3–12.

Fulton A, Reed B, Forero L. 2007. Irrigation. In: Reed B, Forero L (eds.). Irrigated Pasture Production in the Central Valley of California. p 31–6.

Hanson BR, Orloff S, Peters D. 2000. Monitoring soil moisture helps refine irrigation management. Calif Agr 54(3):38–42.

Howard RF, Bowman RH. 1991. Soil Survey of Mendocino County, Eastern Part, and Trinity County, Southwestern part, California. United States Department of Agriculture, Soil Conservation Service, in cooperation with USDA Forest Service; United States Department of Interior, Bureau of Land Management and Bureau of Indian Affairs; and Regents of the University of California (Agriculture Experiment Station). 419 p.

Linegar T. 2008. Mendocino County Crop Report. Mendocino County Agricultural Commissioner and California Department of Food and Agriculture. Ukiah, California. 15 p.

Marquez MF, Sandoval-Solis S, DeVicentis AJ, et al. 2017. Water budget development for SGMA compliance, case study: Ukiah Valley Groundwater Basin. J Contemp Water Research Education 162:112–27.

Metzger LR, Farra CD, Koczot KM, Reichard EG. 2006. Geohydrology and water chemistry of the Alexander Valley, Sonoma County, California. U.S. Geological Survey Scientific Investigations Report 2006-5115. 95 p.

Nagi R. 2011. Classifying Landsat image services to make a land cover map. ESRI ArcGIS Blog. May 28, 2011. www.esri.com/arcgis-blog/products/product/imagery/classifying-landsat-image-services-to-make-a-land-cover-map/

National Agricultural Imagery Program [NAIP]. 2009. NAIP Quarter Qaud Shapefile for 2009. USDA Farm Services Agency. www.fsa.usda.gov/programs-and-services/aerial-photography/imagery-programs/naip-qq-and-photo-center-shapefiles/index

[NOAA] National Oceanic and Atmospheric Administration. 2005. Endangered and Threatened species: Designation of critical habitat for seven evolutionary significant units of pacific salmon and steelhead in California; Final rule. September 2, 2005. 70 FR 52488. United States Dept. of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service. Federal Register, Volume 70, p 52488–52627.

Prichard TL, Smith RJ, Verdegaal PS. 2007. Regulated deficit irrigation management for winegrapes. UC Davis Department of Land, Air, and Water Resources and UC Cooperative Extension. Davis, California. 23 p.

Rittiman CA, Thorson T. 1993. Soil Survey of Mendocino County, California, Western Part. United States Department of Agriculture and Natural Resources Conservation Service in cooperation with California Department of Forestry; Soil Vegetation Survey; Georgia-Pacific Corporation; Regents of the University of California (Agricultural Experiment Station); and the United States Department of the Interior, Bureau of Land Management. 459 p plus maps.

Robinson Z. 2007. Climate is changing in North Coast grape growing region. Practical Winery & Vineyard. May/June. 5 p.

Schwankl LJ. 2007. Irrigation systems. In: Mitcham EJ, Elkins RB (eds.). *Pear Production and Handling Manual*. University of California Division of Agriculture and Natural Resources. Publication 3483. p 113–16.

Schwankl LJ, Smith RJ. 2004. Determining the irrigation amount: How to calculate the number of hours to run your drip system in order to apply a net amount of gallons per vine. UC Davis Department of Land, Air, and Water Resources and UC Cooperative Extension Sonoma County. 10 p.

Snyder RL. 2007. Frost protection. In: Mitcham EJ, Elkins RB (eds.). *Pear Production and Handling Manual*. University of California Agriculture and Natural Resources. Publication 3483. P 117–23.

Sommarstrom S. 1986. An Inventory of Water Use and Future Needs in the Russian River Basin of Mendocino County. Mendocino County Flood Control and Water Conservation District, Ukiah, California. 69 p.

State Water Commission and USGS. 2017. National Elevation Dataset. https://catalog.data.gov/dataset/usgs-national-elevation-dataset-ned

[SWRCB] State Water Resources Control Board. 2013. Adoption of a proposed policy for maintaining instream flows in northern California coastal streams. Resolution 2013-0035. State Water Resources Control Board, Sacramento, California. 4 p.

SWRCB. 2014. Policy for maintaining instream flows in Northern California Coastal Streams. Division of Water Rights: State Water Resources Control Board, California Environmental Protection Agency. Sacramento, California. 141 p.

[UFD] Ukiah Fire Department. 2008. Rainfall data recorded at the Ukiah Fire Department Headquarters. Ukiah, California.

Weber E, Grattan SR, Hanson BR, et al. 2014. Recycled water causes no salinity or toxicity in Napa vineyard. Calif Agr 68(3):59–67.

Williams LE, Ayars JE. 2005. Grapevine water use and the crop coefficient are linear functions of the shaded area measured beneath the canopy. Agr Forest Meteorol 132:201–11.

Winzler & Kelly. 2007. Incremental Recycled Water Program: 2007 Update to the Recycled Water Master Plan. Prepared for the City of Santa Rosa Utilities Department. Santa Rosa, California. 77 p.

UNIVERSITY OF CALIFORNIA
Agriculture and Natural Resources

California Agriculture
2801 Second Street
Room 181A
Davis, CA 95618-7779

Phone: (530) 750-1223
Fax: (530) 756-1079

Visit us online:

calag.ucanr.edu
twitter @Cal_Ag
www.facebook.com/CaliforniaAgriculture

Upcoming UC ANR events

Spring Celebration — Hopland Research and Extension Center

https://ucanr.edu/survey/survey.cfm?surveynumber=28212

Date: March 15, 2020
Time: 10:00 a.m. to 3:00 p.m.
Location: 4070 University Road, Hopland
Contact: Hannah Bird hbird@ucanr.edu or 707-744-1424 ext 105

Shafter Cover Crop Field Day

http://ciwr.ucanr.edu/Programs/ClimateSmartAg/News_700/?g=109703&calitem=476792

Date: March 19, 2020
Time: 9:00 a.m. to 11:00 a.m.
Location: Intersection of Mettler Ave. and Madera Ave., Shafter
Contact: Shulamit Shroder sashroder@ucanr.edu or 661-868-6218


Shulamit Shroder


Susie Kocher

Spring 2020 Prescribed Fire on Private Lands Workshop — Auburn

https://ucanr.edu/sites/csnce/files/318712.pdf

Date: March 26, 2020
Time: 8:30 a.m. to 4:30 p.m.
Location: Auburn City Fire Department, Station #1, 485 High Street, Auburn
Contact: Susie Kocher sdkocher@ucanr.edu or 530-542-2571