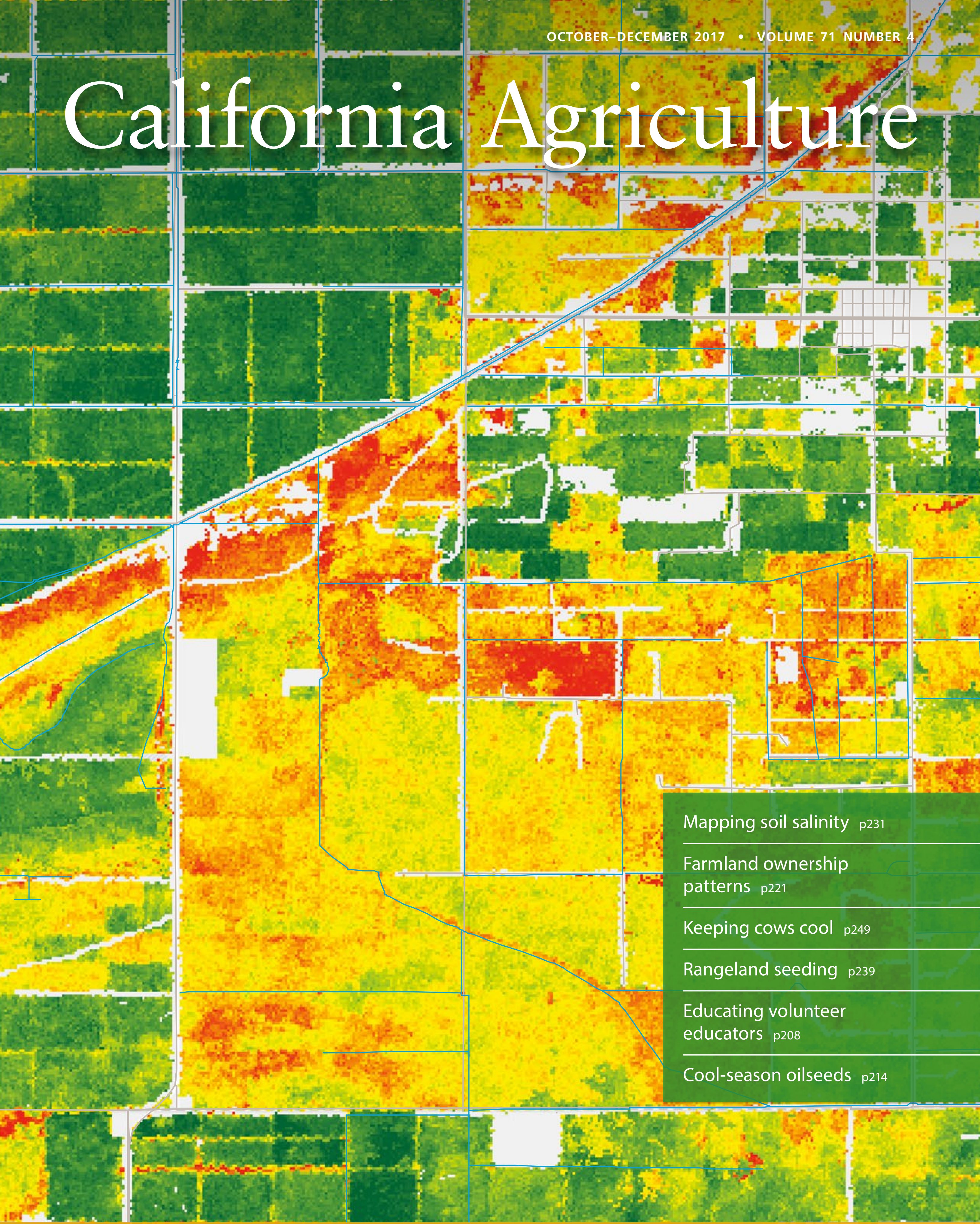
OCTOBER–DECEMBER 2017 • VOLUME 71 NUMBER 4

California Agriculture



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California Agriculture

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ORDERS AND SUBSCRIPTIONS

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EDITORIAL

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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 (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 2016 Thomson JCR, the journal's 5-year impact factor was 1.0.

Authors. Most authors (75%) are among the roughly 1,000 academics affiliated with 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.

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UNIVERSITY OF CALIFORNIA

University *of* California
Agriculture and Natural Resources

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RESEARCH NEWS

COVER: Scudiero et al. (page 231) used satellite imagery to model root-zone soil salinity in the western San Joaquin Valley. They found 30% of mapped farmland to be strongly or extremely saline. In the map section shown on the cover, soil salinity ranges from non-saline (dark green) to extremely saline (red). Image credit: USDA-ARS and University of California Riverside.

Donald Suarez, USDA Salinity Laboratory

Research and review articles

EDITORIAL

Measuring our impact, setting our course

Wendy Powers, Associate Vice President of UC Agriculture and Natural Resources

Wendy Powers

UC ANR is a network of change agents who care about the health and welfare of people, communities and natural resources. We effect change by translating science into practices and behaviors that transform thinking and lives. Our programs in agriculture, youth development, nutrition and natural resources make a difference. We see it in our communities and we hear it from our clients and partnering organizations. But how do we help those who are more distant from our efforts understand the difference we make, not for the sake of recognition but rather to recruit more people to engage with us and benefit from what UC ANR has to offer? And how do we determine what differences we want to make?

Since arriving last year to serve as Associate Vice President for UC ANR statewide programs and UC Cooperative Extension, one of my key responsibilities has been to ensure that our research and extension activities are on track to meet our ambitious Strategic Vision 2025 targets. As Apple co-founder Steve Jobs said, "Deciding what not to do is as important as deciding what to do." (Isaacson 2012). If we want to achieve our targets, UC ANR must identify the differences we want to make and steer our efforts in that direction.

In recent months, I have been working with academics across the division to develop a new structure for focusing on those differences and identifying the evidence we will use to document the changes that result from our work. This structure will be formalized as *condition changes*. Academics can demonstrate how their own work supports the condition changes through *condition indicators*.

Condition changes are broad, state-level or societal-level changes that we hope to effect (recognizing, of course, that UC ANR is one of many organizations working in these subject areas). The research articles in this issue highlight UC ANR's work towards the following condition changes: improved water resource utilization, increased farmer or rancher profitability, enhanced resiliency towards climate uncertainties, and increased college readiness of youth.

Condition indicators provide quantitative evidence of our progress toward a given condition change. There may be many condition indicators for each condition change. Examples from the research papers in this issue that correspond to the above condition changes might include: decreased water used for cooling cows, reduced soil salinity or increased forage yields, avoidance of catastrophic crop loss during drought years, and an elevated college acceptance rate for youth participating in 4-H.

Our approach to measuring incremental change embraces the philosophy of children's rights activist Marian Wright Edelman, who advises that "we must not, in trying to think about how we can make a big difference, ignore the small daily differences we can make which, over time, add up to big differences that we often cannot foresee."

In UC Cooperative Extension county offices, on campuses and at Research and Extension Centers, we are committed to constant and continuous improvement of what we do, to achieve our strategic vision. We value the need for new partnerships, and for professional development across the continuum. We will continue to identify what outcomes are needed from our work, measuring our progress, and, just as importantly now, equipping leadership to share more broadly the impact of our work, to reach more people and soar over the ever-rising bar that life's challenges bring. CA

References

Isaacson W. 2012. The real leadership lessons of Steve Jobs. Harvard Bus Rev. April 2012. https://hbr.org/2012/04/the-real-leadership-lessons-of-steve-jobs.

Building climate change resilience in California through UC Cooperative Extension

A survey of UC ANR academics found opportunities for expanding the role of climate change in extension work.

Theodore Grantham, Assistant Cooperative Extension Specialist, Department of Environmental Science, Policy, and Management, University of California, Berkeley

Faith Kearns, Academic Coordinator, California Institute for Water Resources

Susie Kocher, Forestry and Natural Resources Advisor, Central Sierra Cooperative Extension

Leslie Roche, Assistant Cooperative Extension Specialist, Department of Plant Sciences, University of California, Davis

Tapan Pathak, Assistant Cooperative Extension Specialist, Sierra Nevada Research Institute, University of California, Merced

Climate change is a global challenge. Yet, the impacts are local and already being felt in California. Rising summer temperatures and extreme events — including the recent swing from a 5-year drought to one of the wettest winters on record — are indicative of a warmer, more variable climate future. The changing climate has already begun to stress our social, economic and ecological systems. It is threatening crops, increasing catastrophic wildfires, harming fish and wildlife, limiting water supplies while also increasing flood risk, and ultimately impacting the health and quality of life for Californians.

The University of California's Division of Agriculture and Natural Resources (UC ANR) has worked with Californians for more than 100 years through its statewide network — which includes UC Cooperative Extension and the Agricultural Experiment Station campuses — to solve problems in agriculture, natural resources and food systems. Climate change compounds these problems, making it more difficult for UC ANR to achieve its vision for "a thriving California in 2025 where healthy people and communities, healthy food systems, and healthy environments are strengthened through partnerships between UC and the people of the state."

UC ANR academics and staff are mobilizing to address the threat of climate change. In November 2013, UC President Janet Napolitano announced the Carbon Neutrality Initiative (CNI). The initiative committed UC to emitting net zero greenhouse gases from its buildings and vehicle fleet by 2025, the first commitment of its kind by any major university. Within UC ANR, the CNI provided small financial incentives for academics to develop climate change–related projects across many program areas, including agriculture, natural resources, nutrition and youth development.

Snowmelt fills the South Yuba River near Emigrant Gap in March 2016. Climate change is expected to reduce the Sierra snowpack, resulting in major shifts in the timing and magnitude of flows in rivers fed by snowmelt.

Kelly M. Grow/California Department of Water Resources

UC ANR leadership also supported the establishment of a climate change program team in 2015, with the primary goal of building capacity within UC Cooperative Extension to better serve the public in addressing climate change impacts and adaptation challenges. As members of the program team, we decided an important first step to support this goal was to assess the scope of current climate science research and extension within UC ANR. We designed and distributed an online survey in early 2017, reaching out to approximately 1,000 UC ANR faculty, specialists, advisors and staff to evaluate interests and experiences in incorporating climate change science into research and extension programs. We received feedback from 144 respondents (fig. 1).

We found that there was overwhelming agreement on the importance of addressing climate change (fig. 1). Nearly all respondents (88%) believe it is important to incorporate information about climate change impacts, adaptation approaches, and mitigation strategies into extension programs. At the same time, fewer than half of the respondents (43%) currently incorporate climate change in their extension programming in some way. Because responses were voluntary and probably overrepresented those interested in climate change, the actual percentage of ANR

Fig. 1. Results from the UC ANR climate science, outreach, and needs survey.

UC Agriculture and Natural Resources

Climate science, outreach, and needs survey

In 2017, the authors surveyed UC ANR scientists and outreach professionals. The 144 responses highlight the broad range of efforts by UC Cooperative Extension and the Agricultural Experiment Station in building climate change resilience across California, as well as opportunities to further grow capacity in these areas.

Respondents

County advisors
46

Community education specialists
38

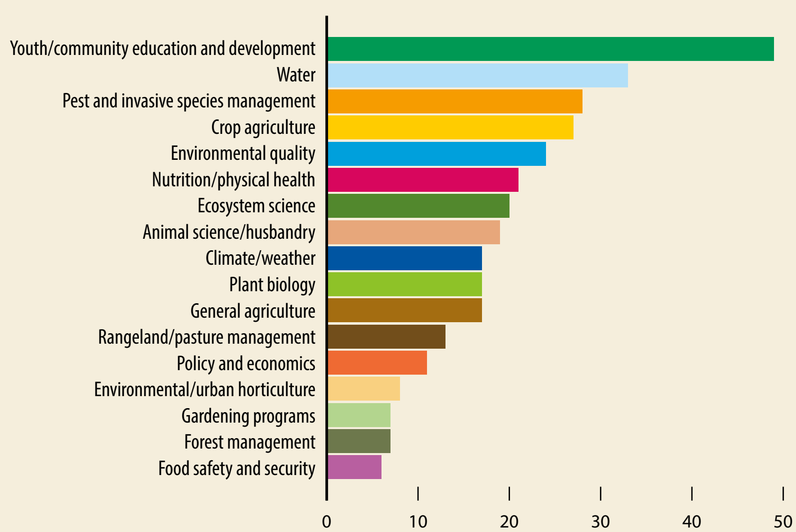
Cooperative Extension specialists
23

Campus faculty (Agricultural Experiment Station)
22

Academic coordinators and support personnel
15

Area of expertise

(324 unique responses; respondents could choose more than one area)



Primary clientele

Agriculture
47%

Natural resources
22%

Youth development
17%

Family and consumer science
14%

academics and staff directly engaging with climate change is likely lower.

Many respondents had a low level of confidence in their current ability to incorporate climate change in their extension programming. Perceived barriers included lack of access to climate information relevant to their extension programs and clientele, limited familiarity with climate science fundamentals, and fear of alienating clientele by talking about a contentious topic.

In addition, 25% of the respondents who currently incorporate climate change in their programming felt that they did not have adequate support from UC ANR to work on climate change issues. Respondents expressed interest in professional development opportunities, including education on technical tools and information resources, as well as training in climate science communication.

In summary, the survey revealed that UC ANR personnel recognize the importance of addressing climate change and that additional training and institutional support are critical for building capacity to incorporate climate change within extension programs. In response, the climate change program team is working to develop a series of workshops to address these barriers and to identify the tools, resources and information

Concerns expressed by respondents who currently incorporate climate change into their extension programming

1. No concerns
35%

2. Unsure about presenting complex climate data accurately
32%

3. Don't feel they have adequate support from UC ANR to work on issue
25%

4. Concerned about the reaction of clientele to climate change information
22%

Concerns expressed by respondents who do not currently incorporate climate change into their extension programming

1. No access to curriculum specific to field
51%

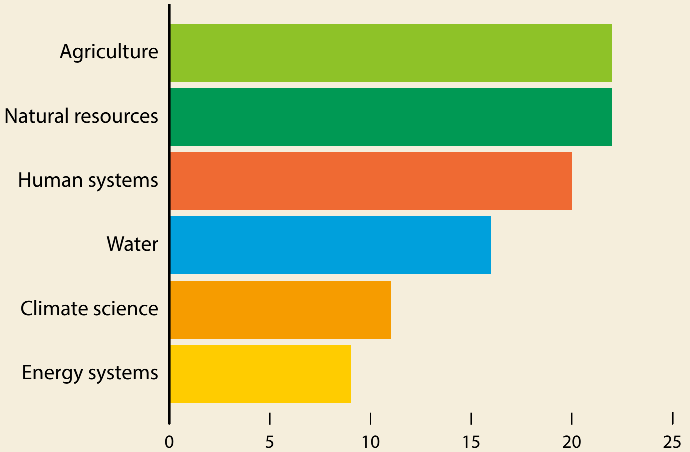
2. Unsure about presenting complex climate data accurately
32%

3. Don't have good source of climate change information to share
30%

4. Concerned about the reaction of clientele to climate change information
24%

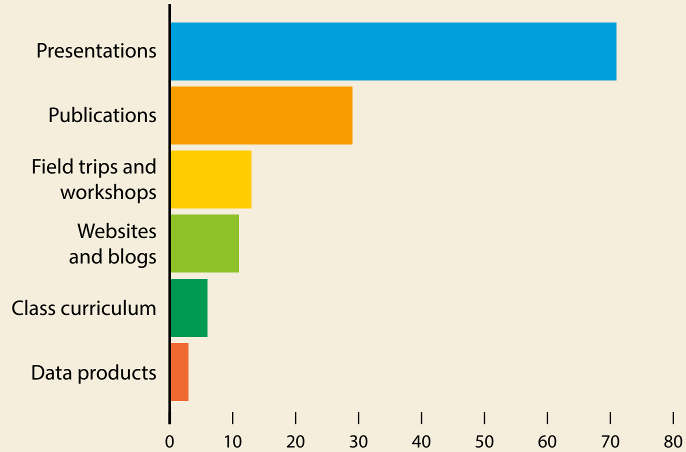
Topics covered currently by respondents who are incorporating climate change into their extension programming

(101 unique responses; respondents could select more than one topic)



Strategies used currently by respondents who are incorporating climate change into their extension programming

(133 unique responses; respondents could select more than one strategy)



that UC ANR extension personnel need to more effectively engage with climate change.

There are several existing programs that provide models for those seeking to incorporate climate change in their extension work. These include extension publications to help forest managers adapt to climate change and rancher outreach programs focused on enhancing the resilience of rangelands to climate stresses. The extreme drought that gripped the state from 2012 to 2016 offered a glimpse into California's climate future, and UC ANR was actively involved in developing fact sheets and workshops to assist growers and ranchers in coping with water scarcity. UC ANR academics have contributed to the development of the Cal-Adapt.org website to allow for easy access to climate change data and have been active in the state capitol, providing testimony on climate change adaptation and resilience efforts by Cooperative Extension. Finally, the Master Gardener Program has long taught "climate-smart" approaches to gardening, landscaping and irrigation. Through diverse extension approaches, UC ANR is already taking an active role in addressing climate change impacts in California.

To further increase the capacity of UC ANR staff to support the needs of their clientele and the broader public, professional development around climate science fundamentals, communication, and adaptation strategies is critical. In particular, discussing climate change with our stakeholders can feel challenging to both the new and well-worn relationships that are fundamental to the success of our work. UC ANR personnel work hard to build and maintain trusting relationships and are understandably reluctant to address difficult, politicized issues such as climate change. Workshops that address the challenges of communicating climate science information to clientele and future professional development opportunities that enable UC ANR personnel to feel more comfortable working with difficult and controversial topics would be valuable. In addition, UC ANR staff would benefit from tailored trainings on climate change information resources that are most relevant to their stakeholders.

Beyond professional development opportunities, UC ANR can do more to increase the visibility of its climate change research and extension programs in its media campaigns, government relations, and strategic planning efforts. Expanding the CNI's program to provide seed funding for projects would spur creative activity and foster new collaborations around climate change extension. The statewide California Naturalist Program provides a network of partnering organizations who are well-positioned to improve climate-change literacy and advance local adaptation efforts through science-based education and service opportunities. Efforts to expand this growing network and provide a community of practice for climate education and stewardship should be supported.

As federal efforts to combat climate change stall, California has embraced an ambitious climate change strategy — increasing renewable energy, investing in research, and reducing greenhouse gas emissions. Yet, the public is still uncertain about how climate change will affect their lives and how they should respond. According to a recent climate opinion study, most Californians (79%) recognize that climate change is happening, but fewer believe it will harm their communities (56%), families (54%), or themselves personally (44%). UC ANR's representation across the state and engagement with the state's diverse communities makes us uniquely positioned to understand and communicate the consequences of climate change to the public, and to identify strategies to mitigate negative outcomes for local economies, the environment and public health. Looking to the future, UC ANR can become a powerful catalyst for climate adaptation and we should embrace a leadership role in advancing the knowledge and tools needed for a climate-resilient California. CA

This photo from a 2016 aerial detection survey of the Sierra and Sequoia national forests shows a high concentration of dead and dying trees. Climate change is expected to lead to longer droughts and higher temperatures, stressing trees and making them more vulnerable to pests and diseases.

For more information on UC ANR's ongoing and planned research and extension activities relating to climate change, please contact climate change program team co-leaders Ted Grantham, Susie Kocher and Tapan Pathak.

Desert REC: Educational outreach and crop breeding

Jairo Diaz

Located in the Imperial Valley, this research station runs UC ANR's biggest agricultural outreach program and hosts the largest public carrot breeding program in the Americas.

Previous page: New carrot varieties are evaluated at Desert REC for field production performance. Seed companies include their top-selling carrot varieties, along with the best new carrot varieties they have developed, among the nearly 200 entries in the annual carrot field trials at Desert REC. As the best new varieties go on to replace older varieties, carrot growers and consumers benefit from crop improvements tested in these trials.

The Imperial Valley is a place of extremes — and that's a big part of what makes the UC ANR Desert Research and Extension Center (REC) so useful.

Average high temperatures at Desert REC exceed 100°F for a full 4 months in the summer, and rainfall totals around 3 inches per year. But the flip side of the scorching summer is a pleasantly mild winter that makes the 225-acre research center a great spot for plant breeding. For a half century, the U.S. Department of Agriculture's carrot breeding program has been based here in the cool months (split with summers in Wisconsin). And many varieties of other crops have been developed at Desert REC over the decades — from alfalfa and asparagus to barley and lettuce.

The hot climate and issues such as the salinity of the region's irrigation supply (drawn from the Colorado River) create a set of unique challenges for agriculture in the Imperial Valley. The search for ways to manage those challenges has forged strong links between researchers and the growers who work the valley's 500,000 acres of farmland. Desert REC, which opened in 1912 as the Meloland Field Station, today operates with strong support from local farms and livestock operations as well as the Imperial Irrigation District — bringing in cash contributions as well as in-kind donations of everything from vegetable seedlings to porta-potties.

That farming works at all in such an inhospitable climate is a source of wonder for many of the tourists that visit the center in the winter. Those visitors bring revenue and volunteer labor to Desert REC that then help to support the center's thriving youth outreach program, Farm Smart.

Harvesting vegetables from the Desert REC garden is a highlight of the elementary school programs.

Farm Smart

Established in 2001, the Farm Smart agricultural outreach program is the largest in the UC ANR REC system. It includes two programs — one targeting grades K-12, the other adults — and has now logged more than 137,000 visitors.

The children's program changes with the seasons, covering dairy and livestock in fall, corn in winter, vegetables in early spring, and pest management in late spring. It's a hands-on program (with plenty of eating) that explains where food comes from and how farms work. Each day ends with the children visiting the center's 3-acre vegetable garden for a mini-harvest. "Even though they've grown up here, a lot of them have never picked a vegetable to eat," said Farm Smart Community Educator Stephanie Collins, one of the program's two staff members.

The program hosts about 10,000 K-6 students annually, in groups of 50 to 100. Farm Smart attracts classes from every school district in the region. It reaches a substantial fraction of all children in Imperial County, which has a total population of 177,000.

In the winter, Farm Smart hosts a week-long outreach program for local high school students that focuses on careers in agriculture. Students talk with

Students on a hayride around DREC.

researchers and growers about their work, and learn about modern farm technology by using an iPad to control an irrigation system and climbing into the cab of a GPS-guided tractor. Representatives from the USDA and the University of Arizona Yuma — the nearest four-year college offering degrees in agriculture, science and engineering — talk with students about degree and career options in agriculture and related fields. Imperial County has the lowest per-capita income in California, and the farm and livestock industries offer some of the best local job opportunities for college graduates (through a recent agreement, Imperial Valley community college students can transfer to the Yuma campus and pay tuition at the in-state rate).

In addition to the two student programs, Farm Smart runs wintertime tours for tourists curious about Imperial Valley agriculture. For a $25 fee, visitors can go on a day-long tour that includes science presentations, the obligatory hayride, and the opportunity to take home an armload of produce from the vegetable garden. Revenue from the adult-visitor program helps support the Farm Smart programs for children. It also operates as a volunteer recruiting tool: visitors who'd like to stay and help out at Desert REC can park their RVs on site for free (there are four sets of RV hookups) for a few days or weeks. Collins said they get about 2,000 hours of volunteer labor that way each year.

"There's no fee, but it's a lot of work," she said

Carrot breeding

The research at Desert REC is a big part of what makes the tours so interesting. Among the largest and longest-running strands of work is the development of new carrot varieties.

Since the 1960s, Desert REC has hosted the winter plantings of the USDA's carrot breeding program, which is based at the University of Wisconsin. The year-round arrangement allows for twice as many generations of carrots per year, speeding up the breeding process. It's also useful to have a breeding center based in California, because the state accounts for about 80% of the U.S. carrot harvest. Varieties developed through the USDA program are released to commercial seed companies for production and sale.

Over the years, the program has developed, or contributed to the development of, many of the carrot varieties that are now in both organic and conventional production in the United States.

There are now varieties specific to baby carrot production, for instance — long and thin so they can be planted densely, each one long enough to yield four to five baby carrots when processed. Multi-colored carrot varieties are particularly popular with organic growers.

Increasing nutrient content has also been a priority (not the case with every crop), and today's carrots have 40% to 50% higher concentrations of beta-carotene than commercial varieties 50 years ago. Beta-carotene, the orange pigment that gives carrots their color, is a key source of vitamin A, and carrots now account for 13% to 15% of U.S. vitamin A intake.

Still, there's always room for improvement. One of the challenges in breeding is identifying new genes that can be bred into existing varieties, yielding an improvement in one or more traits.

Under a recent $3.65 million grant from the USDA's Specialty Crop Research Initiative, the carrot breeding program at Desert REC will be part of a major effort to identify potentially useful genetic material among the roughly 700 carrot varieties maintained in the USDA germplasm collection in Ames, Iowa.


Gilberto Magallon

The carrot breeding program at Desert REC will be part of a major effort to identify potentially useful genetic material among the roughly 700 carrot varieties maintained in the USDA germplasm collection in Ames, Iowa.

"This gives us the opportunity to go back to these old carrots and see if there's anything promising," said Philipp Simon, the USDA plant breeder who has led the carrot program for the past 35 years.

The carrot archive in Iowa includes hundreds of heirloom cultivated varieties as well as several hundred types of wild carrot, some collected as long ago as the early 19th century.

The project, said Simon, grew out of a gathering in 2015 of carrot growers, breeders and seed producers in Bakersfield, near the center of the California carrot industry (more than 70% of the state's carrot production is in Kern County). They developed a list of the top priorities for breeding — from nematode resistance and early stand establishment (growing quickly enough to compete with weeds) to flavor, shape and color. That led to a grant application to systematically review the available genes in the nation's carrot archive — and eventually to the work now underway at Desert REC. CA

—Jim Downing

Research highlights

Recent scientific articles from the Agricultural Experiment Station campuses.

Dominic Sherony, www.flickr.com

Researchers found that grazed plots had more native plants than ungrazed ones and that all three bird species studied — Western meadowlark (*Sturnella neglecta*), Horned lark (*Eremophila alpestris*), and Grasshopper sparrow (*Ammodramus savannarum*, above) — had positive associations with native plant abundance.

Livestock grazing supports native plants and songbirds in a California grassland

California's grasslands provide fresh water, recreational opportunities, food, and climate mitigation benefits. They are also home to many species of native plants and wildlife, including a suite of grassland-dependent songbirds whose populations are declining precipitously across the western United States.

Livestock grazing is the most widely used tool to manage and restore grasslands. To better understand the effects of grazing on native plants and grassland bird habitat, a team of scientists led by James Bartolome, professor in the Department of Environmental Science, Policy, and Management at UC Berkeley, studied three bird species in central California — Western meadowlark (*Sturnella neglecta*), Horned lark (*Eremophila alpestris*), and Grasshopper sparrow (*Ammodramus savannarum*).

The researchers found that grazed plots had more native plants than ungrazed ones and that all three bird species had positive associations with native plant abundance. Their results suggest that livestock grazing in annual grasslands is compatible with, and may enhance, bird conservation in grasslands in Mediterranean climates.

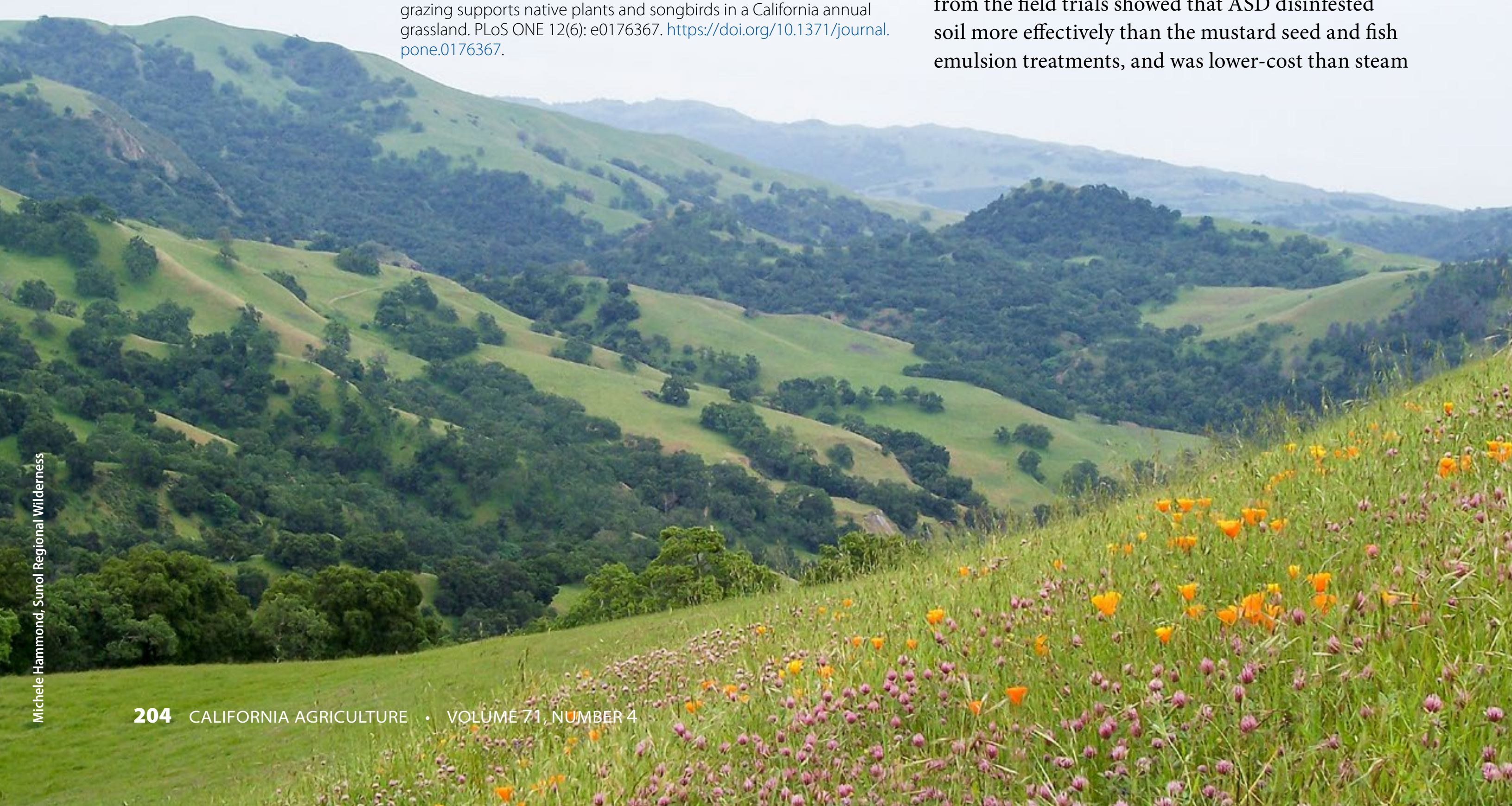
Gennet S, Spotswood E, Hammond M, Bartolome JW. 2017. Livestock grazing supports native plants and songbirds in a California annual grassland. PLoS ONE 12(6): e0176367. https://doi.org/10.1371/journal.pone.0176367.

Anaerobic soil disinfestation can be an effective and economical alternative to fumigation

For decades, California strawberry growers used methyl bromide to control soilborne diseases, nematodes and weeds in their fields. Use of the fumigant has been phased out, with the last strawberry applications in 2016. The use of other chemical fumigants, such as chloropicrin, has increased.

Because fumigants are heavily regulated and pose health and environmental risks, scientists are investigating alternatives to soil fumigation. In this study (Shennan et al. 2017), a group of UC, USDA and private sector researchers investigated the effectiveness of anaerobic soil disinfestation (ASD) in controlling pathogens, including the fungus *Verticillium dahliae*, the cause of verticillium wilt. The team conducted controlled-environment experiments of ASD, as well as on-farm field trials comparing ASD — using rice bran as a carbon source — with control treatments, along with other nonfumigant soil disinfestation treatments (steam treatment, "biofumigation" with mustard seed meal, and the application of fish emulsion).

Results from the controlled-environment trials showed the importance of soil temperature to the effectiveness of ASD: at soil temperatures of 15°C, ASD was ineffective, while at 25°C it was highly effective. Results from the field trials showed that ASD disinfested soil more effectively than the mustard seed and fish emulsion treatments, and was lower-cost than steam



Michele Hammond, Sunol Regional Wilderness

In field trials conducted on organic strawberries by Shennan et al., plants in plots treated with anaerobic soil disinfestation (ASD), *right*, were larger and produced higher yields than plants in untreated plots, *left*.

treatment. In three out of the four field trials, estimated cash returns from the ASD plots were 92% to 96% of those from beds fumigated with chloropicrin.

Steam currently appears to be the most effective nonfumigant soil treatment for strawberries, though it remains more expensive than ASD (see, e.g., Fennimore and Goodhue 2016 and Xu et al. 2017). Research on both techniques continues.

Shennan C, Muramoto J, Koike S, et al. 2017. Anaerobic soil disinfestation is an alternative to soil fumigation for control of some soilborne pathogens in strawberry production. Plant Pathol. https://doi.org/10.1111/ppa.12721.

See also:

Xu Y, Goodhue RE, Chalfant JA. 2017. Economic viability of steam as an alternative to preplant soil fumigation in California strawberry production. Hortscience 52(3): 401–7. https://doi.org/10.21273/HORTSCI11486-16.

Fennimore SA, Goodhue RE. 2016. Soil disinfestation with steam: A review of economics, engineering, and soil pest control in California strawberry. Int J Fruit Sci. https://doi.org/10.1080/15538362.2016.1195312.

Three decades of change in forest management

In this review article, a group of researchers including Professor Kevin O'Hara, Department of Environmental Science, Policy, and Management at UC Berkeley, highlight the changes that have influenced silviculture since 1986 and explore how it may evolve in the future.

One of the main takeaways from the past 30 years is that the magnitude of the changes could not have been anticipated. The expansion in management objectives to respond to environmental and social concerns is one such change: In addition to managing for sustained timber yield, the authors note, forest management now includes goals such as improving water quality and supporting biological diversity.

The authors also review the dramatic changes in forest conditions: an increasing number of megafires and the proliferation of invasive plants and insects, frequently the result of drought in combination with fire suppression and management policies. Other changes reviewed in the article include industry consolidation, the rise of conservation easements, and advances in tools for gathering and analyzing data.

D'Amato AW, Jokela EJ, O'Hara KL, Long JN. 2017. Silviculture in the United States: An amazing period of change over the past 30 years. J Forest. https://doi.org/10.5849/JOF-2016-035.

Biochar actively promotes soil carbon sequestration

Biochar is a carbon-based byproduct made, as charcoal is, by burning biomass in a low-oxygen environment. Adding biochar to agricultural soils shows promise as a way to sequester carbon; it also has been shown to improve soil quality in several ways, including reduced nutrient leaching and increased water holding capacity.

However, a variety of unknowns remain about the effect of biochar on soil properties such as structure, organic matter, chemistry and microbial communities, as well as the effects of differences in soil and biochar composition.

To address some of these questions, a team of UC Davis researchers conducted laboratory tests of two types of biochar added at multiple concentrations to two types of agricultural soils.

A key finding was that the biochar, by promoting the formation of stable aggregates of soil particles, actively promotes soil carbon storage. That is, it appears to contribute to soil carbon sequestration in two ways: it represents a recalcitrant sink of carbon itself, and it promotes changes in soil structure that help to keep existing soil carbon in the soil.

Wang D, Fonte SJ, Parikh SJ, Six J, Scow KM. 2017. Biochar additions can enhance soil structure and the physical stabilization of C in aggregates. Geoderma 303:110–7. https://doi.org/10.1016/j.geoderma.2017.05.027.

Multiaged mixed conifer stand in the Sierra Nevada.

Left, The Salton Sea is shrinking, exposing more of its playa, which contains a number of chemicals of concern. *Right*, UC Riverside graduate student Justin Dingle collects playa samples for source chemical characterization.

How the Salton Sea playa contributes to local air pollution

In the coming years, changes in water availability and management in the Imperial Valley are expected to decrease inflows to the Salton Sea, reducing its size and exposing large areas of dry lakebed, or playa.

Playas can be major sources of dust pollution. In addition, because of the high concentrations of metals and pesticides in the sediments of the Salton Sea, the dust from its playa raises toxicity concerns.

Roya Bahreini, associate professor of environmental sciences at UC Riverside, and her students and collaborators sampled dust in two communities on the shore of the Salton Sea to assess the playa's contribution to overall dust pollution in the region (measured as PM_{10}, particulate matter less than 10 microns in diameter) as well as its contribution of individual elements of concern, such as arsenic, selenium and sodium.

The playa contributed about 9% of total PM_{10} in the local air (in a region where particulate matter pollution already exceeds federal standards), and was the source of a large fraction of some airborne elements — for instance, 38% to 68% of the sodium in the air came from the playa.

The study found that the playa is not currently a source of airborne toxics at levels of concern for nearby population centers. However, as the Salton Sea shrinks, the playa will become a larger source of pollutants. In addition, high concentrations of elements such as sodium in dust can affect downwind soil composition in natural and agricultural systems significantly. The methods developed for the project can be applied elsewhere in the world to study air pollutants generated by playa systems.

Frie AL, Dingle JH, Ying SC, Bahreini R. 2017. The effect of a receding saline lake (the Salton Sea) on airborne particulate matter composition. Environ Sci Technol 51(15):8283–92. https://doi.org/10.1021/acs.est.7b01773.

How vegetation affects urban climates

Since the mid-20th century urban areas have been warming twice as fast as surrounding rural and wild areas, a phenomenon known as the urban heat island effect.

Vegetation in urban areas provides cooling, through shading as well as evapotranspiration. It can also increase relative humidity, which increases the heat index, a measure of human-perceived heat. However, the balance of these effects and their spatial variability within cities has been little studied.

To investigate these dynamics, Darrel Jenerette, professor of landscape ecology at UC Riverside, and his collaborators deployed networks of sensors in multiple locations with varying degrees of vegetation cover along a coastal to inland desert gradient in Southern California.

They found the effect of vegetation on air temperature to be substantially greater at night than during the day, likely due to daytime shading that reduces the buildup of heat energy in asphalt and other built surfaces, which continue to release heat to the air after the sun sets. This nighttime cooling effect increased further from the coast as average temperature increased. Vegetation-related cooling also reduced the heat index, despite an increase in relative humidity.

The results also suggest an important for role for wind in determining the local temperature effect of vegetation cover; through mixing, wind can reduce the air temperature difference between vegetated and non-vegetated areas. Hot days in Southern California typically result in reduced wind near the coast but increased wind inland, and the temperature variability readings gathered by the researchers were consistent with a wind-mixing effect.

Crum SM, Shiflett SA, Jenerette GD. 2017. The influence of vegetation, mesoclimate and meteorology on urban atmospheric microclimates across a coastal to desert climate gradient. J Environ Manage 200:295–303. https://doi.org/10.1016/j.jenvman.2017.05.077.

PROFILE

Teaching volunteer educators to tinker

Steven Worker is helping to improve out-of-school-time pedagogy.

Steven Worker

In May 2016, Steven Worker began as a 4-H Youth Development Advisor for Marin, Sonoma and Napa counties. His mission is to study pedagogical practices of 4-H volunteer educators and use that to improve future 4-H volunteer development efforts.

Worker holds a Ph.D. in education (emphasis in learning sciences) from UC Davis. As part of his dissertation (Worker 2016), he studied how volunteer educators engage youth in science and engineering education (see page 208 of this issue). He observed 4-H youth and adults engaged in 4-H projects using the 4-H *Junk Drawer Robotics* curriculum, which emphasizes inquiry-based pedagogy — basically, tinkering. While the volunteer instructors were provided with guidelines that emphasized a hands-on, tinkering-oriented approach, Worker found that they interpreted the directions in a variety of ways, based on their own ideas and values about teaching. Some, for instance, spent some of the class time lecturing.

Volunteer educators for 4-H science and engineering programs may need content expertise, but Worker says that just having that is not enough. They also need to understand how their pedagogical practices help shape learning outcomes. Volunteers bring their own goals, values and assumptions when working with youth. There's value in understanding and engaging these underlying values, otherwise "we won't know the full story of what contributes to 4-H learning experiences," Worker says.

To meet the needs of 4-H youth, UC Cooperative Extension needs to expand what counts as learning, according to Worker et al. (2017). To this end, Worker in his dissertation studied expanded indicators of learning, such as cultivating dispositions (expressed, for instance, as resiliency, connection and creativity), learning to use tools, and improved motivation for learning. Worker has thought extensively about how best to explore out-of-school-time pedagogies to help reach those outcomes.

Worker joined UC Cooperative Extension in December 2001 at the State 4-H Office, where he was responsible for adolescent leadership development, recognition programs, and technology education. He's also a 4-H veteran — as a youth he was a Santa Barbara County All-Star 4-H County Ambassador, and then a 4-H State Ambassador.

Worker participates in Cooperative Extension teams piloting new models of volunteer development that expand on traditional one-time workshops. These new models of volunteer development, including communities of practice and lesson study, involve iterative cycles of 4-H volunteers learning together and improving their pedagogical practices. CA

—Editors

4-H youth engage in a *Junk Drawer Robotics* activity.

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Worker SM, Ouellette KL, Maille A. 2017. Redefining the concept of learning in Cooperative Extension. J Extension 55(3). www.joe.org/joe/2017june/a3.php.

RESEARCH ARTICLE

Volunteer educators bring their own ideas about effective teaching to a 4-H curriculum

Pragmatic and structural constraints shaped the pedagogical choices volunteer educators made, as did their professional identification and comfort with engineering.

by Steven Worker

Abstract

Youth programs implemented during out-of-school time often rely on volunteers. These volunteers are responsible for selecting and adapting curriculum and facilitating activities, so their pedagogical practices become primary contributors to program quality, and ultimately, youth outcomes. To describe volunteers' pedagogical practices, I conducted a qualitative case study at three sites where volunteer educators were implementing a design-based 4-H curriculum. The curriculum advanced youth scientific literacy by supporting scientific inquiry in conjunction with planning, designing and making shareable artifacts. Through detailed observations, videos and focus groups, I identified six common pedagogical practices, though educators differed widely in which ones they used. Pragmatic and structural constraints shaped their choices, as did their professional identification as engineers, or not, and their relative comfort with engineering. To support volunteer educators in implementing a learner-centered educational program, curricula designers might be more specific in recommending and explaining pedagogical practices, and program managers might better train volunteer educators in those preferred practices.

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The 4-H Youth Development Program, as well as other out-of-school youth programs, relies heavily on volunteers to extend its reach with youth clientele. Volunteers serve as the direct educator to youth, and thus are often described as the "heart and soul of 4-H" (Radhakrishna and Ewing 2011). Not enough is known about when and how 4-H volunteer educators change their pedagogical practices. The educational value of design-based science teaching, for example, is an emerging pedagogical model (e.g., Apedoe and Schunn 2013); it is learner-centered and has shown success in school environments when facilitated by trained teachers (e.g., Kolodner et al. 2003), but there is limited empirical study of its applicability when facilitated by volunteers.

Adults fulfilling volunteer positions bring diverse experiences, abilities and values; they "come from all walks of life, bringing varied and rich experiences to the 4-H program" (Radhakrishna and Ewing 2011). Some may identify as a content expert, others with youth development experience, but many lack competence or confidence in implementing a learner-centered educational approach (Chi et al. 2013; Kaslon et al. 2005). Regardless of experience and abilities, volunteers serving in an educator role develop programs, select and adapt curriculum, and facilitate activities (Fritz et al. 2003; White and Arnold 2003); thus their pedagogical practices

To help improve scientific literacy among youth, the 4-H Youth Development Program offers a design-based science curriculum, *Junk Drawer Robotics*, that features engineering activities.

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become primary contributors to program quality and, ultimately, youth outcomes.

While the literature on volunteer educator pedagogical practices is broad, varied and incomplete, researchers agree the volunteer educator role is complex and has a significant influence on the structure of the learning environment (Borden et al. 2011; Evans et al. 2012). Furthermore, there is evidence to suggest that volunteer educators often fall back on didactic teaching strategies (Patrick 2017). Volunteer development would improve competence and confidence, but the 4-H program has not offered comprehensive preparation; instead, it has offered volunteers one-time, short-duration events, typically face-to-face, led by an expert (Smith and Schmitt-McQuitty 2013), which are generally considered ineffective in improving practice (Penuel et al. 2007).

Science inquiry + engineering design

Improving scientific literacy requires effective pedagogical models that support open-ended problem-solving and science learning, broadly referred to as learner-centered educational approaches (NRC 2000). Design-based science is a learner-centered pedagogical model gaining recognition; it integrates science inquiry with engineering design (e.g., Apedoe and Schunn 2013; Fortus et al. 2004; Kolodner et al. 2003; Roth 2001).

Science inquiry is a process of exploration where one poses a question, conducts experiments, collects and interprets data, and communicates findings; it places youth as active agents in their own learning through the practices of science (Lazonder and Harmsen 2016). Design is a process of planning and making in order to accomplish a goal to satisfy requirements subject to constraints (e.g., Dym and Little 2009). Specifically, design-based science engages students in science learning through a design process that involves the planning, designing and making of shareable artifacts. Educators facilitate a sequence of instruction grounded in an engineering design process.

Improving scientific literacy

Scientific literacy is an important educational goal (NRC 2009a, 2012; UC ANR 2009). Young people in the United States are maturing into a society that has complex challenges. Competency in science, technology, engineering and mathematics (STEM) may help them engage in important issues around economic well-being, public health, the environment and energy conservation (National Academies 2007). These are issues requiring creative and collaborative problem solvers who are highly literate in science and engineering (NRC 2012).

STEM education has become a national emphasis, both in and out of school (NRC 2009a, 2009b). It's a core part of UC ANR's 4-H Youth Development Program, the UC ANR Strategic Vision 2025 and the California 4-H STEM Initiative.

Design-based science, which originated from research in the K-12 school environment, has shown promise in improving students' content knowledge (Kolodner et al. 2003) and interest in science and engineering careers (Mehalik et al. 2008). Furthermore, research has demonstrated that students gain STEM content knowledge with design-based science methods equal to or greater than with didactic science teaching methods (Mehalik et al. 2008; Silk et al. 2009).

As with most teaching, and particularly in learner-centered educational approaches, the educator serves a prime role in affording and/or constraining opportunities for youth to participate, learn and ultimately improve their scientific literacy. Thus, the educator's abilities to facilitate design-based science are of critical importance.

Study of volunteer educators

The 4-H Youth Development Program places a heavy reliance on volunteers to facilitate science education. To support the goal of improved scientific literacy, the program needs to recognize how volunteers understand, adapt and implement a curriculum, and their use of various teaching methods (e.g., pedagogical practices such as facilitation and questioning strategies, and interaction with learners). The purpose of this qualitative case study at multiple sites was to describe volunteer educators' pedagogical practices as they implemented a 4-H design-based science curriculum. The specific research questions addressed were: What are the pedagogical practices employed by volunteer educators? What explanations do volunteer educators provide for these practices?

The research context was three *4-H Junk Drawer Robotics* (Mahacek et al. 2011) projects organized by adult 4-H volunteers in three California counties (sites A, B and C). *Junk Drawer Robotics* is a peer-reviewed, design-based curriculum providing a sequence of science inquiry activities followed by engineering design challenges. Noncompetitive design activities invite youth to design, build and test artifacts using common items (e.g., paper clips, rubber bands, craft sticks, tubing and syringes), with multiple solution pathways.

The study involved observing the 4-H volunteer educators and youth over an extended period as the volunteer educators

In the design and build participation structure, volunteer educators presented youth with a design challenge and asked them to design and build a device, such as the arm/gripper shown here, to solve the problem. Educators used a variety of teaching techniques for design and build, including targeted questions and offering specific design suggestions.

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At site C, a girl follows the adult educator's instructions to solder two wires together to make a bracelet. In this participation structure, known as scripted build, the educators give young people instructions and monitor their progress. This structure was introduced by the educators and was not part of the 4-H curriculum.

implemented the curriculum. Data sources included participant observations, videos of and interviews with educators (Seidman 2013) and focus groups with youth (Krueger and Casey 2015). Data collection took place between 2014 and 2015 at the three sites. I analyzed the data for common trends in pedagogical practices and sought to explain these patterns through interviews with the educators.

At site A, a male educator (Eugene) and seven youth (three male, four female; between 11 and 16 years old) met for 2-hour meetings twice per month for 3 months (six meetings). At site B, three educators (one male, two female; Doug, Joyce and Robin) and eight youth (all male, between 10 and 12 years old) met for 1 hour once per month for seven months (seven meetings). At site C, a male educator (Sawyer) and seven youth (three male, four female; between 9 and 15 years old) met for 1 hour once per month for 6 months (six meetings).

The final data corpus consisted of 17 field notes (with 139 minutes of video and 846 photographs), seven educator interviews (five individuals, 273 minutes), three youth focus groups and two youth interviews (130 minutes). Data analysis was oriented by an inductive and comparative process beginning during fieldwork in the form of analytical notes (Merriam and Tisdell 2016). After data collection was complete, field notes were delimited using markers to segment data for deeper analysis. Analysis of focus group and interview data followed a systematic process of abstraction, delineating the transcripts using the same markers. This process of analyzing field notes separately from the individual data supported triangulation as I sought to identify concurrences with and inconsistencies in educator's narratives and participant observations.

Six participation structures

I employed participation structures as an analytical lens to describe the pedagogical practices I observed at each site. Participation structures have been used in educational research to describe patterns in discourse, interaction and activity that influence affordances for participation and learning (for theoretical background, see Greeno 2006; Jordan and Henderson 1995). For example, Vadeboncoeur (2006, 248) advanced a participation structures approach as "a frame for identifying patterns of relationships and interactions constituted in social and discursive practices." I identified six discrete participation structures as I observed the curriculum implementation.

Lecture. Activity period when educator shared or explained a learning concept before youth experienced an activity or build time. Lectures were implemented by the educators at site A (with digital slides) and site C (verbal only) but minimally at site B. Youth watched and listened to educator, although in some cases educator asked focused questions and awaited response.

Demonstration. Activity period when educator provided demonstration (and related explanation) of devices, artifacts, tools and materials. Youth observed and listened but did not touch or explore.

Learning activity (nonbuild). Hands-on activity with manipulatives facilitated by educator, such as "Sense of Balance", an activity in which youth balanced unequal weights on a balance beam by moving the pivot point. The curriculum identifies the learning concepts (related to engineering, such as level, balance and fulcrum) for each learning activity; most of the concepts I observed educators addressing before, during or after the learning activity originated from the curriculum, but I also observed educators adapting, modifying or expanding the activity from its written form to relate it other concepts.

Group sharing and reflection. Intentionally facilitated full-group time when youth had opportunities to show their effort through a shareable artifact, receive design feedback from peers and educators, and receive coaching from educator. Sharing and reflection reinforced the value of peer-to-peer collaboration, whether youth were working on separate artifacts or in teams. Responding to questions provided youth space to think about their design decisions and provide a rationale for them.

Design and build. Activity period when youth designed and/or built and tested artifacts, either individually or in groups. Typically, educators presented a design challenge (problem) and asked youth to design and then build something using the materials available to solve the challenge. Educators used several pedagogical techniques, such as targeted questions, offering specific design suggestions, connecting what youth were doing to an engineering concept and sometimes swooping in and modifying an artifact themselves.

Scripted build. During this activity period, youth were asked to follow build directions and were discouraged from deviating from these instructions. The resulting artifacts were usually identical for each youth.

I observed the educator issuing instructions, monitoring progress and demonstrating and/or teaching youth how to use any tools required in the activity. The scripted build was specific to site C, and not tied to the curriculum.

Time spent in participation structures

I calculated the amount of time spent in each participation structure over time by site (fig. 1). The amount varied, with site B dedicating the most time (81%) to design and build, site A dedicating much less time (46%) to design and build, and site C dedicating the least time (11%) to design and build but more time to scripted build (31%, only site C offered scripted build) and learning activities (33%). Site C allocated the most time to lecture (22%). Site A spent more time in group sharing and reflection (22%) than the other sites.

The *4-H Junk Drawer Robotics* curriculum includes only three of the six participation structures — learning activity (nonbuild), group sharing and reflection, and design and build. It does not include instructions or recommendations for lecture, demonstration or scripted build. These three participation structures were introduced by the educators.

To review: participation structures afford and/or constrain opportunities for youth to participate and learn. While a full discussion of youth learning is outside the scope of this paper (but see Worker 2016), it is significant that the three participation structures the educators introduced — lecture, demonstration and scripted build — emphasized STEM content learning. The other three participation structures, those that were in the curriculum — learning activity, sharing and reflection, and design and build — afforded a broader range of learning outcomes, such as deepening engagement in design practices, offering opportunities to manifest resilient, playful and reciprocal dispositions, and developing psychological ownership.

Patterns in pedagogical practices

I interviewed educators to explore how they rationalized implementing various participation structures. Two key findings surfaced: educators were dealing with pragmatic and structural constraints, and their identification and comfort with engineering shaped their practice.

Practical and structural constraints

Volunteer educators adapted their teaching practices to the structural constraints of the sites. There were many constraints, including time limitations for the program meetings, voluntary youth participation and frequent absences, and a wide range of youth ages. Educators adapted to voluntary participation by ensuring meetings were fun. They spoke frequently about voluntary participation in relation to their pedagogical practices:

> *Sawyer: Because this still has to be fun. As much as I love teaching engineering and being excited about this stuff we're doing, if it's not fun the kids won't be back. (Interview, site C, Oct. 13, 2014.)*

Educators at the other two sites also recognized this practical constraint of voluntary participation — that is, youth may not return if they are not enjoying themselves. The nature and definition of fun was seen as hands-on activities. The meaning of *hands-on*, however, differed. At site C and site A, educators used the term *hands-on* to indicate a fun method that reinforced engineering learning after concepts were introduced. The nature of the hands-on experience was in service of the engineering concept. In contrast, the educators at site B shared their meaning of hands-on as being important to tinkering — creative problem-solving emphasizing open-ended design (Bevan et al. 2014), or learning by playing with the materials.

Two key findings surfaced: educators were dealing with pragmatic and structural constraints, and their identification and comfort with engineering shaped their practice.

Maintaining youth engagement and interest was often seen as so crucial that educators felt they had to make compromises to maintain the fun. One of the consequences was unplanned activities, like site C's scripted builds, that preserved hands-on fun but at the expense of affording youth opportunities to engage in design practices, exhibit resiliency or improve feelings of ownership. Not all adaptations made by educators were detrimental to learning; for example, at site C, the educator adapted a curriculum activity that involved craft sticks to help youth understand the concepts of lever, balance and fulcrum and built instead a full-sized teeter-totter.

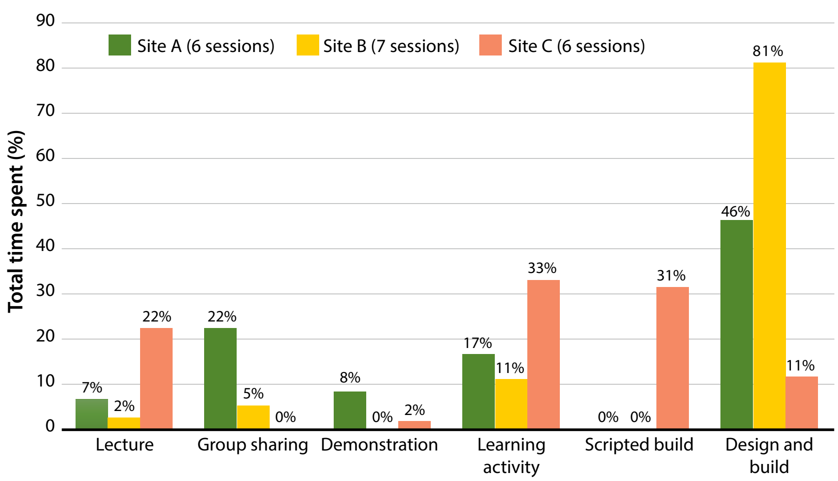

Fig. 1. Percentage of total time volunteer educators spent in each participation structure, by site. The amount of time educators allocated for each participation structure was associated with their ideas and values about teaching — for instance, site B educators who prioritized hands-on tinkering spent more time on the design and build structure than they did on lecture and demonstration.

The *Junk Drawer Robotics* curriculum included a group sharing participation structure in which youth showed their finished devices to their peers. The study found that volunteer educators adapted their teaching practices depending on practical constraints, such as voluntary youth participation, and whether they self-identified as engineers.

Identification, comfort with engineering

Educators' identification with a professional engineering community was associated with their pedagogical practices. Educators' instructional practices, and the time allocated for participation structures, were related to their knowledge of the concepts, value they placed in engineering practices, and having been socialized into engineering culture. Educators who self-identified as professional engineers were better able to articulate learning objectives that connected to professional practice, and their pedagogical practices more closely aligned with realizing those learning objectives.

I probed into educators' ideas and values about teaching and learning. I associated site C educator's prioritizing engineering as his learning objective for youth participants with the time he devoted to lecture (22%), and his interest in making may have been connected to his use of scripted build time (31%). The site A educator valued group sharing, which was reflected in the time he designated to share and reflect (22%). In contrast, at Site B two of the three educators did not identify as engineers (the third identified as a computer science student) and they prioritized tinkering and teamwork as their goals, and their pedagogical practices aligned more closely with time for youth to design, build and test in small groups (81%).

The two educators who identified as engineers, Sawyer and Eugene, did not believe that the final artifact, designed and built by youth, was evidence of learning. Rather, they wanted youth to understand engineering fundamentals, so they reported intentionally structuring meetings so they could share information before youth began to design and build. Sawyer stated, "You have to learn the fundamentals first" (interview, site C, May 4, 2015). Eugene reported his meetings "naturally progressed to a lecture style thing for a little bit and then some discussion and … then we wanted to build something" (interview, site A, Apr. 2, 2014). One youth wanted less talking and more building, to which Eugene responded, "I think in the very beginning if I didn't talk a lot it would be difficult for you, in my mind, to start working" (field note, site A, Mar. 26, 2015).

In contrast, one educator who did not identify as an engineer most valued hands-on design experience, for its value in the service of tinkering:

> *Robin: I'm a hands-on learner. … some of today's youth are the same way. They have to do it to physically learn it, and that's how I am. So I like to tinker and play with stuff. (Interview, site B, Jun. 22, 2015.)*

In general, educators who identified as professional engineers, having been socialized into an engineering way of thinking, allocated more time for lecture, demonstration, learning activities and scripted build than to design and build. They chose participation structures that were oriented toward information sharing, where youth could learn fundamental engineering concepts first and then have it reinforced in hands-on activity.

Curriculum design, educator training

Volunteer educators bring with them their own notions about effective teaching, their own interests and values, and through their pedagogical practice, afford and constrain opportunities for youth to participate and learn. One lesson learned from this study is that volunteer educators make adaptations. The adapted activities may inadvertently constrain, or alternatively strengthen, pathways for youth to participate. Without intentionality on the part of the educator, youth may not reach the intended learning objective outlined by the curriculum.

Other lessons learned from this study involve the development of curricula and professional development. Curriculum designers may need to make more explicit the core functional elements that contribute to the desired learning outcomes (Olson et al. 2015). Specifically, the curriculum should outline its learning objectives and link them clearly to participation structures. For example, a curriculum using group sharing and reflection should explain the intended learning outcome, include a rationale for its importance, tips for successful implementation and ideas to informally evaluate learning outcomes.

Program managers may need to target their recruitment and training to address the internal values, interests and identity that volunteer educators bring with them. As evidenced in the findings, those who identified with a professional field that was related to the subject matter had preconceived ideas about effective pedagogical models, even when the curriculum incorporated a distinct pedagogical model. One potential solution is to focus on expanding volunteer educators' conception of learning to include not only STEM-specific concepts, but also how to improve youth engagement, dispositions and ownership. This might allow educators to see connections between the activity structures and how they afford or constrain learning outcomes.

Educational research

As this qualitative multiple-case study demonstrates, identifying emerging patterns of discourse and activity — participation structures — led to fruitful cross-site comparisons of pedagogical practices. This technique, grounded in sociocultural perspectives of learning, may be applied to other learning environments resulting in meaningful descriptions of practice. CA

S. Worker is UC Cooperative Extension 4-H Youth Development Advisor in Marin, Sonoma and Napa counties.

I extend my appreciation to Cynthia Carter Ching, Lee Martin, and Tobin White for their guidance on the dissertation research from which this article was developed.


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Before adding grippers to their devices, youth experiment with picking up balls with different types of grippers (learning activity participation structure).

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RESEARCH ARTICLE

Modeling identifies optimal fall planting times and irrigation requirements for canola and camelina at locations across California

Sufficient rainfall and appropriate soil temperatures during the canola planting window occur statewide on average 1 in 3 years, but camelina is significantly more drought and cold tolerant.

by Nicholas George, Lucia Levers, Sally Thompson, Joy Hollingsworth and Stephen Kaffka

Abstract

In California, *Brassica* oilseeds may be viable crops for growers to diversify their cool-season crop options, helping them adapt to projected climate change and irrigation water shortages. Field trials have found germination and establishment problems in some late-planted canola, but not camelina at the same locations. We used computer modeling to analyze fall seedbed conditions to better understand this phenomenon. We found seedbeds may be too dry, too cold, or both, to support germination of canola during late fall. Based on seedbed temperatures only, canola should be sown no later than the last week of November in the Central Valley. Camelina has broader temperature and moisture windows for germination and can be sown from October to December with less risk, but yields of camelina are lower than canola yields. In areas without irrigation, growers could plant canola opportunistically when seedbed conditions are favorable and use camelina as a fallback option.

Diversifying crops can improve farm economic performance, aid with weed and pest management, better utilize soil and water resources, and, in the case of *Brassica* oilseeds, provide benefits for pollinators. Growers have relatively few economically viable cool season crop options in California (USDA NASS 2012), but diversifying winter crop options may become more valuable if summer production of irrigated annual or short-term perennial species is limited by shortage of irrigation water, and potentially by climate change (Cayan et al. 2008; George and Kaffka 2017; Jackson et al. 2012).

On an area basis, wheat is the dominant cool-season crop in California (USDA NASS 2012, 2015). There has been long-standing interest in the potential of canola (*Brassica napus*), and other *Brassica* oilseed species, to diversify cereal-based cropping in California (Kaffka et al. 2015; Knowles et al. 1981). In a recent review, Angus et al. (2015) concluded that canola can have synergistic

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An early maturity variety of canola (center) grows next to late maturity varieties in a trial at the UC ANR West Side Research and Extension Center near Five Points. Using canola varieties that germinate reliably under either drier or colder soil conditions could potentially broaden the planting window and increase the number of years in which rain-fed production of canola is viable.

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effects on the productivity of wheat-dominated cropping. It benefits subsequent wheat crops by acting as a disease break, suppressing weed growth and providing more flexibility in herbicide choices.

Canola seed is used for the production of edible oil and high protein oilseed meal used for livestock feed. It is also used for biodiesel production. At present, the demand for these products in the United States is larger than domestic production (FAOSTAT 2015; Johnson and Fritsche 2012; Newkirk 2009; USDA ERS 2014; USDA NASS 2015). Camelina (*Camelina sativa*) is another cool-season oilseed crop of interest to California growers. Currently, camelina is not widely used as a food for either humans or livestock, but it has been used for this in the past, and there is recent research directed towards this use (Betancor et al., 2015; Campbell et al., 2013; Cruz and Dierig 2015; Vollmann et al. 2007). At present, canola and camelina are not important crops in California. If used to diversify cool-season cropping, however, they could help sustain the long-term viability of California agriculture.

Under rain-fed production, the mean yield of canola in the Sacramento Valley (northern Central Valley) is predicted to be over 3,100 pounds per acre (3,500 kilograms per hectare) (George et al. 2017; George and Kaffka 2017). This should make canola, given suitable market development, economically competitive with wheat in the region (George et al. 2017; Winans et al. 2016).

Mean rain-fed yields of current camelina varieties are around 890 pounds per acre (1,000 kilograms per hectare) (George et al. 2017). Camelina is therefore unlikely to be economically competitive with wheat or canola, but it is regarded as a hardy crop, with low input requirements (Berti et al. 2016; Putnam et al. 1993), and recent field studies in California have shown it to be more cold and drought tolerant than canola (George et al. 2017). Camelina may therefore have a niche in production situations where canola and wheat are not viable due to low water availability or cold temperatures, especially if larger yields can be achieved reliably.

Sowing time, establishment issues

The development of a cool-season oilseed industry in California will require locally appropriate agronomic practices for reducing production risks and maximizing yield. In Mediterranean climates like California's, the appropriate fall sowing time is an important consideration for rain-fed production. It involves a trade-off between sowing late enough to reduce the risk of dry conditions during germination and establishment, and sowing early enough to optimize canopy leaf area at flowering, necessary for a high yield potential, and avoiding flowering and seed development during late spring, when hot and dry conditions are common (Farré et al. 2002; Farré et al. 2007; Hocking and Stapper 2001; Si and Walton 2004; Zeleke et al. 2014). Timely establishment in fall therefore increases the likelihood of a high yield for canola, assuming average rainfall and temperatures and suitable agronomic management (George et al. 2017; George and Kaffka 2017).

The ideal planting time for cool-season canola in California has been identified as between late October and early November (George and Kaffka 2017; Knowles et al. 1981), although the optimal time within this

A variety trial of canola several weeks after sowing at UC Davis. Researchers predict that canola yield in the Sacramento Valley could be over 3,100 pounds per acre under rain-fed production, which would make it economically competitive with wheat in the region.


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TABLE 1. The study assessed cool-season growing conditions in three agricultural regions in California

Region	Site	Latitude	Longitude	Years in climate record	Mean temperature of coldest month (Dec) *°F (°C)*	Mean rainfall Oct–Dec *inches (mm)*	Mean rainfall Oct–May *inches (mm)*
Central Coast	Atascadero	35.47	−120.65	13	46 (8)	1.0 (24)	12 (299)
	San Luis Obispo	35.31	−120.66	27	54 (12)	2.2 (55)	19 (485)
Sacramento Valley	Durham	39.61	−121.82	31	45 (7)	2.3 (58)	21 (534)
	Colusa	39.23	−122.03	31	45 (7)	1.5 (39)	16 (400)
	Davis	38.60	−121.54	31	45 (7)	2.0 (51)	17 (429)
	Lodi	38.13	−121.39	14	46 (8)	1.3 (33)	14 (346)
San Joaquin Valley	Los Banos	37.10	−120.75	25	45 (7)	0.8 (20)	9 (216)
	Firebaugh	36.85	−120.59	16	45 (7)	0.7 (17)	10 (247)
	Parlier	36.60	−119.50	31	45 (7)	0.9 (24)	11 (270)
	Five Points	36.34	−120.11	31	46 (8)	0.9 (23)	8 (208)
	Kettleman City	35.87	−119.90	31	46 (8)	0.8 (19)	8 (202)

period is unclear. Furthermore, poor establishment, and even total stand failure, of some but not all later-planted canola crops has been an episodic problem observed in California (George et al. 2017; Kaffka et al. 2015). The reason for this has been unclear. In contrast, camelina sown at the same locations and times has not displayed establishment problems.

Canola seed can exhibit high germination percentages at soil temperatures as low as 40°F (4°C) (Chen et al. 2005; Edwards and Hertel 2011; Vigil et al. 1997), but under field conditions, sustained temperatures below 50°F (10°C) commonly result in low or delayed germination and subsequent poor establishment (Edwards and Hertel 2011; Nykiforuk and Johnson-Flanagan 1994, 1999; Vigil et al. 1997). In terms of water availability, over 90% germination of canola seed is generally achieved at a soil matric potential of −0.4 MPa or greater, and germination percentages then decline to zero between −0.4 MPa and −1.5 MPa (Blackshaw 1991; Williams and Shaykewich 1971).

By contrast, camelina is considered cold tolerant during germination (Allen et al. 2014; Berti et al. 2016; Putnam et al. 1993), with studies finding almost 100% germination and emergence at temperatures below freezing — although time to germination increases from approximately 9 days at 50°F (4°C) to 68 days at 30°F (−0.7°C) (Allen et al. 2014; Russo et al. 2010). Camelina also tolerates lower soil water during germination than canola, 90% germination of camelina has been observed at matric potentials as low as −3.0 MPa, although seedling growth is more vigorous (based on root length) at water potentials over −1.5 MPa (Jiang 2013).

The establishment problems occasionally observed in California for canola, but not camelina, may therefore be due to fall seedbed conditions being episodically suboptimal for canola germination but usually suitable for camelina. To test this hypothesis, we examined the temperature and moisture conditions of seedbeds in potential oilseed production areas of California — which largely overlap with current cereal cropping areas of the state — and assessed the frequency with which conditions suitable for germination of canola and camelina occur during the fall planting window for these crops.

The goal of the study was to identify risks associated with establishing canola and camelina in California under rain-fed conditions, suggest the best times and conditions for oilseed sowing and stand establishment in the region, and provide directions for future research.

Sites, climate data

Our analysis was designed to estimate the proportion of seasons in which soil moisture and soil temperature conditions were simultaneously suitable for the germination of canola or camelina at 11 locations throughout the Sacramento Valley (northern Central Valley), San Joaquin Valley (southern Central Valley) and Central Coast of California (table 1). These regions currently support cereal production and could incorporate canola or camelina production in the future. We considered data from a 31-year period (1983 to 2013), when suitable data (solar radiation, temperature, humidity, wind speed and precipitation) were available from the California Irrigation Management Information System (CIMIS 2015).

Previous work has found that the ideal sowing time for oilseeds in California is between October and November (George and Kaffka 2017; Knowles et al. 1981), so the time period we used for our analysis was Oct. 1 to Dec. 31, with December being the mean coldest month throughout most of the region. Some locations had climate records for fewer than 31 years. Analyses excluding these locations produced similar results to those including them, so all the locations were used in the final results.

Soil temperature and moisture modeling

Soil temperature and soil moisture information was not directly available for the regions of interest. We therefore used established modeling frameworks to estimate temperature and moisture time series at each location.

Soil water (measured in terms of the matric potential, the negative pressure associated with dry soils, which is directly linked to soil water content) was modeled using the Hydrus-1D Richards' equation solver. Richards' equation describes the flow of water through a variably saturated soil (Brutsaert 2005). The implementation of Richards' equation in Hydrus-1D has been extensively tested in representative soils from the Central Valley of California and shown to reproduce observed shallow soil water dynamics (Šimůnek et al. 2008).

Evaporative demand was estimated within the model using climate data (including solar radiation, temperature, humidity and wind speed). The evaporative data were then used to provide an atmospheric boundary condition to Richards' equation, which was solved to estimate soil water content (Brutsaert 2005).

The U.S. Department of Agriculture Natural Resources Conservation Service (USDA NRCS 2015) soils website was used to determine the most common soil types at each location. Loam soils were the dominant soil types, so soil matric potential was estimated to a depth of 1 inch (2.5 centimeters) for loam soil variants (loam, clay loam, silt loam and sandy loams) using the van Genuchten soil water retention model (Brutsaert 2005), with standard soil parameters available in Hydrus from Carsel and Parrish (1988). Initial soil moisture was set to the wilting point, assuming complete drying of the top 1 inch (2.5 centimeters) of the surface soil by the end of summer.

Canola and camelina seed are most commonly planted within 1 inch (2.5 centimeters) of the soil surface in flat fields with no soil cover (crop residue). No-till systems with residue cover were not modeled. Seedbed temperatures were estimated at the same study locations used for soil moisture estimation. We used the method proposed by Kätterer and Andrön (2008) and tested in California by Thompson et al. (2014). In this method, soil temperatures follow air temperatures, and their fluctuations lag with depth and soil thermal conductivity. With these assumptions, temperatures at 1 inch (2.5 centimeters) below the soil surface were estimated. Thermal conductivity of the soil was adjusted for changes in water content (wet soils conduct heat more effectively than dry soils), using the parallel Hydrus-1D soil moisture computations described above. All calculations were conducted in R (R Core Team 2016).

A field of canola in full bloom at West Side Research and Extension Center. A high canola yield is more likely if it is sown at the right time — it must be late enough in the fall that the risk of dry conditions during germination and establishment is low, and early enough to optimize canopy leaf area at flowering.

The model did not account for soil cover or field-scale variation in topography or microclimate, which have acknowledged effects on soil moisture and temperature dynamics, and which, consequently, could be influential at specific sites. Results are therefore idealized predictions of likely germination and emergence behavior of canola and camelina in response to the variety of climate and soil conditions experienced throughout likely production regions in California.

Germination thresholds

To relate the modeled time series of soil moisture and temperature to seed germination and emergence likelihood, temperature and moisture ranges that support germination were identified from the literature. Based on these literature values, the minimum soil water threshold for canola germination was set to −0.4 MPa, and to −1.5 MPa for camelina (Blackshaw 1991; Jiang 2013; Williams and Shaykewich 1971). Minimum soil temperature requirements for germination of canola and camelina were set to 50°F (10°C) and 40°F (4°C), respectively (Allen et al. 2014; Edwards and Hertel 2011; Nykiforuk and Johnson-Flanagan 1994, 1999; Russo et al. 2010; Vigil et al. 1997).

Data analysis

To explore the likelihood of optimal seedbed conditions occurring in the October to December planting window at each site, we counted the number of years in which temperature and moisture (treated both independently and jointly) exceeded the germination thresholds identified, for each day of the planting window. This enabled us to estimate the probability of optimal seedbed conditions occurring before the cutoff date in any given season. A joint analysis of these conditions was undertaken because temperature and moisture are correlated in the winter rainfall–dominated Mediterranean climate of California.

Across all sites, suitable temperature and moisture conditions for canola germination were met jointly in only 36% of years.

Probability of good germination

At the Central Valley locations, soil temperatures were predicted to drop below the 50°F (10°C) canola germination threshold by mid-November, and at coastal locations this threshold was crossed by December (fig. 1A). Based on seedbed temperature criteria alone, canola sown after the end of November in the Central Valley is likely to germinate well in fewer than 30% of years (fig. 1B). Camelina, by contrast, is likely to experience acceptable temperatures for germination to the end of November in most years, and through the end of December in 70% to 80% of years (fig. 1B).

The probability of soil moisture exceeding the minimum canola threshold for germination is less than 50% until early November in the Sacramento Valley, and until early December in the San Joaquin Valley and Central Coast (fig. 1C). The probability of soil moisture exceeding the minimum camelina threshold for germination exceeds 50% by October (fig. 1C).

The joint probability of meeting temperature and moisture conditions simultaneously is shown in figure 1D. There is a relatively low probability that a seedbed on an arbitrarily selected day in the period from October to December will meet both temperature and moisture requirements for canola germination. Across all sites, suitable temperature and moisture conditions for canola germination were met jointly in only 36% of years. The probability of meeting the conditions simultaneously peaks around Nov. 15. Optimal conditions

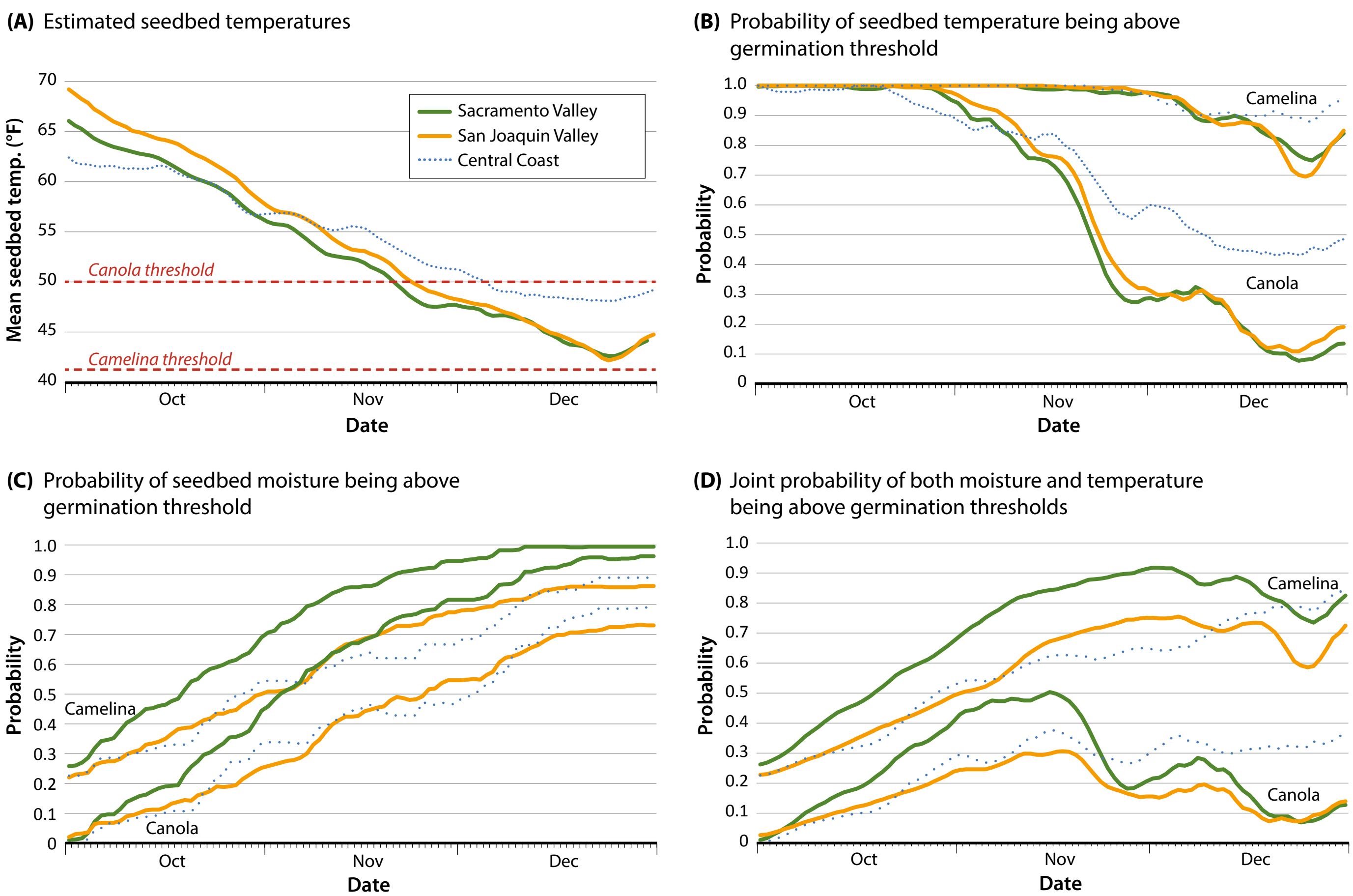

Fig. 1. (A) The estimated mean seedbed temperature, adjusted for moisture content, for different regions of California, relative to approximate minimum temperatures for germination of canola and camelina. (B) The probability of seedbed temperature being above the minimum temperature for germination for canola and camelina for different regions of California. (C) The probability of seedbed moisture being above the minimum water content for canola and camelina germination. (D) The joint probability of seedbeds meeting both the minimum matric potential and temperature requirements for germination of canola and camelina in different regions of California.

for camelina are achieved in approximately 85% of years, and the probability of meeting both moisture and temperature conditions peaks on approximately Dec. 1.

Establishment challenges

Our modeling work supported the hypothesis that episodic problems with the establishment of some later-planted canola crops, and the acceptable establishment of camelina at the same locations, are due to seedbed conditions that are suboptimal for canola but not camelina. The Sacramento and San Joaquin Valleys showed similar temporal trends in temperature, moisture and the probability of jointly meeting moisture and temperature germination requirements. The Sacramento Valley has a higher probability of achieving minimum soil moisture thresholds than does the San Joaquin Valley, reflecting the earlier onset and higher average winter rainfall in that region. The Central Coast and San Joaquin Valley locations have a lower likelihood of achieving suitable soil moisture levels than the Central Valley but are predicted to stay warmer later in the season.

Based on seedbed temperatures only, canola should be sown no later than the end of November in the Central Valley and no later than the third week of November near the Central Coast. The number of growing degree-days following sowing needed for the emergence of canola is 80°C (base 0°C) (Chen et al. 2005; Vigil et al. 1997), therefore a more conservative sowing date would be approximately a week earlier than those times. Under a best-case scenario, in approximately 50% of years in the Sacramento Valley and in the majority of years in the San Joaquin Valley and Central Coast, supplemental irrigation will be needed to ensure successful stand establishment (fig. 1D). In production situations with either water supply constraints or no ability to irrigate, canola should be planted opportunistically — under conditions of both sufficient rainfall and warm seedbed conditions. These conditions may exist only 1 in every 3 years, which requires growers to quantitatively monitor soil moisture and temperature during the planting season.

Under rain-fed farming conditions, camelina poses fewer risks during establishment than canola. The germination requirements of camelina, in terms of temperature and soil moisture, are likely to be met from October to December throughout the Central Valley and Central Coast. There may be a yield penalty associated with later sowing (for the same reasons as for canola), but this is not demonstrated in the research literature or empirically for California at present.

Camelina is not economically competitive with canola in California, due to its lower mean yields (George et al. 2017; Winans et al. 2016), but our analyses suggest that in locations or seasons where canola cannot be planted due to prevailing conditions, camelina represents a lower-risk oilseed option, particularly if yields can be increased reliably to the higher range of potential yields observed in field trials (George et al. 2017; Kaffka et al. 2015).

Irrigation, new varieties, no-till

The establishment challenges for canola identified here could be addressed through several approaches. Irrigation reduces risk during crop establishment and extends the growing season by permitting earlier sowing — which may be useful even in areas where the mean winter rainfall may be sufficient to support relatively high yields. Crop simulation modeling suggests irrigation is also important for increasing yields and minimizing variability for canola production in California (George and Kaffka 2017). Total irrigation requirements of canola and cool-season cereals are similar (George and Kaffka 2017; Jackson et al. 2006), and lower than the irrigation needs of many current warm-season crops.

Using canola varieties that germinate reliably under either drier (< −0.4 MPa) or colder (< 50°F/10°C) soil conditions could make planting viable earlier or later in the season. This would potentially broaden the planting window and increasing the number of years in which rain-fed production of canola is viable.

Screening for varieties that germinate reliably at lower temperatures or at deeper sowing depths, where

Although camelina has lower yields, it is more drought tolerant than canola and is a less risky option when canola cannot be planted as a result of suboptimal seedbed conditions. At Rossier Family Farm in Paso Robles, this field of camelina (left) produced a harvestable crop, while an adjacent field of canola (right) failed due to a lack of rain.

soil temperatures will remain higher later in the season, would be valuable.

Agronomic management methodologies that increase soil water and temperature in early fall could also be considered as part of a canola production system. For example, canola could be produced using minimum- or no-tillage methods, which have been shown to preserve soil moisture in California (Mitchell et al. 2012). CA

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RESEARCH ARTICLE

Ownership characteristics and crop selection in California cropland

Analyses of cropland ownership patterns can help researchers prioritize outreach efforts and tailor research to stakeholders' needs.

by Luke Macaulay and Van Butsic

Abstract

Land ownership is one of the primary determinants of how agricultural land is used, and property size has been shown to drive many land use decisions. Land ownership information is also key to understanding food production systems and land fragmentation, and in targeting outreach materials to improve agricultural production and conservation practices. Using a parcel dataset containing all 58 California counties, we describe the characteristics of cropland ownership across California. The largest 5% of properties — with "property" defined as all parcels owned by a given landowner — account for 50.6% of California cropland, while the smallest 84% of properties account for 25% of cropland. Cropland ownership inequality (few large properties, many small properties) was greatest in Kings, Kern and Contra Costa counties and lowest in Mendocino, Napa and Santa Clara counties. Of crop types, rice properties had the largest median size, while properties with orchard trees had the smallest median sizes. Cluster analysis of crop mixes revealed that properties with grapes, rice, almonds and alfalfa/hay tended to be planted to individual crops, while crops such as grains, tomatoes and vegetables were more likely to be mixed within a single property. Analyses of cropland ownership patterns can help researchers prioritize outreach efforts and tailor research to stakeholders' needs.

Agriculture plays a major role in shaping California landscapes, and land ownership characteristics are an important predictor of economic decision-making, conservation practices and recreational use (Ferranto et al. 2013; Macaulay 2016). As such, improved information on agricultural land ownership is necessary for continued improvements in agricultural efficiency and environmental protection. Although California has a robust history of collecting agricultural statistics at the county scale in county agricultural reports, these reports do not include information on the ownership characteristics of cropland in their county, such as average property size, the distribution of ownership, and what kind of crops were planted together on individual properties.

Improvements in remote sensing technologies have allowed for increasingly accurate maps that specify where crops are planted, and advances in geographic information systems processing capacity is allowing for owner-level analysis of agricultural land use. This study presents a novel analysis that draws on publicly available satellite-based cropland data and a spatially explicit land ownership database that was developed by the authors.

The U.S. Department of Agriculture (USDA) Census of Agriculture surveys growers every 5 years and provides substantial summary information on farms by acreage range and crop type. Our method supplements that data by providing information at the property level, which we define as all parcels owned by a given landowner. This method allows the generation of ownership summary statistics and measures of inequality by county and by crop. The method also provides new

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Almond orchards in Stanislaus County. Analyzing land ownership distribution in California by crop type and property size can help scientists and extension professionals shape research programs according to the needs of local growers.

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information on crop mixes by property, and presents the complex information in graphs and figures for ease of comprehension and further analysis.

Information about the property-size distribution and use of agricultural land at the property level is useful in assessing technology adoption, fragmentation of land, pesticide application, wildlife connectivity and many other issues (Brodt et al. 2006; Greiner and Gregg 2011; Sunding and Zilberman 2001). Data on agricultural landownership patterns can also help answer a host of important questions such as the characteristics of properties that are planted with a particular crop; variation in ownership patterns across counties; and cropping combinations. Finally, ownership information also can be useful for organizations providing technical and conservation support on a landscape scale.

Methods

Ownership data

The study describes California's cropland. Private cropland includes land owned by private companies, individuals, nongovernmental organizations, and American Indian tribes (fig. 1A). Analyses were performed using two main datasets, a spatially explicit land ownership database and the USDA National

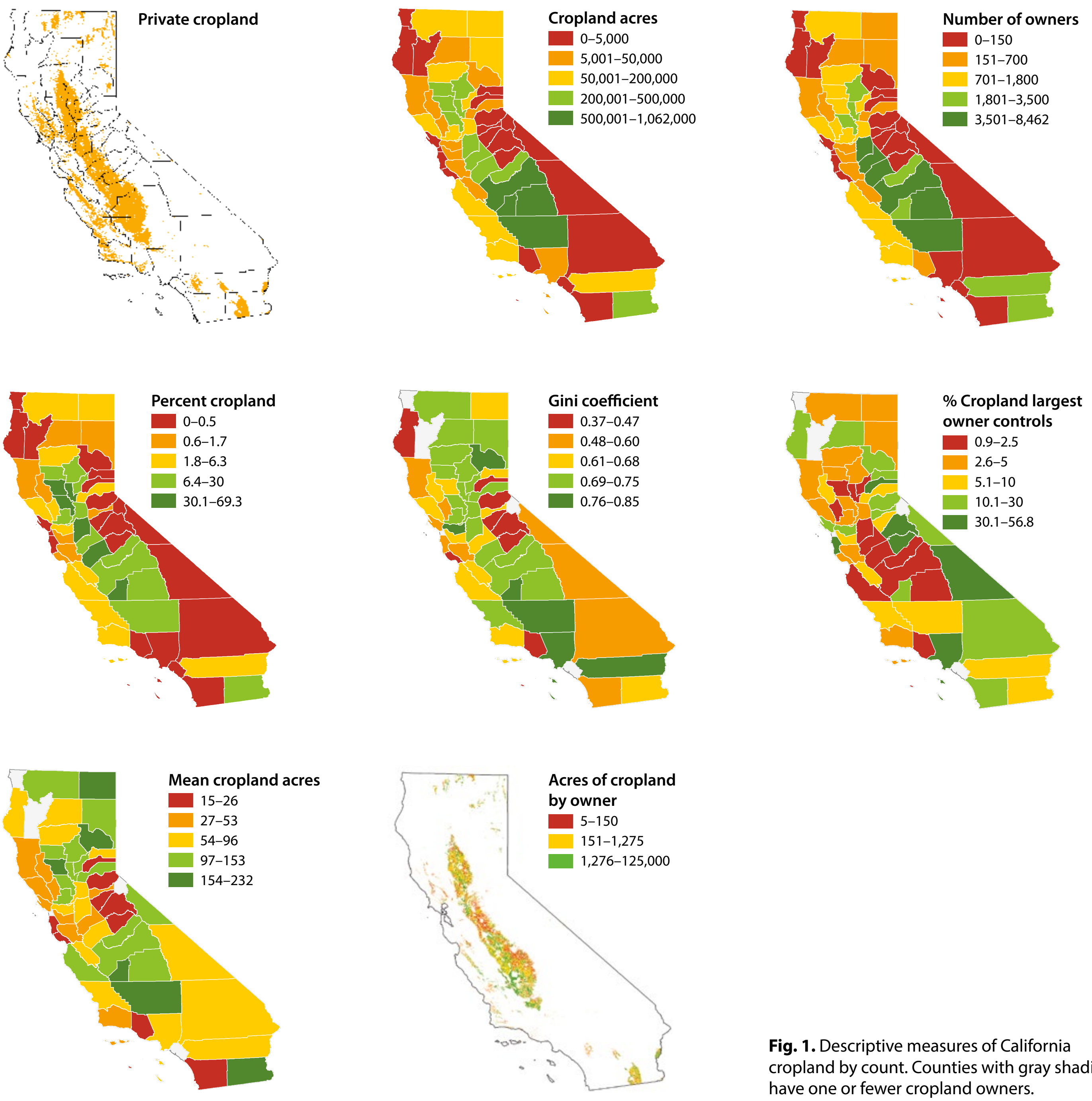

Fig. 1. Descriptive measures of California cropland by count. Counties with gray shading have one or fewer cropland owners.

Agricultural Statistics Service (NASS) Cropland Data Layer (CDL).

Parcel data was assembled for all 58 California counties. Parcel data with ownership information for 49 counties was derived from Boundary Solutions Inc., with the remaining nine counties assembled by contacting individual county governments. These county parcel data sets came from varying years, with 49 counties from 2011 to 2015 and nine counties from 2005 to 2010. Although this does not provide a completely current ownership map at a single point in time, most counties have recent data. Additionally, studies indicate that only 0.5% of U.S. farmland is sold annually, suggesting that the impact of land sales on the results presented here should be small (Sherrick and Barry 2003). In considering the ownership data presented here, it is also important to note that a sizeable percentage of landowners of California agricultural land (37%) are non-farming owners and rent or lease out their land to others (Bigelow et al. 2016).

To develop an ownership map for some counties, we merged data from separate files (nonspatial ownership information and spatial polygons) using a common field of assessor parcel numbers (APNs). After assembling county parcel maps for the entire state, we then dissolved parcels by owner name to remove interior borders of parcels owned by the same entity and to calculate total area under each ownership, which we refer to as a property. For analyses that used the county as the unit of analysis (section titled "County cropland ownership," table 1 and fig. 1), the analysis only considered ownership within that county. For all other analyses, ownerships were combined across all counties, so that land in multiple counties with a single owner was considered to be a single property.

Several counties had incomplete ownership data, and this initial mapping resulted in approximately 8% of the state's area with unknown ownership information (~8.25 million acres). To reduce the area of unknown ownership, we overlaid three separate ownership maps that cover public land and conservation easements and used these maps to assign ownership to parcels that did not have ownership information from original parcel data (CCED 2015; CDFFP 2014; CPAD 2015). This process reduced unknown ownership to approximately 2.7% of California's total land area (~2.85 million acres) and 4.4% (~385,000 acres) of California's cropland. Although unknown ownership is likely to be private, it was omitted from calculations. Ownerships were further categorized as public or private using 80 search terms in the ownership name field. The final ownership map was composed of approximately 543,495 properties greater than 5 acres across the state of California.

Cropland data

The USDA CDL was used to assess crops grown in California. The CDL is a raster, geo-referenced, crop-specific land cover data layer with a ground resolution of 30 meters. It is produced using satellite imagery from the Landsat 8 OLI/TIRS sensor and the Disaster Monitoring Constellation DEIMOS-1 and UK2 sensors collected during the 2013 growing season. The CDL methodology accommodates single and double crop plantings by using Farm Service Agency Common Land Unit data as training data. The CDL estimates occurrence of 99 different crops, which were condensed by the authors to 14 broad crop categories. In making this classification, any single crop with more than 250,000 acres statewide was left as an individual crop type (see supplemental table 1 at ucanr.edu/u.cfm?id=182). The crop type grown on individual properties was determined by overlaying the CDL with the spatial ownership database. The number of pixels of each particular crop type occurring within each ownership boundary was calculated and converted to acres. The results provided in this analysis pertaining to crop category (tables 2 and 3) indicate the acres of crops grown within a property (rather than the total property size). Discussion of county-level results focuses on counties with more than 5,000 acres of cropland and more than 250 owners.

California Land Use and Ownership Portal

The authors, in collaboration with UC Agriculture and Natural Resources' IGIS program, have also developed the California Land Use and Ownership Portal, which has an interactive map displaying the information contained in this article and much more. The portal allows users to view each county's cropland ownership and planting statistics as well as information about the natural vegetation found in the county. This tool is useful for gaining a broad understanding of land use and land ownership at the county level in California. The portal allows users to export images, figures and charts of land ownership, crop cover and natural vegetation. You can access it at http://callands.ucanr.edu.

The CDL includes an accuracy assessment that includes the user's accuracy and producer's accuracy (USDA-NASS 2014). The user's accuracy indicates the probability that a pixel from the CDL classification matches the ground truth data, while the producer's accuracy indicates the probability that a ground truth pixel will be correctly mapped. We weighted the accuracies for all crop types based on their percentage of total cropland, resulting in a weighted average accuracy of 82% for both user and producer accuracy.

To reduce the effect of this error in the CDL, this study excluded properties smaller than 5 acres and those composed of less than 5% cropland, under the assumption that production of less than 5 acres, while possible, was not oriented towards production agriculture and had a higher likelihood of being a remote sensing error. This exclusion reduced the overall private cropland area by 491,522 acres or 5.9%, resulting in a total private cropland area in this study of 7,872,543 acres. The number of owners was reduced more drastically, dropping from 112,419 to 68,699, a reduction of

38.9%. Due to these reductions, we believe the estimates in this study to be conservative, while minimizing the effect of remote sensing errors.

While we believe that our method of combining ownership and crop data produces a very high-quality map, some characteristics of the data influence the results and some error likely remains. Acreage statistics are greatly affected by the cutoff value of the minimum size of cropland ownership (in this case 5 acres). Raising or lowering the minimum size farm in the dataset increases or decreases the mean and median statistics correspondingly. After evaluating various cutoff values, we felt that 5 acres was an appropriate cutoff that would include many of the small farmers in California, but minimize impacts of remote sensing error.

Another trend occurring in some parts of California that could affect results is the separation of large farming operations into multiple corporate entities to reduce liability risks. Although this practice would lead to a reduction in the mean acreage values, we don't expect this practice to be widespread enough to significantly alter the results presented here. Additional sources of error include those arising from county level parcel data, from combining properties with very similar names (as noted in the methods section below) and the aggregation of ownership maps over multiple years.

Additionally, the crop data is a snapshot in time. 2013 was a drought year, with likely many more acres left fallow than in a wetter year. Our analysis estimates fallow land at a total of 1.14 million acres. By comparison, a previous analysis (NASA 2015) of 2011, a wetter year, estimated 500,000 acres of fallowed land. As such, our results should be viewed as reflecting dry year conditions, with reduced acreage planted to crops compared with an average or wetter year.

Analytical methods

Several analytical techniques are described that were used to prepare this data for analysis, including matching similar owner names, calculating equality metrics, and clustering properties based on planted crops.

Matching similar ownership names. In some cases, there were minor variations in owner names arising from different data entry protocols by county, punctuation standards, abbreviations and typographical errors (for example "California State University" and "California State Univ"). To correct for these inconsistencies, we used the Jaro-Winkler distance measure (using a weight of $p = 0.08$, and a cutoff distance value of < 0.05 for statewide matching and < 0.06 for county-level matching) to link records that have slightly different ownership names (Jaro 1989; Winkler 1990). The algorithm linked 14,459 records from the original dataset of 119,226 private cropland ownerships. These linked records were combined and aggregated into 7,665 records. The combined records were evaluated for accuracy and resulted in an estimated

TABLE 1. Descriptive measures of California private cropland by county

County	Total crop acres	Number of owners	Percent cropland in county	25th percentile	Median acres	75th percentile	95th percentile	Largest crop ownership	Percent of cropland in largest ownership	Average acres	Gini coefficient	Government acres	Unknown acres
Alameda	6,912	156	1.3%	10	15	39	161	613	8.9%	44	0.64	435	228
Alpine	179	1	0.0%	179	179	179	179	179	100.0%	179	0.00		
Amador	4,826	121	1.2%	9	17	34	149	663	13.7%	40	0.61	8	150
Butte	245,032	2,082	22.8%	10	25	97	441	11,723	4.8%	118	0.75	16,816	1,400
Calaveras	829	32	0.1%	10	18	37	67	80	9.7%	26	0.43	6	5
Colusa	307,138	1,694	41.5%	15	64	209	706	4,933	1.6%	181	0.67	5,222	829
Contra Costa	32,268	425	6.3%	8	15	36	201	7,499	23.2%	76	0.81	29	
El Dorado	738	49	0.1%	7	12	16	38	87	11.8%	15	0.39		
Fresno	1,061,382	8,462	27.6%	15	31	82	598	11,920	1.1%	125	0.75	13,346	91,892
Glenn	237,535	1,753	28.0%	15	38	145	555	5,954	2.5%	136	0.69	10,312	13,432
Humboldt	1,501	20	0.1%	27	64	99	188	240	16.0%	75	0.42	342	13,211
Imperial	411,466	2,166	14.3%	33	81	190	632	31,012	7.5%	190	0.64	16,767	23,292
Inyo	549	9	0.0%	22	28	113	165	196	35.8%	61	0.52	1,567	
Kern	787,189	3,642	15.1%	14	37	141	728	70,355	8.9%	216	0.81	41,868	100,531
Kings	571,143	2,457	64.1%	12	33	116	644	113,969	20.0%	232	0.85	37,774	17
Lake	9,891	273	1.2%	8	14	31	139	798	8.1%	36	0.64	102	
Lassen	52,306	384	1.7%	13	36	137	610	2,314	4.4%	136	0.71	2,562	720
Los Angeles	7,162	114	0.3%	9	13	26	133	3,414	47.7%	63	0.78	182	776

Madera	322,758	2,178	23.4%	17	40	116	612	5,425	1.7%	148	0.73	2,472	2,192
Marin	2,073	60	0.5%	8	14	35	110	280	13.5%	35	0.60	1,262	
Mariposa	69	4	0.0%	7	13	23	36	39	56.8%	17	0.41	7	10
Mendocino	20,921	513	0.9%	9	19	42	148	644	3.1%	41	0.59	255	
Merced	483,024	5,044	38.2%	15	27	74	378	4,425	0.9%	96	0.72	8,102	2,555
Modoc	114,637	660	4.3%	29	87	199	661	3,614	3.2%	174	0.61	7,910	315
Mono	3,919	26	0.2%	35	90	195	472	879	22.4%	151	0.58	132	
Monterey	124,733	1,202	5.9%	14	38	96	426	2,385	1.9%	104	0.68	1,176	2,625
Napa	29,849	880	5.9%	9	15	31	123	745	2.5%	34	0.60	317	3,368
Nevada	135	8	0.0%	8	13	18	39	44	32.9%	17	0.37		
Placer	41,980	401	4.4%	10	21	95	460	2,589	6.2%	105	0.72	2,620	1,171
Plumas	8,738	53	0.5%	10	28	110	988	2,049	23.5%	165	0.77	15	89
Riverside	172,716	1,969	3.7%	8	18	52	317	10,485	6.1%	88	0.78	9,795	134
Sacramento	122,736	1,313	19.3%	11	29	91	362	3,789	3.1%	93	0.69	19,762	17,735
San Benito	26,480	433	3.0%	11	23	59	207	2,327	8.8%	61	0.66	171	3,014
San Bernardino	1,874	32	0.0%	10	35	79	179	290	15.5%	59	0.55	2,322	5
San Diego	311	16	0.0%	7	9	24	58	78	24.9%	19	0.50	287	
San Joaquin	419,338	5,134	46.0%	11	27	68	299	8,520	2.0%	82	0.70	5,904	62,364
San Luis Obispo	94,798	1,391	4.5%	9	18	50	266	6,704	7.1%	68	0.73	2,044	13,268
San Mateo	469	18	0.1%	9	13	27	71	149	31.6%	26	0.51	5	
Santa Barbara	61,611	1,164	3.5%	8	18	49	188	1,778	2.9%	53	0.67	5,398	186
Santa Clara	12,202	373	1.5%	8	16	34	116	383	3.1%	33	0.57	234	51
Santa Cruz	3,093	145	1.1%	8	14	24	68	153	5.0%	21	0.46	30	24
Shasta	28,271	306	1.1%	8	21	97	342	3,947	14.0%	92	0.74	680	387
Sierra	2,345	39	0.4%	8	25	65	168	484	20.6%	60	0.66	106	243
Siskiyou	146,547	1,029	3.6%	14	42	138	573	5,772	3.9%	142	0.70	29,923	1,521
Solano	144,009	1,235	24.7%	13	37	115	441	5,311	3.7%	117	0.70	1,276	874
Sonoma	58,319	1,401	5.7%	8	14	31	145	2,119	3.6%	42	0.67	1,133	1,869
Stanislaus	291,369	5,550	30.0%	10	20	49	203	2,538	0.9%	52	0.64	4,289	17,889
Sutter	269,933	2,221	69.3%	15	37	129	507	6,060	2.2%	122	0.69	5,916	3,580
Tehama	67,569	1,123	3.6%	8	14	39	216	2,950	4.4%	60	0.74	127	493
Trinity	8	1	0.0%	8	8	8	8	8	100.0%	8	0.00	50	
Tulare	664,392	6,519	21.4%	12	29	81	432	7,387	1.1%	102	0.72	20,134	275
Tuolumne	113	7	0.0%	5	6	25	42	42	37.5%	16	0.47	17	11
Ventura	4,325	228	0.4%	8	13	24	49	103	2.4%	19	0.41	104	107
Yolo	301,554	1,976	46.1%	17	53	144	518	14,485	4.8%	153	0.71	19,619	13,843
Yuba	100,145	851	24.3%	10	30	102	536	2,425	2.4%	118	0.73	2,998	964

error rate of 4% based on a random sample of 100 linked names. Because only 12% of records were identified for combining, in the context of the entire dataset the error rate of mistakenly combined records is 0.23% of all records. After this processing, the total number of owners with any cropland was 112,419.

Evaluating land concentration. For each county, we used the assembled ownership data to calculate the Gini coefficient of land ownership. The Gini coefficient is a measure of statistical dispersion that is commonly used as a measure of inequality. The coefficient values range from 0 to 1, where a value of 0 signifies perfect equality (every person owns the same amount of land) and a value near 1 equals perfect inequality (one individual owns all the land). The R package ineq (Zeileis 2014) was used to calculate Gini coefficients for each county.

Clustering of crop types. We used hierarchical clustering to evaluate combinations of crops planted together on a single property. Fourteen variables (representing 14 crop categories) were created corresponding to the fraction of a property planted to a given crop category. We then standardized the values of these variables by subtracting the mean and dividing by the standard deviation. We ran a hierarchical cluster analysis that compares the dissimilarity of the 68,699 ownerships being clustered. In this method, each object is initially assigned to its own cluster and then the algorithm proceeds by joining the two most similar objects, continuing iteratively through the dataset until there is just a single cluster. We selected the Ward's minimum variance method, which seeks to find compact spherical clusters using Euclidean distance, to cluster the ownerships based on mixes of crops present. We used the fastcluster package to implement the clustering algorithm, which has memory-saving routines and allowed for this analysis without creating a distance matrix (Müllner 2013). Caution should be taken in extrapolating 2013 crop mixes to other years, given that the analysis was performed during a drought year and farmers may have been making crop adjustments.

TABLE 2. Acres of government-owned cropland by crop type

	Federal	State	Local	Special district	Miscellaneous government	Total acres
Alfalfa/hay	15,252	12,853	16,538	2,326	3,474	50,444
Almonds	2,358	1,169	3,363	1,363	139	8,393
Corn	408	3,429	1,597	600	10	6,044
Cotton	1,287	139	1,116	1,594	1,856	5,992
Fallow	48,222	46,704	25,325	34,121	6,303	160,675
Fruit trees	1,593	416	1,228	268	73	3,579
Grain crops	33,413	1,868	7,674	1,491	1,329	45,775
Grapes	312	1,024	2,347	709	19	4,410
Other tree crops	1,344	1,194	1,094	619	1	4,252
Rice	520	1,469	667	854	7	3,517
Tomatoes	916	162	538	699	1,170	3,484
Vegetables/ fruit	4,810	1,435	1,240	771	634	8,891
Walnuts	1,016	375	1,214	1,011	264	3,881
Winter wheat	1,849	2,478	5,500	3,422	1,382	14,631
Total acres	**113,302**	**74,715**	**69,440**	**49,846**	**16,663**	**323,967**

TABLE 3. Descriptive statistics of crop types

Crop category	Total acres	Number of owners	25th percentile	Median acres	75th percentile	95th percentile	Largest crop ownership	Percent of crop in largest ownership	Average acres	Coefficient of variation	Gini coefficient
Alfalfa/hay	1,305,745	21,086	4.0	12.7	52.9	254.8	16,399	1.3%	61.9	3.7	0.76
Fallow	1,141,035	25,265	3.6	8.9	25.4	151.2	60,683	5.3%	45.2	10.3	0.80
Almonds	1,066,419	24,120	2.7	8.2	28.7	172.6	39,193	3.7%	44.2	7.4	0.80
Grapes	761,517	18,015	4.0	10.7	31.8	158.0	6,794	0.9%	42.3	3.5	0.76
Grain crops	674,197	13,214	3.3	12.0	46.9	205.1	12,153	1.8%	51.0	3.4	0.75
Rice	557,149	2,599	39.6	118.8	258.3	696.1	10,543	1.9%	214.4	1.9	0.61
Winter wheat	410,790	8,994	2.9	10.2	39.1	183.9	8,866	2.2%	45.7	3.3	0.76
Fruit trees	391,900	14,168	3.1	8.5	23.1	103.0	5,283	1.3%	27.7	3.5	0.73
Walnuts	313,258	11,284	2.2	6.7	22.7	115.2	8,225	2.6%	27.8	3.9	0.75
Cotton	277,694	2,374	5.8	30.5	98.3	340.4	56,602	20.4%	117.0	10.3	0.78
Tomatoes	272,021	4,051	3.3	14.7	69.8	299.7	3,179	1.2%	67.1	2.3	0.74
Corn	248,064	3,556	4.7	20.9	67.2	249.4	11,164	4.5%	69.8	3.8	0.73
Vegetables/ fruit	247,844	4,891	4.7	15.8	55.3	203.3	3,655	1.5%	50.7	2.2	0.70
Other tree crops	203,908	5,779	1.6	5.3	16.9	134.8	14,275	7.0%	35.3	6.8	0.84

California cropland ownership characteristics

Approximately 96% of California cropland is privately owned, followed by 1.4% federal, 0.9% state, 0.8% local and 0.6% special districts (e.g., irrigation districts). Of the government-owned land, 50% is fallow, 16% is alfalfa or hay and 14% is grain crops, with all other crops making up less than 5% of the total (table 2).

In 2013, there were approximately 7.87 million acres of private cropland in California greater than 5 acres or 5% of an owner's property, made up by approximately 68,699 owners. The largest 1% of cropland properties (the 687 properties larger than 1,277 acres) accounted for 26.5% of California's cropland. The largest 5% of properties (3,435 properties that are larger than 477 acres) account for just over half (50.6%) of California's cropland. The remaining 95% of properties (65,370 properties) compose the remainder (49.4%) of the state's cropland. The 25% of California cropland composed of the smallest properties is made up of 57,490 properties, 84% of all owners, and these properties are less than 152 acres (table 4 and fig. 2). The median acreage of properties was 29.8 acres and mean acreage was 120.7 acres.

TABLE 4. Frequency table of ownership of California cropland based on size class

Size category (acres)	Total acres	Percent of total acres	Cumulative sum of acres	Number of owners	Percent of total owners	Cumulative sum of owners
5–10	97,056	1.2%	97,056	13,327	19.4%	13,327
10–25	301,931	3.6%	398,988	18,413	26.8%	31,740
25–50	423,983	5.1%	822,970	11,853	17.3%	43,593
50–75	347,432	4.2%	1,170,402	5,573	8.1%	49,166
75–100	305,583	3.7%	1,475,985	3,572	5.2%	52,738
100–250	1,391,963	16.8%	2,867,948	8,875	12.9%	61,613
250–500	1,367,857	16.5%	4,235,805	3,934	5.7%	65,547
1,000	1,459,906	17.6%	5,695,711	2,106	3.1%	67,653
5,000	1,695,154	20.4%	7,390,865	975	1.4%	68,628
10,000	348,303	4.2%	7,739,168	51	0.1%	68,679
> 10,000	558,856	6.7%	8,298,024	20	0.03%	68,699

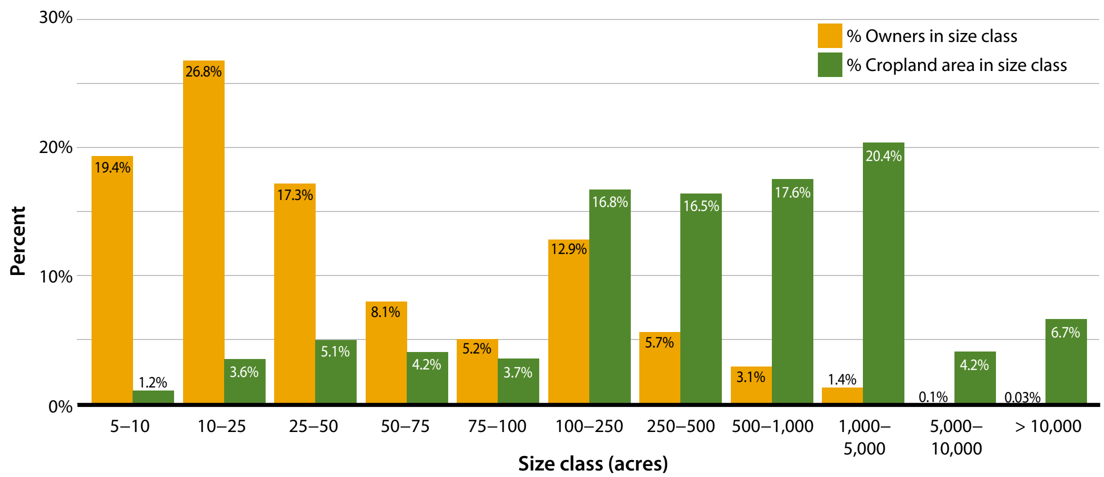

Fig. 2. Distribution of number of owners and percent of private cropland ownership greater than 5 acres in particular size classes of ownership.

County cropland ownership

We calculated metrics of cropland ownership on a county basis, including an analysis of equality of ownership, represented by the Gini coefficient. Fresno, Kern and Tulare counties were the three counties with the largest overall area of cropland. Of the three, Kern County has the fewest number of properties (3,642 versus > 6,500). Two other counties, Sutter and Kings counties, were notable for their land area being dominated by cropland, with over 64% of their land area composed of private cropland, with the next highest amount at 46% in Yolo and San Joaquin Counties. Median size of cropland property tended to be largest in the rural corners of California, with the highest values in Imperial and Modoc counties (> 80 acres).

More urban and tourism-focused counties (Los Angeles, Lake and Sonoma counties) tended to have lower median property size. Equality of cropland ownership, however, was not well-predicted by whether a county is rural or developed; rather, it tended to be most associated with the size and number of the largest landowners in the county or regulations implementing a minimum parcel size. Kings County has the most unequal cropland ownership, followed by Kern and Contra Costa counties. The most equal cropland ownership (of counties with > 5,000 acres of private cropland) was found in Santa Clara, Napa and Mendocino counties (table 1 and fig. 1).

Crop types

Many crops had similar ownership characteristics with a few exceptions. Rice and cotton had large average acreages planted, while fruit trees, walnut trees and other tree crops had small average size plantings (table 3 and fig. 3).

Among properties growing rice, the average acres planted to rice were far larger (214 acres) than the average acreages grown in all other crop categories. There were also few properties that planted small areas of rice; the 25th percentile of rice acres planted was 40 acres, more than six times larger than the equivalent measure for any other crop type. Properties planted with cotton in 2013 had the second highest average (117 acres), but the median acreage of cotton properties was similar to other crops. The metric that tends to set cotton apart from rice is its much higher maximum acres grown on a single property (~56,600 acres). Rice and cotton had comparatively few properties planted, ranking 13th and 14th in number of owners across 14 crop categories, yet they ranked 6th and 10th in acres planted out of the crop categories.

The crop categories of fruit trees, walnuts and other tree crops were notable for their comparatively small ownerships. Mean ownership was between 27 and 35 acres, and median values were below 8.45 acres. While two other crop types, almonds and fallow land, had median values around 8 acres, their average values were comparatively larger.

The year 2013 was the second year of the recent and ongoing drought in California, and approximately 25,265 owners had over a million acres left fallow, with 45 acres being the average area left fallow. Nearly 60,000 of those acres were left fallow by a single property owner in Kings, Kern and Tulare counties, an area where crops grown are highly dependent on irrigation.

Land planted with rice, which had the highest average acreage planted, also had the most equal distribution of land, in part because there were relatively few small properties. The most unequal ownership came in the other tree crops category, which is composed of 82% pistachios, 1% pecans and 17% all other tree crops. In that crop category, a single ownership that was planted with pistachios accounted for 7% of that crop category's area. This, combined with an abundance of small owners (evidenced by the lowest median ownership size of all crop categories), led to a high inequality measure.

Crop mixes

Many landowners or their tenants plant multiple crops, either in rotation or as market demands shift. We used our database to calculate typologies of properties based on the similarities of crops that were planted together. Seven crop clusters were identified that yield interesting insights into how farmers specialize or mix crops (fig. 4). Three clusters tended to mix crops or orchards, with no single category composing more than half of the property area, while four clusters tended to specialize in a particular crop type with more than 79% planted in a single crop type. Many grape, rice, almond and alfalfa/hay producers tended to focus the majority of their plantings in their primary crop. Of the three clusters that mixed crops, one was mixtures of fruit trees, almonds and walnuts; the second was dominated by fallow land and a mixture of other crops; the third group was very diverse, and tended towards a comparatively even mixture of grain crops, tomatoes, alfalfa/hay and fallow land. Of the farmers who specialized in single crops, those who grew grapes had the strongest specialization, followed by rice, alfalfa/hay and almonds.

Implications for research and extension

Agricultural statistics are crucial to decision-making, to improving agricultural efficiency and to protecting the environment. Improvements in remote sensing technologies along with the availability of parcel data allow researchers to present agricultural statistics in new ways. We do that here and show, to our knowledge for the first time, how land ownership is distributed for multiple crops throughout the state. We do not comment here on whether this ownership arrangement is efficient, just or fair.

From the perspective of resource agencies and Cooperative Extension, these ownership patterns present opportunities for tailoring research and extension programs to their desired audience. For example, knowledge of the average size and distribution of cropland ownership in a particular type of crop can assist researchers developing more efficient harvest methods geared towards a particular sized parcel, or in prioritizing outreach activities and methods of communication. In terms of outreach, natural resource

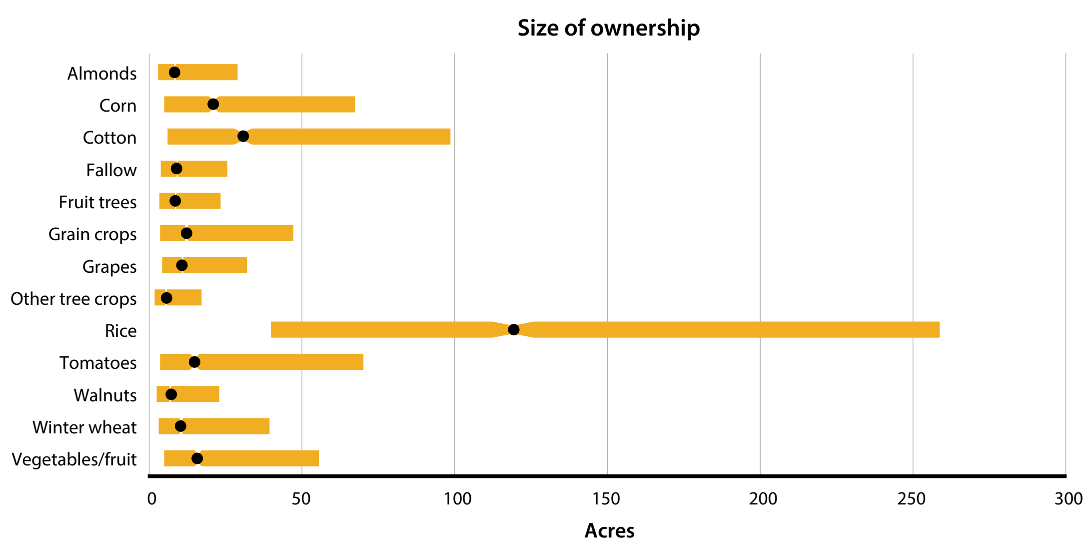

Fig. 3. Measures of acres planted by individual owners by crop type. Median represented by black dot, 1st and 3rd quartile value at outer edge of boxes.

professionals seeking to increase adoption of best practices in particular counties or for certain crop types can benefit from this knowledge. For example, in crop types dominated by a few large properties, individual outreach may be an appropriate method of extension given the disproportionate area of cropland affected. Alternatively, crops dominated by many small properties like fruit trees or walnuts will likely require efforts utilizing mass communication tools that can reach thousands of owners. For crops with comparatively low variation in ownership size (rice and tomatoes), outreach agencies may be able to reach a broad audience by focusing on challenges facing an average sized farm. Crops with wide variation in property size (e.g., almonds, other tree crops and properties with fallow land), may require an approach that reaches owners of small, medium and large properties. While the vegetables/fruit category exhibits low variation in property size owned, it contains the widest variation of crop types, requiring a large diversity of subject matter experts that can be devoted to relatively similar sized properties.

The analysis of crop mixes yields insights into guiding research and extension approaches, as well as information for equipment or seed sellers. Knowing that grapes, rice, alfalfa/hay and almonds all tended towards specialization suggests that specialized outreach may be most effective. Crop types that tend to be mixed may warrant the collaboration of researchers and advisors for synergies that can be gained in a mixed planting system. The characteristics of the clusters can also help these collaborators know their audience; for example, properties with mixed crops from clusters 2 and 4 were

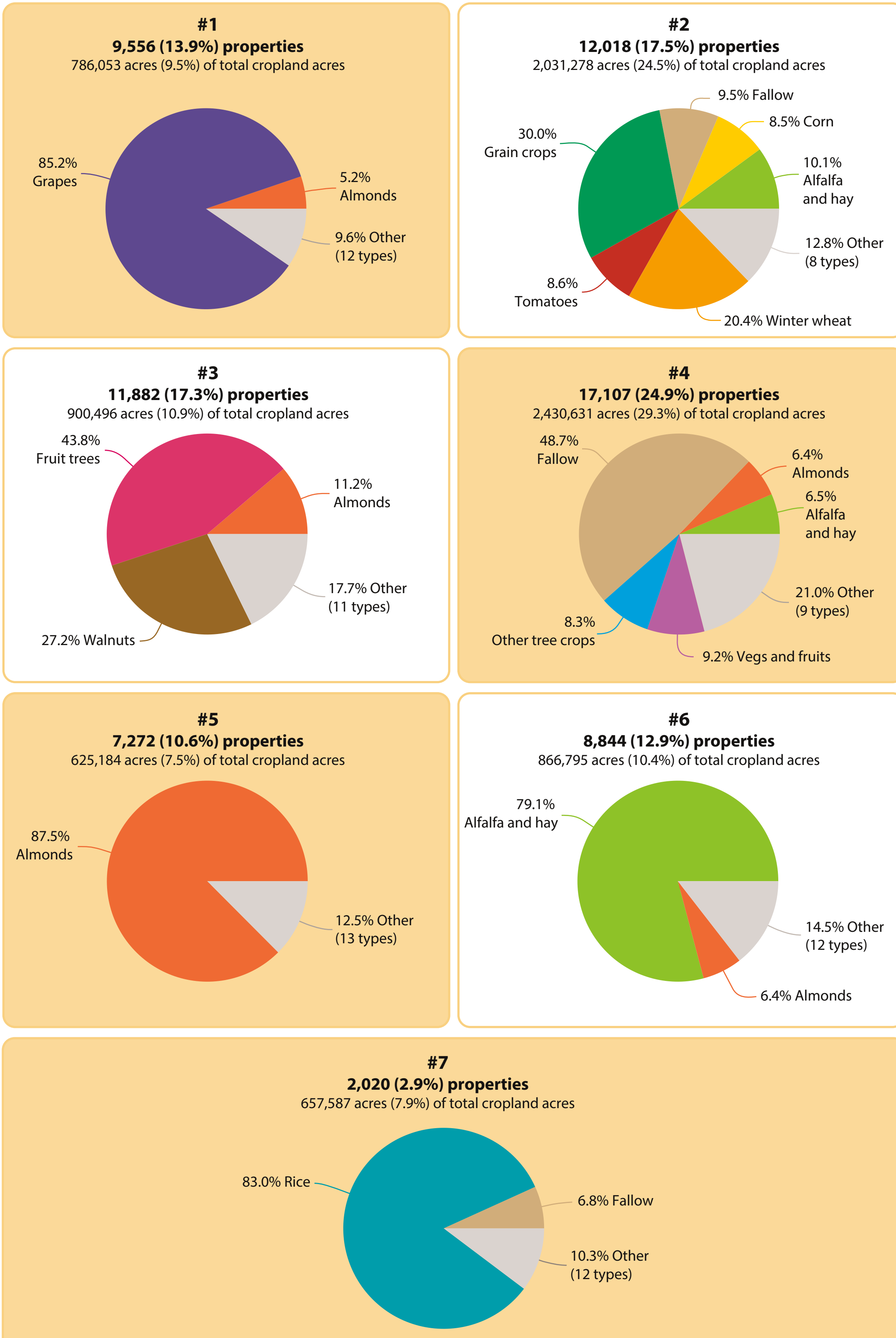

Fig. 4. Hierarchical clustering results based on the average percentages of crop category grown for each owner.

larger than the average farm, while the tree crop mix (cluster 3) was composed of smaller properties than average.

The differences in distribution of ownership by different crop types or counties are likely influenced by the suitability of land for particular crops, historical settlement patterns, whether economies of scale are present for growing the crop, and local land use ordinances. Walnuts had small median and mean area planted, which is likely driven by their requirements for high quality alluvial soils that occur along rivers flowing out of the Sierra Nevada. These lands have generally coincided with historic small towns that have been farmed for longer periods of time, leading to greater fragmentation as generations turn over and land holdings are split among family members (UC Agricultural Issues Center 1994a; Dr. Katherine Pope and Dr. David Ramos, UC Agriculture and Natural Resources, personal communication). Much of the state's rice is grown on soils that have such a high clay content that no other crops can be productively grown on them, possibly reducing small-farm demand and subdivision for this type of land (UC Agricultural Issues Center 1994b; Dr. Jim Hill, UC Davis, personal communication). The consolidation of cotton plantings occurred historically and likely is impacted by a variety of factors, including the relative difficulty in growing cotton, its greater ability to grow in saline soils, and economies of scale in producing sufficient cotton to sustain a ginning operation (Dr. Robert Hutmacher, UC Agriculture and Natural Resources, personal communication).

The relative equality of ownership in counties like Santa Clara, Mendocino and Napa counties may be driven by earlier settlement and homesteading patterns where the size of farm was limited by the amount of labor available (usually the immediate family), making large aggregations of acreage more difficult (Glenn McGourty, UC Agriculture and Natural Resources, personal communication). Additionally, Napa County enacted the Agricultural Preserve Act and Measure P, which implements minimum parcel size regulations and zones agricultural use as the best use in many areas of Napa County (Dr. Monica Cooper, UC Agriculture and Natural Resources, personal communication). These factors have led to comparatively few dominant landowners in these coastal agricultural areas, and in the case of Napa, fewer smallholders, which limits the measure of inequality.

These results provide useful information for Cooperative Extension efforts seeking to target growers by particular crop varieties or by various localities. This assessment can provide help in prioritizing outreach activities and methods of communication, as well as in tailoring research efforts to stakeholders' needs. They may also prove useful in allocating resources regionally depending on the area of cropland, type of crop and number of people served. Continuing to track the relationship between ownership patterns and crop patterns in the future will be a valuable way to analyze the ever-changing landscape of agriculture in California. CA

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RESEARCH ARTICLE

Remote sensing is a viable tool for mapping soil salinity in agricultural lands

Remote-sensing modeling produces an accurate regional salinity map of the western San Joaquin Valley, useful for growers and state agencies.

by Elia Scudiero, Dennis L. Corwin, Ray G. Anderson, Kevin Yemoto, Wesley Clary, Zhi "Luke" Wang and Todd H. Skaggs

Abstract

Soil salinity negatively impacts the productivity and profitability of western San Joaquin Valley (WSJV) farmland. Many factors, including drought, climate change, reduced water allocations, and land-use changes could worsen salinity conditions there, and in other agricultural lands in the state. Mapping soil salinity at regional and state levels is essential for identifying drivers and trends in agricultural soil salinity, and for developing mitigation strategies, but traditional soil sampling for salinity does not allow for accurate large-scale mapping. We tested remote-sensing modeling to map root zone soil salinity for farmland in the WSJV. According to our map, 0.78 million acres are salt affected (i.e., EC_e > 4 dS/m), which represents 45% of the mapped farmland; 30% of that acreage is strongly or extremely saline. Independent validations of the remote-sensing estimations indicated acceptable to excellent correspondences, except in areas of low salinity and high soil heterogeneity. Remote sensing is a viable tool for helping landowners make decisions about land use and also for helping water districts and state agencies develop salinity mitigation strategies.

Soil salinity is a known constraint on agricultural production in the Central Valley, particularly in the western San Joaquin Valley (WSJV), where soils are naturally high in salts due to the marine origin of their Coastal Range alluvium parent material (Letey 2000). In such a large region, it is difficult to quantify and map the full extent of soil salinity and its impact on agricultural production and profits. Many geological, meteorological and management factors affect the salinity levels of irrigated soils, including irrigation water quality, irrigation management, drainage conditions, rainfall and evapotranspiration totals and cultural practices. Across a region such as WSJV, most of those factors vary at multiple spatial and temporal scales, making it difficult to extrapolate local point measurements of soil salinity to regional scales.

Although agricultural salinity is a generally well-known issue, communicating the full extent and severity of the problem to policymakers, stakeholders and other nonspecialists is a challenge. Detailed regional maps present the problem visually and can help spur action on planning, management and conservation. Letey (2000) argued that long-term sustainable and profitable agriculture in California can be achieved only if regional-scale salt balances can be obtained. Regional-scale salinity maps provide irrigation district managers, water resource specialists and state and federal authorities with timely information that can guide decisions on water allocation needs and groundwater regulation.

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This electromagnetic induction rig was developed at the USDA-ARS U.S. Salinity Laboratory for mapping soil salinity and other soil properties (e.g., texture, water content, bulk density, organic matter) at field scale. Regional-scale salinity maps provide irrigation district managers, water resource specialists and state and federal authorities with timely information that can guide decisions on water allocation needs and groundwater regulation.

Walter Russel

Remote sensing of soil salinity

In the past decade, efforts to map soil salinity at regional scales and characterize its spatial variability have focused on the use of predictor covariates that can be observed remotely with continuous spatial coverage across a region (e.g., Lobell et al. 2007). Remote sensing is ideal for identifying within-field variability, which is known to exist in the farmland of the WSJV (e.g., Lesch et al. 1992). This remote-sensing approach is in contrast to traditional methods of assessing soil salinity by soil sampling, which are typically carried out at coarse resolution (e.g., soil samples every ~ 1,000 to 1,500 yards). In their recent soil survey reports (e.g., Arroues 2006), the Natural Resources Conservation Service (NRCS) provided salinity estimations only for nonirrigated soils because the influence of irrigation on soil salinity cannot be accounted for at the regional scale using traditional soil survey protocols. Remote sensing, however, is able to capture abrupt changes between neighboring fields that have the same soil type but are managed differently (fallow vs. irrigated, drip vs. flood irrigation).

In discussing remote sensing of saline soils, one must distinguish between salinity at the soil surface (sometimes visible as salt crusts) and salinity in the soil root zone (i.e., the soil volume down to a depth of about 3 to 5 feet). Soil root zone salinity affects plant growth, and it is the salinity indicator of greatest interest in agricultural assessments.

When a crop is stressed by root zone salinity, an increase in crop reflectance occurs in the blue (B), green (G) and red (R) ranges of the electromagnetic spectrum (e.g., leaves turn from green to hues of yellow and/or red), and a decrease occurs in the near-infrared (NIR) range. Recent research suggests that root zone salinity can be determined indirectly based on canopy reflectance measurements (Lobell et al. 2010; Zhang et al. 2011). Specifically, vegetation indices such as the Normalized Difference Vegetation Index (NDVI) or the Canopy Response Salinity Index (CRSI), calculated from satellite multispectral reflectance data, can be used to infer root zone salinity within a satellite image pixel. Unfortunately, other stressors such as pests and agronomic mismanagement have similar effects on crop reflectance. Thus, it is necessary to devise a procedure for separating the effects of salinity from other stressors.

Whereas most stressors tend to fluctuate within years and from year to year, average root zone salinity is relatively stable assuming consistent farming practices (Lobell et al. 2010). Scudiero et al. (2015) hypothesized that over a period of 5 to 7 years, the year of maximum plant performance (biomass production) as indicated by plant reflectance values would correspond to a time when transient stressors were minimized and salinity stress would be most clearly observable. Scudiero et al. (2015) developed a prediction model for WSJV root zone salinity using CRSI as a predictor variable. The CRSI is defined (Scudiero et al. 2014) as

$$\mathrm{CRSI} = \sqrt{\frac{(\mathrm{NIR} \times \mathrm{R}) - (\mathrm{G} \times \mathrm{B})}{(\mathrm{NIR} \times \mathrm{R}) + (\mathrm{G} \times \mathrm{B})}} \quad (1)$$

Increased plant vigor corresponds to a higher CRSI value. Notice that the CRSI is not a salinity-specific vegetation index; it was selected by Scudiero et al. (2015) because it provided better performance than other vegetation indices when applied to their salinity ground-truth calibration data.

Scudiero et al. (2015) calculated CRSI values using Landsat 7 ETM+ canopy reflectance data with a resolution (pixel size) of 32.8 × 32.8 yards (900 square meters). The pixel root zone (~ 0 to 4 feet) salinity prediction model of Scudiero et al. (2015) for 2007 to 2013 is

$$EC_e = 26.3 + \beta_{crop} \times \mathrm{CRSI}_j + 0.02 \times \mathrm{RAIN}_j + 3.35 \times \mathrm{TEMP}_j \quad (2)$$

where: EC_e is soil salinity (deciSiemens per meter, dS/m, see Box 1), the subscript j indicates the year of the maximum CRSI value, RAIN (mm) is the total rainfall for the year and TEMP (°C) is the average daily minimum temperature for the year. Scudiero et al. (2015) considered various predictor variables and equation formulations before selecting equation 2. Meteorological data were evaluated and included in the model because of their known effects on plant growth. The β_{crop} parameter indicates the presence or absence of cropping and has a value of −100.76 for fallow soils and −93.40 otherwise.

Scudiero et al. (2015) calibrated the model using data for 5,283 Landsat 7 pixels located in 22 WSJV fields that had been extensively surveyed for salinity by Scudiero et al. (2014). The model calibration produced $R^2 = 0.73$. Scudiero et al. (2015) cross-validated the model with traditional k-fold resampling ($k = 22$), yielding an observed-predicted R^2 of 0.68, and with a more conservative spatially independent leave-one-field-out (*lofo*) resampling ($R^2 = 0.61$). In particular, the *lofo* resampling indicated that the mean absolute error (MAE) at unknown fields is expected to be: 2.94 dS/m (nonsaline), 2.12 dS/m (slightly saline), 2.35 dS/m (moderately saline), 3.23 dS/m (strongly saline) and 5.64 dS/m (extremely saline). See Box 1 for definitions of soil salinity classes. Further details on remote-sensing data processing, model development and cross-validation statistics are provided in Scudiero et al. (2015).

For this article, we used the calibrated equation 2 to generate a salinity map for the WSJV. Our goals were

Box 1
Laboratory measurement of soil salinity

Soil salinity is quantified as the electrical conductivity of a saturated soil paste extract (EC_e, dS/m). The United States Salinity Laboratory (Richards 1954) classifies agricultural EC_e in these categories: 0 to 2 dS/m (nonsaline), 2 to 4 dS/m (slightly saline), 4 to 8 dS/m (moderately saline), 8 to 16 dS/m (strongly saline) and > 16 dS/m (extremely saline).

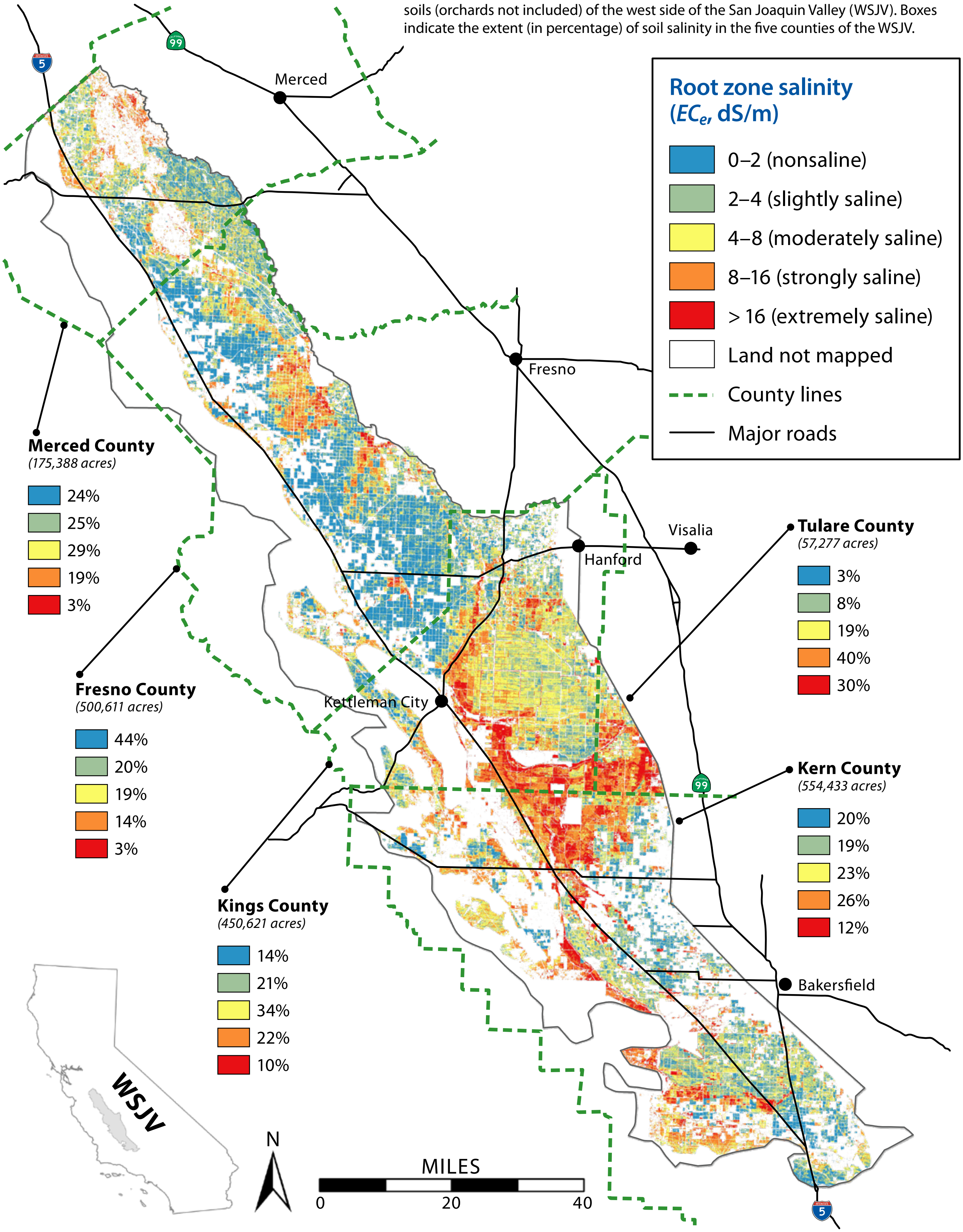
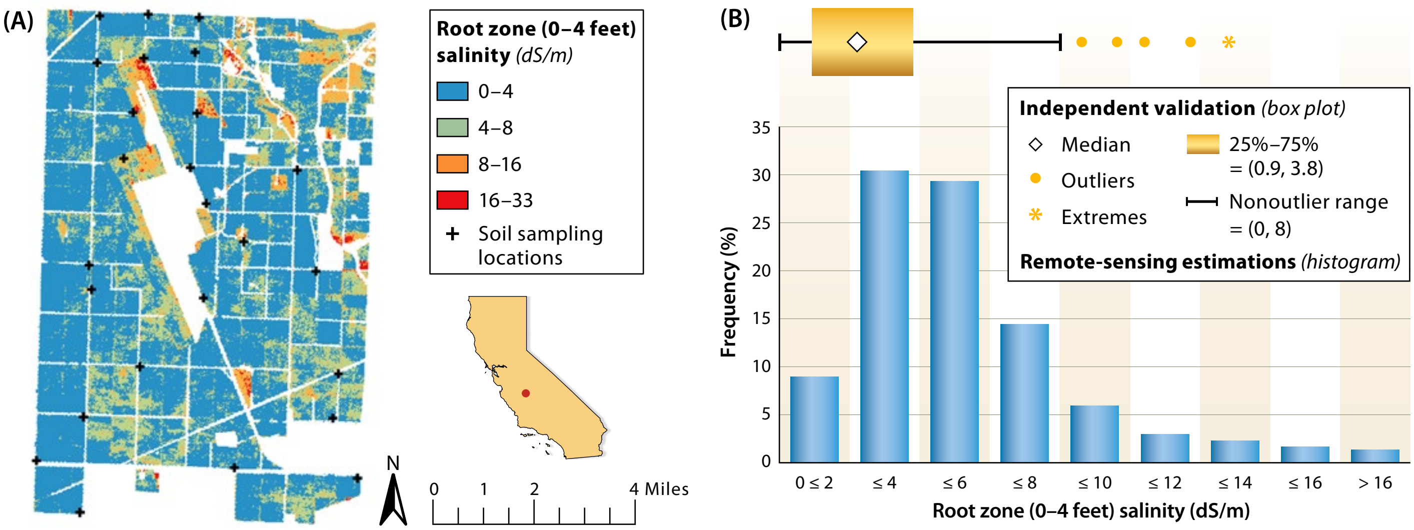


Fig. 1. Remote-sensing estimations of root zone (0 to 4 feet) soil salinity for agricultural soils (orchards not included) of the west side of the San Joaquin Valley (WSJV). Boxes indicate the extent (in percentage) of soil salinity in the five counties of the WSJV.

Fig. 2. (A) Remote-sensing estimations of root zone salinity over ~ 4,000 acres of farmland in Lemoore (Kings County) and (B) the comparison of the remote-sensing estimations frequency distribution with that of independent soil measurements.



to reveal the extent and spatial distribution of salinity across the WSJV and consider the accuracy and possible limitations of the map. We also wanted to explore how remote sensing of soil salinity can be used to support agriculture in California.

WSJV salinity map

Figure 1 shows the remote-sensing root zone salinity map for the WSJV with a resolution of 32.8 × 32.8 yards. The map was generated from equation 2 using spatial input data from 2007 to 2013 — Landsat 7 EMT+ reflectance data, PRISM model meteorological data (Daly et al. 2008) and CropScape (Han et al. 2012) cropping data. Nonagricultural areas (e.g., urban land, water bodies, roadways) were masked. Orchards were also masked because the dataset used by Scudiero et al. (2015) to calibrate equation 2 did not include tree crops. According to the CropScape database, 16.2% of WSJV farmland was cropped with orchards in 2013. Later in this article, we discuss remote-sensing mapping over orchards.

According to our map (fig. 1), 0.78 million acres are salt affected (i.e., $EC_e > 4$ dS/m), which represents 45% of the mapped farmland. The mapped acreage for the different subclasses of soil salinity were 433,777 acres (25%) nonsaline, 349,007 acres (20%) slightly saline, 436,476 acres (25%) moderately saline, 374,000 acres (22%) strongly saline and 145,070 acres (8%) extremely saline. Figure 1 shows breakdowns for individual counties (Merced, Fresno, Kings, Tulare and Kern).

Remote-sensing map accuracy

Scudiero et al. (2015) found good model accuracy when equation 2 was tested using various forms of cross-validation on a large ground-truth dataset representing 22 WSJV fields and thousands of remote-sensing pixels. Compared to that dataset, however, figure 1 represents a substantially greater application of equation 2. Although extensive data for assessing the accuracy of the WSJV map do not exist, some limited evaluation of the map accuracy is possible, because some of the image and landscape variables that influence the accuracy are known.

Independent salinity measurements

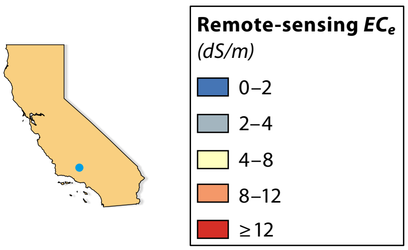
Figure 2 compares the salinity estimated using equation 2 over ~ 4,000 acres (1,619 hectares) of farmland in Lemoore (Kings County) with independent salinity measurements made on 25 soil cores that were sampled in 2011 and 2012 by Wang (2013). According to the NRCS Soil Survey Geographic database (SSURGO), texture in this area is fairly uniform (clay and clay loam, mostly). The independent soil measurements are sparse point data (2-inch-diameter cores) that cannot be usefully compared with the much larger ETM+ pixels. However, since Wang's (2013) soil sampling scheme was not spatially biased (not clustered), the frequency distribution of the independent salinity measurements should be representative of the salinity in the target area (Corwin and Scudiero 2016).

The independent soil sampling had an average EC_e of 2.8 dS/m (median of 2.3 dS/m and standard deviation of 2.4 dS/m); equation 2 produced a map characterized by an average EC_e of 3.2 dS/m (median of 2.5 dS/m and standard deviation of 3.1 dS/m). The similar frequency distributions from the remote-sensing map and independent sampling (fig. 2) indicate acceptable accuracy of the remote-sensing estimations.

Soils with salt crusts

Salt crusts are readily identifiable from remote-sensing imagery (e.g., Metternich 1998). Salt crusts can be seen only on bare soil and have high temporal variability. Although the presence of salt crusts does not necessarily correspond to high root zone salinity, one would expect some correlation to exist (Zare et al.

Fig. 3. (A) National Aerial Imagery Program (NAIP) 2014 image of a site in Bakersfield (Kern County), where the field in the north was cultivated with corn (*Zea mays* L.) and the field in the south was fallow; (B) NAIP pixels classified as white salt crusts by supervised classification (red pixels); (C) remote-sensing estimations for root zone salinity.



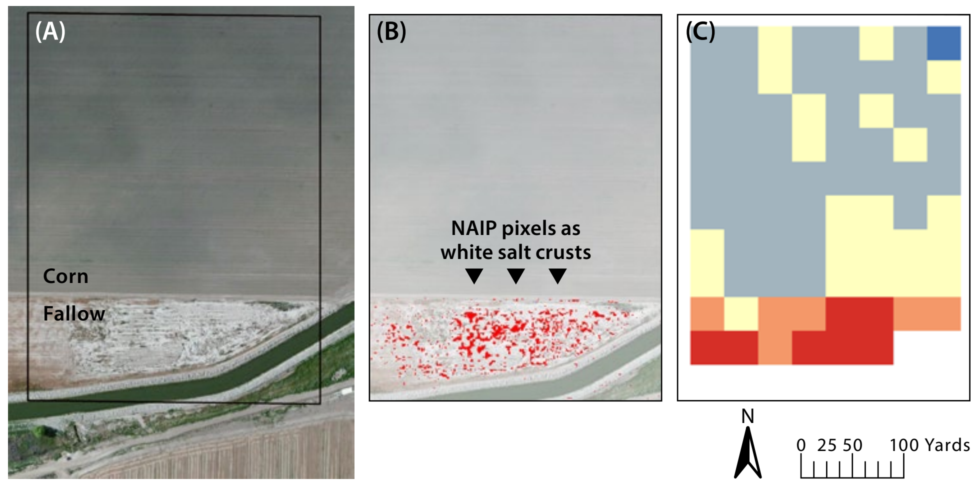
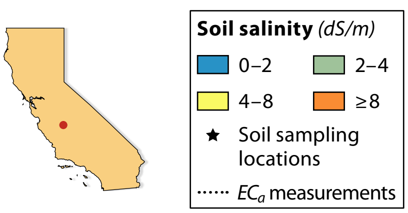
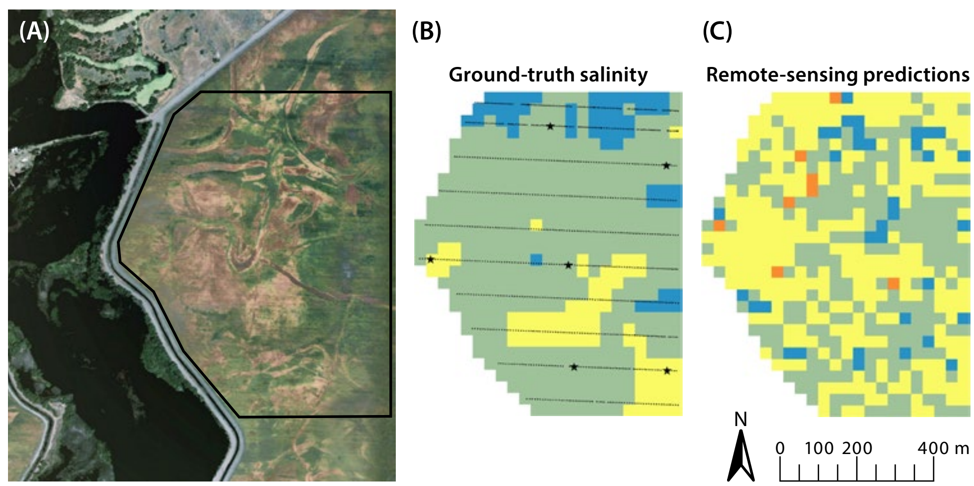


Fig. 4. Example of inaccuracy of remote-sensing estimations in a heterogeneous field with lower salinity values: (A) National Aerial Imagery Program imagery at a test site in Stratford (Kings County) on July 8, 2003; (B) ground-truth root zone (0 to 4 feet) salinity measured by Scudiero et al. (2014) through apparent electrical conductivity (EC_a) measurements and soil sampling; and (C) remote-sensing salinity estimations.





2015). We qualitatively evaluated the correspondence of remote-sensing high salinity predictions with the presence of salt crusts.

To map salt crusts across the WSJV, we used imagery from the 2014 USDA's National Aerial Imagery Program (NAIP) survey (resolution of 1.09 × 1.09 yards, i.e., 1 square meter). A supervised classification (maximum likelihood classification algorithm) was used to identify salt crusts. The classification identified NAIP pixels with reflectance properties similar to those observed at locations known to be affected by salt crusts. This analysis identified salt crusts over 0.5% of WSJV farmland. Figure 3A depicts a site near Bakersfield (Kern County) where salt crusts are clearly visible in the NAIP ortho-imagery over fallow land but not in the neighboring corn (*Zea mays* L.) field. There is excellent correspondence between the high salinity (EC_e > 8 dS/m) sections of the site as estimated by the remote-sensing map (fig. 3C) and the location of the salt crusts (fig. 3B).

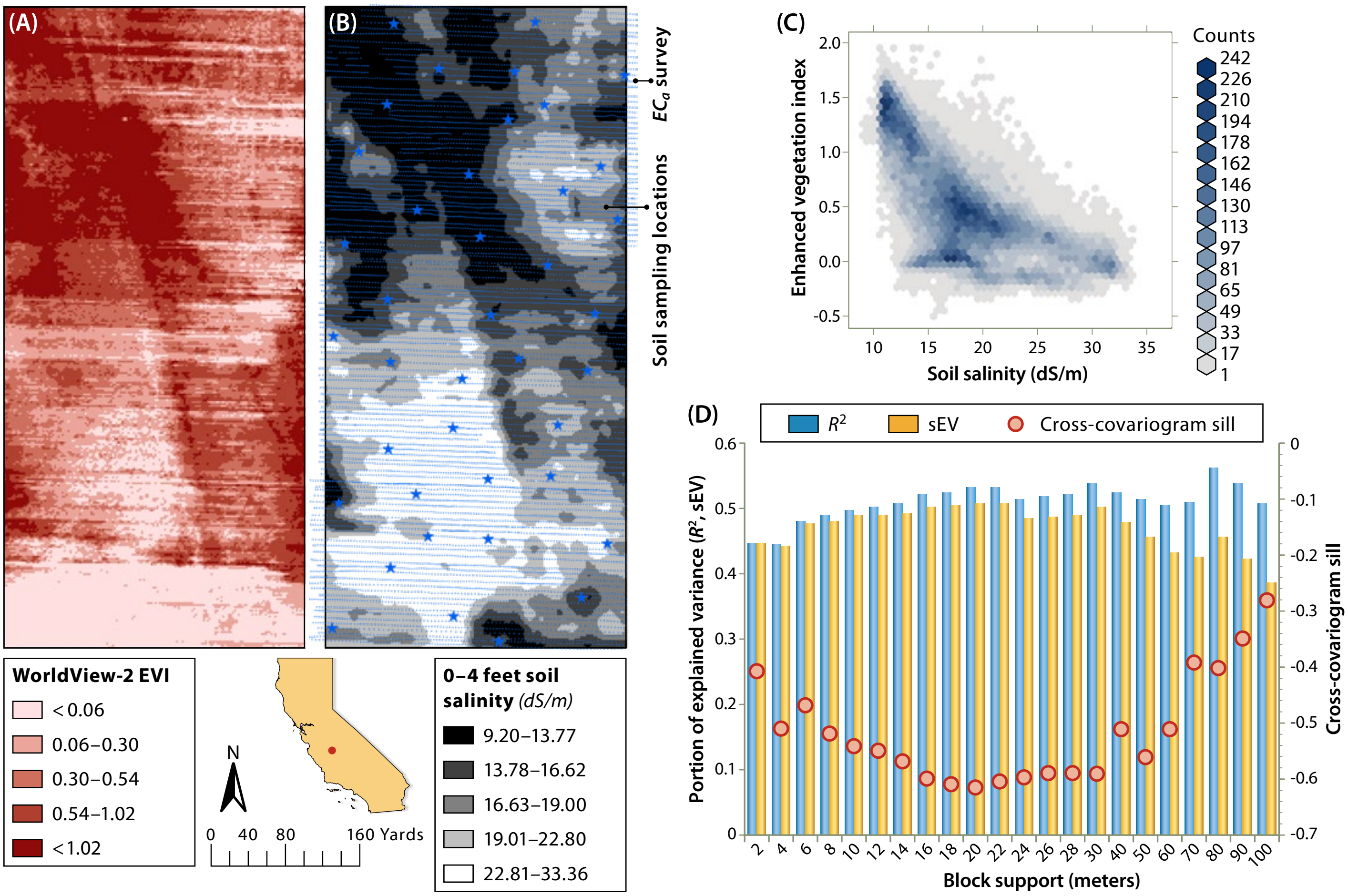
To properly compare the NAIP salt pixel classification with figure 1, we aggregated the NAIP classification at the 32.8 × 32.8 yard (30 × 30 meter) resolution. Only the 32.8 × 32.8 yard (30 × 30 meter) cells that included more than 50% of NAIP salt crusts at the original 1.09 × 1.09 yard (1 × 1 meter) resolution were retained for further analysis. A total of 162,829 "salt-crusted" cells were identified. About 94.3% of the salt-crusted pixels were predicted by equation 2 to be EC_e > 4 dS/m. In total, the salt-crusted pixels had average EC_e of 13.6 dS/m, first quartile of 9.7 dS/m, median of 13.5 dS/m and third quartile of 18.2 dS/m, indicating good correspondence between visibly saline soils and predictions of high salinity by equation 2.

Contrasting soil properties and low salinity

Scudiero et al. (2015) indicated that remote-sensing estimations at low salinity levels (EC_e < 4 dS/m) might be imprecise because plants may not be sufficiently osmotically stressed at low salinity to affect crop health. The spatial variability of other soil properties that influence crop yield within a single field could lead to salinity estimation errors at low salinity. Although subfield variations in soil texture are typically minor in WSJV, some fields exhibit significant variability over short distances. In these cases, soil heterogeneity influences crop performance, introducing uncertainty into the remote-sensing estimations of soil salinity.

As an example, consider the remote-sensing salinity predictions for a slightly to moderately saline

Fig. 5. (A) Enhanced Vegetation Index (EVI) and (B) ground-truth soil salinity (from Scudiero et al. 2014) at 2 × 2 meter resolution for an 80-acre field in California; (C) scatter plot for the two maps; and (D) strength of the relationship at different block supports, measured as coefficient of determination (R^2), scaled explained variance (sEV) and a function of the cross-covariogram sill.



field located near Stratford (Kings County), along the southern branch of the Kings River. As shown in the NAIP ortho-imagery acquired on July 8, 2003 (fig. 4A), the field is characterized by substantial small-scale soil heterogeneity, which is likely due to movements of the Kings River through paleohistory. The root zone salinity measured by Scudiero et al. (2014) is shown in figure 4B (ground-truth data), and the remote-sensing prediction is shown in figure 4C.

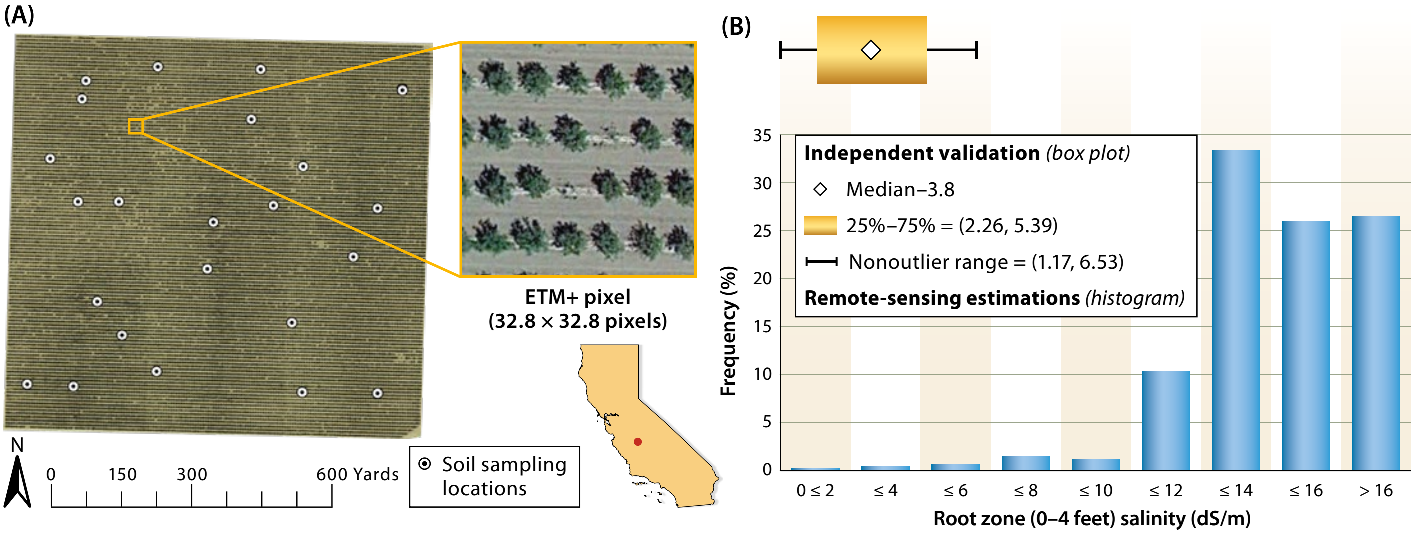
In figure 4B, the average EC_e was 3.01 dS/m (standard deviation of 0.84 dS/m), whereas in figure 4C the average was 4.22 dS/m (standard deviation of 1.57 dS/m). Clearly, the two maps (figs. 4B and 4C) are not spatially correlated. This is likely due to the confounding effect of soil spatial variability on the salinity estimations. This example shows that when soil salinity is not the only limiting factor for crop production, the spatial patterns of the remote-sensing map might not represent the salinity variations within the target field. This issue can be addressed by including information on soil properties, such as texture, in the remote-sensing model. Unfortunately, at the moment, reliable soil texture maps comparable in resolution to Landsat imagery are not available for California.

Map spatial resolution

High-resolution maps (cell size < 10 yards) can be very useful when planning field agricultural operations, especially when precision farming techniques are employed. The spatial resolution (900 square meters, ~ 0.22 acre) of Landsat, which was used to produce the remote-sensing salinity map (fig. 1), may seem too coarse to represent within-field spatial variability of soil salinity. However, desired map resolution is not the only factor to consider. When estimating soil properties using remote sensing, one should keep in mind that correlation between soil properties and satellite data might be optimal at coarser resolutions (Gomez et al. 2015; Miller et al. 2015).

A practical example of this can be seen in figure 5. In this 80-acre fallow field near Stratford (Kings County), salinity was mapped with an apparent electrical conductivity survey and soil sampling by Scudiero et al. (2014). Multitemporal (Aug. 22, 2012; Sept. 29, 2012; and April 21, 2013) WorldView-2 (Digital Globe, Colorado) imagery was acquired that has a native resolution of ~ 2.2 × 2.2 yards (2 × 2 meters). The Enhanced Vegetation Index (EVI) (Huete et al. 2002) was calculated from the imagery, as follows:

Fig. 6. (A) Independent soil sampling over a 150-acre almond (*Prunus dulcis* Mill.) orchard in Kern County (B) compared with remote-sensing estimations of root zone salinity.



$$EVI = 2.5 \times \frac{NIR_{WV2} - RED_{WV2}}{(NIR_{WV2} + 6 \times RED_{WV2} - 7.5 \times BLUE_{WV2} + 1)} \quad (3)$$

where NIR_{WV2} (860–1040 nm), RED_{WV2} (630–690 nm) and $BLUE_{WV2}$ (450–510 nm) are the WorldView-2 bands employed in the calculation.

The EVI was selected to show that vegetation indices other than CRSI can be used to assess soil salinity, provided they reflect plant status at the target location. The multitemporal maximum EVI map (fig. 5A) from the three WorldView-2 images is visually similar to the ground-truth salinity map (fig. 5B). The two maps are negatively correlated, with a coefficient of determination (R^2) of 0.45 (fig. 5C).

Both maps were resampled to coarser resolutions (or block support) to study the changes in the strength of their relationship. As shown in figure 5D, the strength of the salinity-EVI relationship increases as block support decreases. In particular, the scaled explained variance (sEV) and the strength of spatial correlation (see Box 2 for definitions) increase to a maximum at block support of 20 meters (~ 21.8 yards), then steadily decrease as the resolution becomes coarser. The strength of the salinity relationship with EVI at the Landsat block support (30 meters, ~ 32.8 yards) was similar to that at 20 meters, indicating that it could properly represent the salinity spatial patterns at this site, despite being slightly coarser than ideal.

Remote sensing of orchard salinity

Scudiero et al. (2015) focused their research on fields cultivated with annual crops. Their model cannot be applied to orchards, especially young orchards (< ~ 10 years old). Young orchards have little or no within-row or between-row canopy cover; consequently, the vegetation coverage within a Landsat pixel is low. As an example, figure 6A shows a young 150-acre (60.7-hectare) almond (*Prunus dulcis* Mill.) orchard in Kern County. At this site, within the selected ETM+ pixel (fig. 6A), the vegetation coverage is low. Soil was sampled at this site at 24 locations in 2013. Figure 6B shows that the remote-sensing model produced overestimates of the salinity at the site. This inaccuracy is likely due to the low canopy coverage. Bare soil reflectance within ETM+ pixels would lower the CRSI values, producing high salinity estimations.

Given the extent of land farmed with tree crops, future research should focus on developing a remote-sensing model that accounts for partial canopy coverage at these locations. NAIP images could be used to assess the spatial coverage of the tree canopies (and possible presence of cover crops) in order to scale the values of the Landsat vegetation indices to adjust for bare soil reflectance.

Salinity mapping and management

Since the early 1950s, irrigation has played an important role in improving the quality of WSJV soils. As an example, the long-term change in soil salinity for western Fresno County is discussed by Schoups et al. (2005). Schoups and colleagues found that long-term

Box 2.
Quantifying strength of relationships at different spatial resolutions

The variance of a map decreases when it is resampled to coarser resolutions. To compare the relationships between two maps at different resolutions, the coefficient of determination (R^2) is not an ideal tool. Indeed, two R^2s are comparable only if they refer to the same sample (same variance), which is not the case for maps at different resolutions.

There are two alternative ways of assessing relationships at different scales. The first is using the scaled explained variance: the ratio between variance of predicted salinity at the modeled resolution and variance of observed salinity at the highest resolution. The second is using the cross-covariogram sill: the amount of variance that can be obtained in a prediction (e.g., predicted salinity) by using an explanatory variable (e.g., satellite vegetation index). Practically, the larger the absolute value of the cross-covariogram sill, the stronger the spatial correlation between the studied variables. The cross-covariogram sill is obtained by calculating the theoretical cross-covariance function (Goovaerts 1997) between two spatial variables.

A saline-sodic pistachio orchard near Lemoore showing salt crust present in early winter. Remote-sensing predictions of root zone salinity showed excellent correspondence with the presence of salt crusts.

irrigation helped reduce soil salinity across western Fresno County throughout the second half of the 20th century. When irrigation stops, there is a risk that these trends will reverse and that salinity will rapidly increase in lands with shallow groundwater, as observed in the long-term study of Corwin (2012).

Reduced water allocations have caused farmers to use potentially higher salinity groundwater in place of lower salinity surface water and to fallow fields during the ongoing drought. According to the CropScape database, during the drought, fallow land in WSJV increased from an average of 11.8% during the years 2007 to 2010 to 19.2%, 21.0%, 21.6%, 25.9% and 33.7% through the years 2011 to 2015. Land fallowing could lead to increases in root zone salinity, thereby potentially negatively affecting future crop growth in the WSJV (Corwin 2012). When reducing water allocations to farmland, the risks of quick land salinization should be considered.

Updated regional-scale inventories of salinity will provide information for better water management decisions to support statewide agriculture and preserve soil productivity, especially in years of drought, when water resources are limited. With water shortages and droughts likely to become longer and more frequent in the future (Barnett et al. 2008; Cayan et al. 2010), threats from increasing soil salinity are also likely to become more severe and should, therefore, be given serious consideration by landowners, water district managers, and federal, state and local agencies.

Individual soil salinity maps such as presented in this paper can help landowners and water district managers select land they wish to retire or convert to other uses (e.g., solar energy production). But a much greater benefit would be realized if a soil salinity remote-sensing program were established in which maps were created every 5 to 10 years for salinity-affected areas of statewide importance, including the Central and Imperial Valleys. Such a remote-sensing program would allow for the first-time monitoring of soil salinity at regional and state levels, would permit new understandings of drivers and trends in agricultural soil salinity and would aid in the development and assessment of mitigation strategies and management plans. CA

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Forage seeding in rangelands increases production and prevents weed invasion

In a seeding study in the California foothills, annual ryegrass and soft brome performed well in the short term, and Flecha tall fescue, several hardinggrass varieties and Berber orchardgrass worked well in the long term.

by Josh S. Davy, Katherine Dykier, Tony Turri and Elise Gornish

Abstract

Increasing forage productivity in the Sierra foothill rangelands would help sustain the livestock industry as land availability shrinks and lease rates rise, but hardly any studies have been done on forage selections. From 2009 to 2014, in one of the first long-term and replicated studies of seeding Northern California's Mediterranean annual rangeland, we compared the cover of 22 diverse forages to determine their establishment and survivability over time. Among the annual herbs, forage brassica (*Brassica napus* L.) and chicory (*Cichorium intybus* L.) proved viable options. Among the annual grasses, soft brome (*Bromus hordeaceus*) and annual ryegrass (*Lolium multiflorum*) performed well. However, these species will likely require frequent reseeding to maintain dominance. Long-term goals of sustained dominant cover (> 3 years) are best achieved with perennial grasses. Perennial grasses that persisted with greater than 50% cover were Berber orchardgrass (*Dactylis glomerata*), Flecha tall fescue (*Lolium arundinaceum*) and several varieties of hardinggrass (*Phalaris aquatica* L., Perla koleagrass, Holdfast, Advanced AT). In 2014, these successful perennials produced over three times more dry matter (pounds per acre) than the unseeded control and also suppressed annual grasses and yellow starthistle (*Centaurea solstitialis* L.) cover.

California's foothill rangelands are an important source of fall, winter and spring forage for grazing livestock. Though the rangeland acreage represents a major component of California's land area, it is declining. The California Department of Conservation reports dryland farming and grazing acreage losses averaged nearly 54,000 acres per year from 1984 to 2010 (CDC 2014). This makes forage productivity increasingly important to help sustain livestock production in the state. Seeding of desirable plants may be a method to increase a forage base amidst shrinking land availability and increasing livestock lease rates (USDA NASS 2013). Other benefits of seeding productive grasses and herbs include reduced soil erosion (Jankauskas and Jankauskiene 2003; Malik et al. 2000), weed control (Wilson et al. 2010) and potentially enhanced soil carbon storage (Mapfumo et al. 2002).

Scarce research on seeding forage

A majority of the formal experimental research on improving nonirrigated rangeland (annual grassland, in particular) with seeded forage species in California

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Results from a 5-year rangelands study suggest that perennial grasses, including Flecha tall fescue and several varieties of hardinggrass, established well and suppressed yellow starthistle, an invasive weed. Here, yellow starthistle completely invaded the control plot (left), but not the Flecha tall fescue plot (right).

Josh S. Davy

was completed before the 1970s. It focused largely on hardinggrass (*Phalaris aquatica* L.) (Kay 1969; Love 1951; Love et al. 1953; McKell et al. 1966; Miller et al. 1953; Miller et al. 1957; Stebbins 1950). The vast majority of other forages tested during that time failed, including other species of *Phalaris*, Idaho fescue (*Festuca idahoensis* Elmer), varieties of orchardgrass (*Dactylis glomerata* L.) and tall fescue (*Schedonorus arundinaceus* (Schreb.)).

Since that time, many forage varieties and species have become available but have not been experimentally tested. Most have been tried at the ranch level with results never reported. In one of the very few recent studies, Adams et al. (1999) compared the production of the nonnative perennial Berber orchardgrass to accessions of four California native perennial grasses. Except for a site characterized by a coastal influence, they found Berber to be 50% more productive (pounds per acre) than the average of the resident native perennials. Unfortunately, this is the only published rainfed trial in California foothill rangelands documenting forage production and cover comparisons since the 1970s. As a result, land managers lack data-driven recommendations of forage species and cannot adequately assess the efficiency or cost effectiveness of seeding.

Seeding forage and weed control

In addition to increasing forage production, seeding desirable forages may also suppress or prevent weed invasions. For example, James et al. (2015) found that combining forage seeding with other management approaches resulted in higher overall control of medusahead (*Elymus caput-medusae* L.) than using conventional control methods (prescribed fire, grazing, etc.) in isolation.

Intermountain trials with pubescent wheatgrass (*Elytrigia intermedia*) seedings have also proven successful for preventing yellow starthistle (*Centaurea solstitialis* L.) invasion (Enloe et al. 2005). The authors suggest that the perennial grass's late spring and early summer growth period coincided with the water use and growth period of starthistle, and that the grass grew faster and gained competitive dominance for the limited late-season water supply. It did not appear that winter shading of emerging thistle seedlings was a competitive factor because pubescent wheatgrass lacked active winter growth, not differing in cover from the control until later in the season. Other research has found success in seeding both pubescent and crested wheatgrass (*Agropyron cristatum* (L.) Gaertn.) for weed suppression (Blank et al. 2015; Rose et al. 2001; Whitson and Koch 1998).

The utility of forage varieties in suppressing other species is likely specific to the climate in which they are grown. For example, in some cases, wheatgrasses have been shown to be ineffective in suppressing invasive annual grasses, because wheatgrasses lack winter season growth, which is needed to shade out the annual grasses (Borman et al. 1991; Roche et al. 1997).

In a maritime/Mediterranean climate in Oregon, Borman et al. (1991) reported that established stands of Berber orchardgrass were able to prevent the invasion of annual grasses. The authors noted that the perennial grass species that were most successful at suppressing annual grass invasion were those, like Berber orchardgrass, that initiated growth early in the season and continued growth through winter, causing winter shading. This contrast in the ability of different desirable grasses to maintain dominance over other plants highlights the importance of localized research to help ranchers select forages for seeding.

Seeding of a forage test plot in Paskenta (Tehama County), California. Forage productivity has become an increasingly important element in sustaining livestock production as rangeland acreage declines in California — on average, almost 54,000 acres of farming and grazing land were lost each year from 1984 to 2010.

Testing species in local conditions

Borman et al. (1991) provided insight into the ability of forages to maintain a stand once established under a controlled, ideal environment; they transplanted grasses and allowed them to fully establish prior to any pressures of weed invasion. Our interest went further by evaluating the establishment process under a more common production scenario in a Northern California Mediterranean environment.

Norton et al. (2014) demonstrated the ability of new varieties of summer-dormant hardinggrass and Flecha tall fescue to withstand significant dehydration, a factor during the rainless California summers. This highlights them as important potential forage candidates, though the specific varieties tested have not been formally evaluated in California.

Other research has provided a too broad, or not necessarily applicable to California, overview of forage variety candidates. For example, though they are commonly available in California, little is known about the long-term survivability of orchardgrass cultivars (such as Kara and Paiute orchardgrass, which are commonly marketed as dryland grasses), except for the variety Berber. Herbaceous broad-leaved species such as chicory (*Cichorium intybus* L.), forage brassica (*Brassica napus* L.) and plantain (*Plantago lanceolata* L.) have been evaluated for use as forages with varying degrees of success in Australia and the U.S. Northeast (Reed et

The annual herb Winfred forage brassica should be considered a single-season crop due to its lack of seed production.

al. 2008; Sanderson et al. 2003; Wiedenhoeft 1993) but not in California.

Up-to-date research that evaluates forage species for their ability to establish and survive in rainless summer conditions in Northern California does not exist. To address this limitation, we assessed the value of 22 types of forage for seeding, many of them not yet tested in California. We chose a group of forages that included different plant traits: native and nonnative, annual and perennial, summer dormant and winter dormant, broad-leaved species and grass species.

Two experimental sites, soil types

Trials were conducted in Paskenta, Tehama County, California, at an elevation of 725 feet, on alluvial soils. The two experimental sites were close in location but distinctly split by designations of Arbuckle and Tehama soil types (USDA NRCS 2015). Both sites were on nearly level terrain. Soil testing at the time of seeding showed organic matter and cation exchange capacity of 3.5% and 13.2 in the Arbuckle soil, and 3.9% and 22.1 in the Tehama soil, respectively. At a depth of 0 to 39 inches, the Tehama soil can store more water than the Arbuckle series (6.97 inches and 5.37 inches, respectively), due to the higher gravel content of the Arbuckle series. Both soils had a pH of 5.7. Both soils are considered extensive in the northern Sacramento Valley, making result comparisons practical to soils in foothill rangelands classified as three or higher.

The climate is Mediterranean, with mild, wet winters and rainless, hot summers. The rainfall season generally begins in late October and lasts through May. No rainfall occurs during summer months. Paskenta has a 30-year average annual rainfall of 22.8 inches, though only in one of the five study years did rainfall reach that high. Growing season (July–July) rainfall totals were 24.07 inches in 2009–2010, 21.54 inches in 2010–2011, 15 inches in 2011–2012, 16.56 inches in 2012–2013 and 13.32 inches in 2013–2014 (Prism 2016). Following the seasonal rainfall pattern, these rangelands are generally grazed as late fall, winter and spring pasture.

In 2014, the species cover in the control plot for both soil types averaged 36% medusahead, 16% yellow starthistle, 13% slender oat (*Avena barbata* Pott ex Link), 12% annual ryegrass, 6% ripgut brome (*Bromus diandrus* Roth), 6% soft chess, 4% hare barley (*Hordeum murinum* L. subsp. *leporinum* (Link) Arcang.), 1% filaree (*Erodium cicutarium* (L.) L'Hér. ex Aiton) and 1% rose clover (*Trifolium hirtum* All.).

Perennial grasses such as Flecha tall fescue produce abundant forage and also provide a more stable ground cover for a longer period than annuals. *Top*, seedling Flecha tall fescue at the end of the first growing season (May 2010); *bottom*, established Flecha tall fescue (May 2013).

Seeding the plots

The two trials were randomized complete block designs, on different soil types, with three replicates. Seeding included 22 types of perennial and annual grasses and herbs with unseeded controls (table 1). Each plot was 10 feet wide and 200 feet long.

TABLE 1. Forages, seeding rate, seeding year and plants per square foot at establishment and in 2014

Forage species, varieties	Seeding rate	Year seeded (fall)	Density in establishment year and in 2014			
			2010	2011	2012	2014
	lb/ac		Plants/sq ft (SE)			
Perennial grasses						
Orchardgrass (*Dactylis glomerata*)						
Berber	5	2009	11 (3.1)			3 (0.7)
Paiute	5	2009	14 (2.0)			0 (0)
Kara	5	2009	9 (1.1)			0 (0)
Hardinggrass (*Phalaris aquatica*)						
Perla koleagrass	4	2009	11 (1.2)			3 (0.4)
Holdfast	4	2010		4 (0.6)		2 (0.4)
Advanced AT	4	2010		4 (0.6)		2 (0.3)
Australian II	4	2010		2 (0.7)		1 (0.3)
Tall fescue (*Schedonorus arundinaceus (Schreb.)*)						
Flecha	5	2009	9 (1.1)			3 (0.5)
Intermediate/pubescent wheatgrass (*Elytrigia intermedia*)						
Rush, intermediate	15	2009	7 (1.0)			1 (0.4)
Luna, pubescent	15	2010		4 (0.6)		1 (0.4)
Tall wheatgrass (*Thinopyrum ponticum*)						
Alkar	15	2010		6 (4.4)		1 (0.3)
Crested wheatgrass (*Agropyron cristatum*)						
Nordan	15	2010		1 (0.4)		0 (0)
Hycrest	15	2012			0 (0)	0 (0)
Douglas	15	2012			0 (0)	0 (0)
Green wheatgrass (*Elymus hoffmannii*)*						
Saltlander	15	2012			0 (0)	0 (0)
Blue wildrye (*Elymus glaucus*)						
Anderson	15	2010		4 (0.9)		3 (0.4)
Grazing brome (*Bromus stamineus*)						
Gala	25	2009	8 (0.5)			0 (0)
Annual grasses						
Annual ryegrass (*Lolium multiflorum*)						
Gulf	15	2009	9 (0.8)			7 (0.9)
Soft brome (*Bromus hordeaceus*)						
Blando	15	2009	13 (1.8)			5 (1.8)
Herbs						
Chicory (*Cichorium intybus*)						
Grouse	2	2009	5 (1.1)			0 (0)
Plantain (*Plantago lanceolata*)						
Tonic	5	2009	8 (1.2)			0 (0)
Forage brassica (*Brassica napus*)						
Winfred	5	2009	12 (1.6)			0 (0)

* Hybrid between Eurasian bluebunch wheatgrasses (*Pseudoroegneria strigosa*) and quackgrass (*Elymus repens*).

Plots were seeded in early December using an 8-foot-wide Truax Flex II grass drill (Truax Co., New Hope, MN) with an 8-inch row spacing. Seeding rates were based on the recommendations of seed suppliers (table 1). Prior to seeding, weeds were controlled with applications of glyphosate at 2 pints per acre (Roundup WeatherMax, 1.125 pounds acid equivalent per acre). All plots seeded with grasses (but not herbs) were sprayed in late February after seeding with a combination of 2 pints per acre of 2,4-D (Weedar 64, 0.95 pound acid equivalent per acre) and 1 ounce per acre of carfentrazone (Shark EW, 0.015 pound active ingredient per acre) to control broad-leaved weeds in the seeding year only. The herbicides eliminated all broad-leaved weed competition from the grass plots during their seedling year. Since all the plots were in a large pasture with a high proportion of both broad-leaved and annual grass weeds, reinvasion potential was uniform across treatments and soil types.

The perennial forages that survived were generally fully established in the second season after seeding. Perennials were considered established when they could not be manually pulled from the ground. Annual forages were considered established in the spring following seeding. Twelve species were seeded in 2009, seven more varieties became available and were seeded in 2010, and three more were seeded in 2012 as they became available.

Cover, productivity data collection

Annual spring basal cover data was collected at peak standing crop, generally in early June. A total of 10 square-meter quadrats per replication were marked out at intervals of 15 feet, in the center of each plot to reduce edge effects. Quadrat measurements included percentage basal cover estimates of seeded species, nonseeded species and bare ground. In 2014, we added measurements of annual grass and yellow starthistle (*Centaurea solstitialis* L.) cover, and we recorded the entire species composition of the control plots. At the center of each square-meter quadrat, the number of seeded plants in a 1-square-foot quadrat were counted.

In 2010 and 2012, production of the seeded forage plants (not of any other plants present) was measured in each 1-square-foot quadrat using the comparative yield method (George et al. 2009). In 2014, production was measured in every other 1-foot-square quadrat, for a total of five quadrats per replication, with the intention of determining smaller differences in biomass between forages. Again, only the seeded species in each quadrat was clipped and weighed. In the control plots, in both cases, all species were included in production measurements. Samples were weighed and recorded after being oven dried at 130°F for 36 hours. Final weights were recorded when samples were considered fully dry, the point at which weights no longer continued to decrease with drying.

Grazing periods

All plots were grazed annually, toward the end of the dormant summer season to prevent thatch buildup. Grazing was completed concurrently on each site using 15 nonlactating beef cows for 2 to 5 days depending on the amount of forage present in each plot. Grazing ceased when forage was estimated to be approximately 500 pounds per acre dry matter during each event. Since grazing continued until all plots were grazed to a uniform level, estimates of animal preference for particular forages was not credible, but equal comparisons of forage persistence after grazing were possible because they were all grazed equally.

In 2011 and 2013, all plots were flash grazed in late winter and again in spring prior to data collection, so we did not measure forage production in those years. In these two seasons, grazing ceased 30 to 45 days before cover monitoring to allow potential seed production of annuals, as well as perennial plant recovery and survival of the summer dormant season (Cullen et al. 2005; Ogden and Loomis 1972). Grazing the plots during the growing season allowed us to evaluate their resilience to grazing, which is an important component in their potential applicability to improve grazed rangelands.

Data analysis

Because cover data was collected systematically each year (and the production data in only two of the years), we focused our analysis on the cover data. We started with a generalized linear mixed model (GLMM, Poisson distribution) to investigate the contribution of species variety and soil type (Arbuckle and Tehama) on percentage cover. To address differences in environmental conditions across seeding years, varieties seeded in 2009 and 2010 were analyzed using different models. Varieties seeded in 2012 failed to establish and were thus excluded from further analysis. The model for species seeded in 2009 included the fixed factors of seeded variety, life cycle (annual or perennial) and soil type, as well as random factors subplot ($n = 10$) nested in replicate ($n = 3$) and year monitored (to account for repeated measures).

Results from the 2009 variety model suggested that data describing annuals and perennials should be investigated separately. Subsequently, we developed two models on the 2009 seeded species data — one for annual species only and one for perennial species only. Each of these models included the fixed factors of seeded variety, year monitored and soil type, as well as random factors subplot nested in replicate. The model for species seeded in 2010 included the fixed factors of seeded variety, year monitored and soil type (only perennial species were seeded in 2010, so we did not need to include life cycle as a factor), as well as random factors subplot nested in replicate.

In the field, it is sometimes suggested by range professionals and ranchers that the percentage of bare ground, rather than weed cover, most affects perennial grass spread (i.e., greater cover) or establishment. To understand the strength of the relationship between percentage cover of forage species and bare ground and between percentage cover of forage species and weeds, we conducted correlation tests. The data was again separated by year seeded (2009 or 2010) and, within 2009, by life cycle (annual and perennial). All analyses were conducted in R version 3.2.2 using the lme4 package (R Development Core Team 2008).

Results

Soil type did not contribute to significant differences in cover across varieties seeded in 2009 ($p = 0.25$) or for varieties seeded in 2010 ($p = 0.12$). However, some varieties demonstrated idiosyncratic differences in cover in response to the different soil types through time. For example, the orchardgrasses Berber and Paiute both demonstrated significantly lower cover on Tehama soil than on Arbuckle soil (a 15% difference in cover for Berber and a 28% difference in cover for Paiute). There was also no difference between the cover of annuals (mean cover = 40.73%, SE = 12.8) and perennials (mean

Established Berber orchardgrass (May 2013). By 2014, the Berber grass plot was almost 3 times more productive than the unseeded control plot. In addition, of the three orchardgrass varieties tested, only Berber survived the hot, dry summer.

Tonic plantain, a perennial herb, at the end of the first growing season. Trial results suggest that the herb species are best utilized as short rotations before another crop or when high quality forage is needed for the short term.

Gulf annual ryegrass established vigorously during its seeding year (April 2010).

cover = 36.19%, SE = 12.02) seeded in 2009 across soil types (p = 0.10).

The cover of all three annuals declined through time (fig. 1; estimate = −0.18, SE = 0.006, $p < 0.001$). Both annual ryegrass (mean cover = 57.33%, SE = 10.65) and Blando brome (mean cover = 36.06%, SE = 12.58) demonstrated significantly higher cover than Winfred forage brassica (mean cover = 28.28%, SE = 13.22) through time, likely because they have the ability to produce seeds. Only annual ryegrass showed significantly lower cover on Tehama soil (mean cover = 51.17%, SE = 11.71) than on Arbuckle soil (mean cover = 63.51%, SE = 9.10; estimate = −0.22, SE = 0.03, $p < 0.001$).

Fig. 1. Mean percentage cover (%) ± SE of annual forage species by soil type.

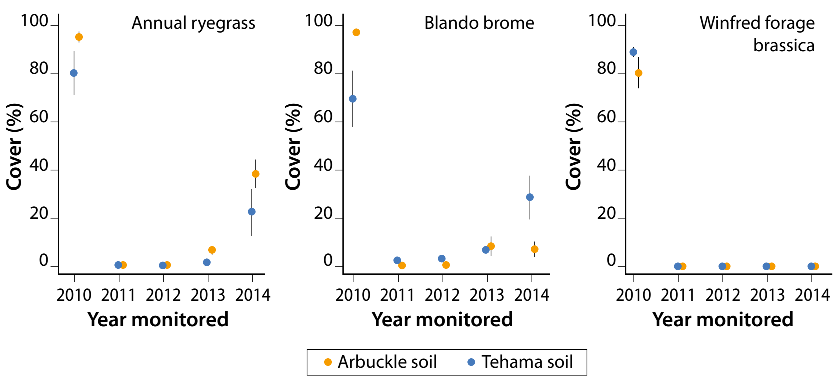

TABLE 2. Production (lb/ac dry matter) of seeded forages, 2010 and 2014, and of all species in the control plots, 2014

Forage species, varieties	Dry matter 2010	Dry matter 2014
	lb/ac (SE)	
Gala brome	1,416 (172)	0 (0)
Grouse chicory	1,188 (277)	0 (0)
Winfred forage brassica	1,802 (300)	0 (0)
Blando brome	2,590 (458)	394 (309)
Annual ryegrass	8,669 (772)	2,870 (481)
Nordan crested wheatgrass	NA*	0 (0)
Tonic plantain	NA	0 (0)
Paiute orchardgrass	NA	0 (0)
Kara orchardgrass	NA	0 (0)
Control		**1,596 (266)**
Luna pubescent wheatgrass	NA	1,725 (587)
Rush intermediate wheatgrass	NA	2,514 (788)
Australian II hardinggrass	NA	2,538 (910)
Anderson blue wildrye	NA	3,047 (891)
Berber orchardgrass	NA	4,369 (1,219)
Alkar tall wheatgrass	NA	4,572 (1,160)
Perla koleagrass (hardinggrass)	NA	4,970 (808)
Holdfast hardinggrass	NA	5,155 (954)
Flecha tall fescue	NA	5,302 (963)
Advanced AT hardinggrass	NA	6,366 (1,729)

* Not harvested, due to inadequate readiness for grazing at the time of monitoring.

Although most perennial varieties seeded in 2009 decreased in cover through time (fig. 2), several hardinggrass varieties, including Perla koleagrass (estimate = 0.199, SE = 0.02, $p < 0.001$), and Flecha tall fescue (estimate = 0.21, SE = 0.02, $p < 0.001$) either maintained or increased cover through time. The varieties that performed the best in the short term (i.e., between 1 and 3 years after seeding), which included Gala brome (mean cover = 78.05%, SE = 5.5), Grouse chicory (mean cover = 79.85%, SE = 8.1) and Tonic plantain (mean cover = 79.8%, SE = 7.7), were unable to maintain cover well. The varieties that demonstrated the best cover for multiple years were Berber orchardgrass (mean cover = 58.3%, SE = 10.3), Flecha tall fescue (mean cover = 57.48%, SE = 10.6) and Perla koleagrass (mean cover = 65.03%, SE = 9.3).

Although the overall cover of varieties seeded in 2010 did not change through time (estimate = −0.07, SE = 0.10, p = 0.48; fig. 2), some varieties, such as Advanced AT (estimate = 0.18, SE = 0.01, $p < 0.001$), did increase in cover through time. We also found that varieties seeded in 2010 demonstrated idiosyncratic differences in cover in response to the different soil types. For example, Advanced AT (estimate = 0.18, SE = 0.02, $p < 0.001$) and Australian II hardinggrasses (estimate = 0.44, SE = 0.04, $p < 0.001$) consistently demonstrated better cover on the Tehama soil through time (fig. 2). Although Luna pubescent wheatgrass was the forage that performed best in the short term (mean cover = 50.8%, SE = 6.05), Holdfast hardinggrass performed the best overall (mean cover = 51.9%, SE = 10.7).

As might be expected, forage production (table 2) was positively correlated with percentage cover for both annual (r = 0.53, t = 9.29, $p < 0.001$) and perennial forage species (r = 0.61, t = 33.86, $p < 0.001$). Average invasive annual grass and yellow starthistle cover also differed among the forage seeding treatments (tables 3 and 4). For forage annuals seeded in 2009, there was a negative correlation between bare ground and forage cover (r = −0.49, t = −9.43, $p < 0.001$), as well as between weed cover and forage cover (r = −0.66, t = −9.48, $p <$ 0.001). For forage perennials seeded in 2009 and 2010, there was a negative correlation between bare ground and forage cover (2009 r = −0.41, t = −7.85, $p < 0.001$, and 2010 r = −0.12, t = −2.48, p = 0.01), as well as between weed cover and forage cover (2009 r = −0.84, t = −26.93, $p < 0.001$, and 2010 r = −0.82, t = −29.53, $p <$ 0.001).

Clear differences in cover, production

We considered a forage variety successful if it produced a stand of 50% ground cover, thus expressing its relative dominance over all other species. Clear differences were obvious in the performance of annual vs. perennial forage varieties in providing forage (cover and production) from a single seeding in the short term (1 to 3 years) and long term (> 3 years). To maintain the stand of any of the seeded annuals in the trial, even the reseeding varieties, we suggest resowing within a few years, which has been suggested elsewhere (Papanastasis 1976).

Performance of annual grass species

Because the annual grass varieties Blando brome and Gulf annual ryegrass provided high cover and production quickly, they appear to be good candidates for forage in the year they are seeded (fig 1., table 2). Blando brome does not appear to be as productive as annual ryegrass.

Though a robust stand in terms of cover never occurred from annual ryegrass reseeding, as a volunteer stand in subsequent years, annual ryegrass cover in the seeded plots was double the annual ryegrass cover in the control and produced 1,274 pounds per acre dry matter in 2014 (2,870 pounds per acre vs. 1,596 pounds per acre dry matter, table 2). Although both annual grasses in the trial were capable of producing seeds for germination in subsequent years, sustained cover after the seeding year was unreliable, difficult to differentiate from the natural seedbank and always below our target of a dominant stand that exceeds 50% cover.

Performance of herb forage species

The annual herb Winfred forage brassica produced a robust stand in the year of seeding but should be considered a single-season crop due to its lack of seed production. We would not expect this forage to have enough time to mature and produce seeds in a dryland situation.

Perennial herbs Tonic plantain and Grouse chicory established well the first year, with some plants surviving into the second season. Although the surviving second-year plants looked healthy early in the season, almost no plants were evident in the third season. When the surviving herbs were grazed in the second season (2010–2011), they did not appear to recover and regrow, which made us speculate that the herbs were best suited to a single-harvest situation. The herb species appear to be options for a short rotation before another crop, or when a high-quality source of forage is needed for the short term.

Performance of perennial forage species

None of the perennial forage varieties investigated in this study established fast enough to be grazed in their seedling year. In management scenarios, perennial grass forage production should be considered zero in the first year, as stands appear to be easily damaged by grazing during establishment. This could be due to the slow growth rate of seedling perennials compared to

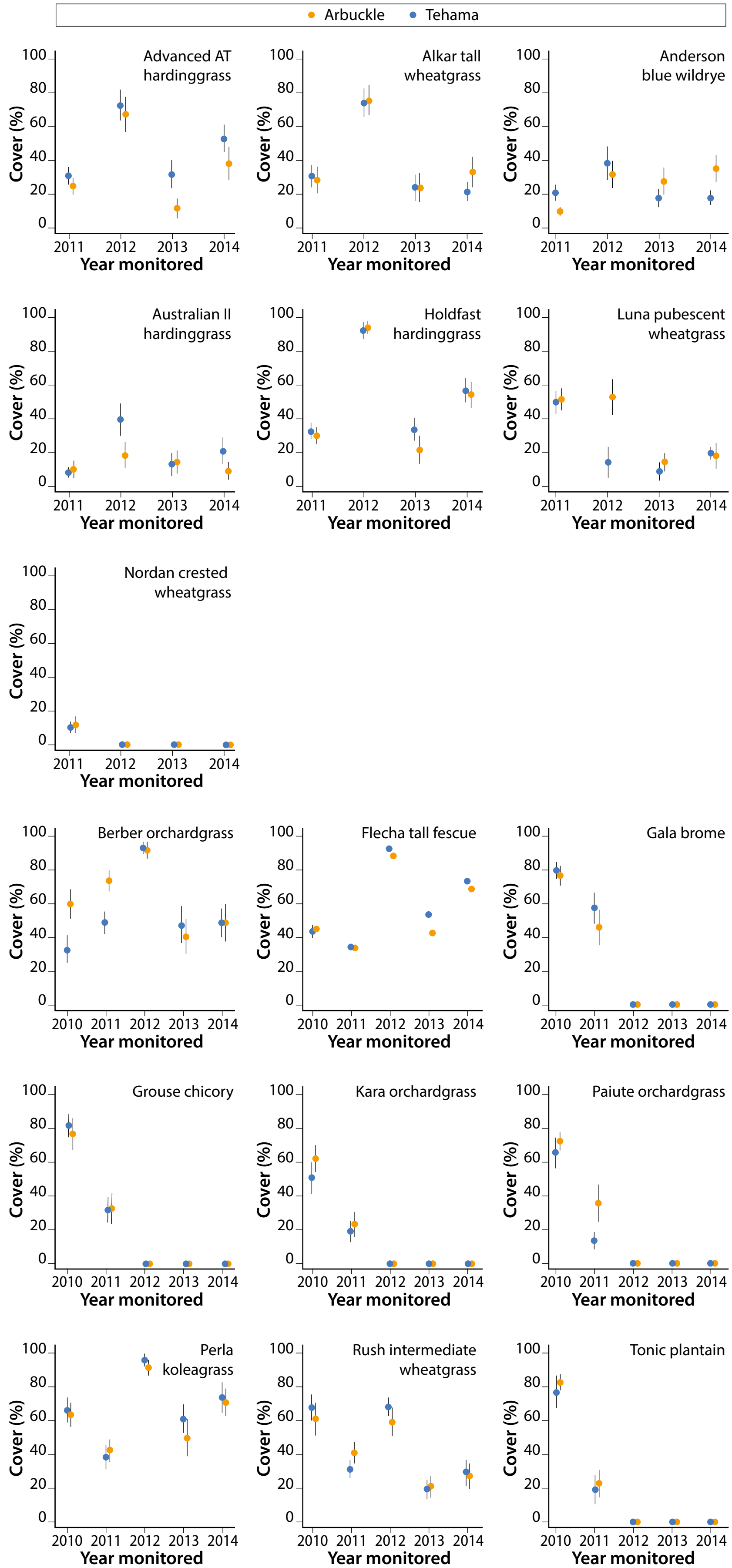

Fig. 2. Mean percentage cover (%) ± SE through time of perennial forage species seeded in 2009 and 2010 by soil type.

Holdfast hardinggrass, a perennial developed in Australia, proved to be a viable replacement for Perla koleagrass if Perla seeds are not available.

The six top-producing perennial grasses ranged from nearly three (Berber orchardgrass) to four (Advanced AT hardinggrass) times more productive than the unseeded control.

seedling annuals (Garnier 1992), which causes seedling perennials to be easily uprooted prior to establishment. Although withholding grazing the first year of a perennial seeding will enhance establishment, the loss of a season of grazing incurs a substantial cost (USDA NASS 2013) and must be considered in ranch planning.

If the grazing deferment period can be tolerated, perennial grasses provide a more stable ground cover for a longer period than annuals. They also produce abundant forage. In 2014, the six top-producing perennial grasses ranged from nearly three (Berber orchardgrass) to four (Advanced AT hardinggrass) times more productive than the unseeded control (table 2). We found this increased forage production particularly impressive because, unlike the sampling in the control, which included weighing all plants in the quadrat, sampling of the seeded quadrats included only the weight of the seeded forage species, and excluded all other species.

Most perennial seedings looked successful at the completion of the seedling year, but they did not all survive the first summer. Although we did not quantify summer dormancy, we assumed failed forages did not exhibit enough summer dormancy to survive, in contrast to those that successfully maintained a stand into the second year. For example, the failure of Paiute orchardgrass (fig. 2) was unexpected because it appeared to have good seedling vigor and has been recommended for seeding in semi-arid dryland situations (Monsen and Stevens 1985). Of the three orchardgrass varieties tested, only Berber survived the hot, dry summer of this California foothills region. Likewise, though Gala brome is considered a perennial species for drought areas (Stewart 1992), individual plants did not survive their first summer. Gala did produce an abundance of seeds, giving it the capacity to regenerate a stand in the short term (second year only).

Like Norton et al. (2006), we found that Flecha tall fescue displayed enough summer dormancy to survive the rainless summer. To our knowledge, this is the first test of Flecha tall fescue in California, though it has been tested in the Southern Great Plains (Malinowski et al. 2005). Results from our study suggest that Flecha fescue appears to be highly productive, producing 3.3 times more forage than the unseeded control. It should be considered a viable candidate for improving California rangelands if a perennial grass is desired.

We found all of the hardinggrass varieties adequately adapted for summer survival, with seedings of Perla koleagrass, Advanced AT and Holdfast all successful and highly productive. Even though Australian II did not produce the 50% ground cover we considered necessary for a successful stand, the stand remained stable after the first year (fig. 2), though it did not produce any more forage than the unseeded control in 2014. Perla koleagrass was developed in California by the California Agricultural Experiment Station and USDA (USDA SCS 1985), which has made it the most commonly planted cultivar of hardinggrass, although seed is not available every year. In the absence of adequate Perla koleagrass seed, Australian-bred varieties Holdfast and Advanced AT appear to be viable replacement options.

The only native perennial grass tested was Anderson blue wildrye. The blue wildrye stand had the same number of plants per square foot in 2014 as Perla koleagrass, Berber orchardgrass and Flecha tall fescue (table 1), but it never reached our target of 50% cover of the seeded forage (fig. 2). This could be due to its upright (rather than bunching) growth habit. Blue wildrye plants survived well; however, we are not confident in the ability of blue wildrye, seeded alone, to suppress weed invasion, especially compared to the other perennials, which were able to sequester more ground cover (table 3). Blue wildrye produced significantly less forage than the top six nonnative perennial grasses; however, it still produced nearly double the amount of forage as the control in 2014 (3,047 pounds per acre compared to 1,596 pounds per acre dry matter, respectively; table 2).

The utility of wheatgrass varieties for forage is limited by their season of growth. Unlike the results from trials in higher elevation areas (Enloe et al. 2005), results from our study in California foothill rangelands suggest that wheatgrass varieties should not be used for short- or long-term forage cover. Only Alkar tall, Luna pubescent and Rush intermediate wheatgrasses even produced initial stands, and these declined once grazed. Of all the perennial wheatgrasses seeded, only Alkar tall produced more forage than the unseeded control in 2014, which we attribute to a relatively high dry matter weight of individual plants because the stand lacked robust cover.

Seeding of crested wheatgrass varieties failed to produce a single successful stand. We suspect that their late spring and early summer growing season did not match this climate. It is likely that moisture was limited during early summer, at their peak growth phase. They germinated, but the plants failed to survive the first summer. Borman et al. (1991) documented that the lack of fall and winter growth of crested wheatgrass varieties makes them highly susceptible to annual grass invasion (table 3). In accordance with findings by Borman et al. (1991), we found the most successful perennial grasses commenced growth early in the fall, continued through winter and peaked in late spring.

TABLE 3. Invasive annual grass cover (%) in established perennial plots, 2014

	Average annual grass cover	
Forage species, varieties	%	*SE*
Perla koleagrass	22	7.7
Flecha tall fescue	22	8.7
Holdfast hardinggrass	35	7.1
Berber orchardgrass	37	10.0
Advanced AT hardinggrass	48	10.0
Rush intermediate wheatgrass	52	8.7
Alkar tall wheatgrass	58	9.0
Anderson blue wildrye	70	7.7
Luna pubescent wheatgrass	72	8.1
Australian II hardinggrass	73	8.1
Control	**78**	**8.7**

TABLE 4. Yellow starthistle cover (%) in forage plots, 2014

	Yellow starthistle cover	
Forage species, varieties	%	*SE*
Holdfast hardinggrass	0	0
Flecha tall fescue	0	0
Berber orchardgrass	0	0
Perla koleagrass	0	0
Australian II hardinggrass	0.10	0.10
Rush intermediate wheatgrass	0.10	0.20
Advanced AT hardinggrass	0.10	0.23
Anderson blue wildrye	0.25	0.61
Luna pubescent wheatgrass	0.33	0.65
Alkar tall wheatgrass	0.50	0.71
Blando brome	7.00	5.87
Annual ryegrass	11.90	6.71
Control	**15.50**	**5.00**

Ability of forage seedings to prevent weed invasion

Perennial grasses differed in their ability to prevent the invasion of annual grasses. During the 2014 season, we monitored the percentage cover of annual grasses that had encroached into the perennial plots (table 3). No seeded forages entirely prevented annual grass invasion, but several clearly limited invasion. Annual grass invasion into perennial grass plots ranged from 22% to 73% of the plot area. Surprisingly, invasion of annual grasses into established perennial grass stands was not largely different from, and even slightly less than, recorded by Borman et al (1991). For example, our annual grass invasion into Berber orchardgrass was 37% compared to their 44%, and into tall wheatgrass it was 58% compared to their 65%. We found this very encouraging in terms of the success of our seeding in a production environment that was far less optimal than the transplanting method used in the Borman et al. (1991) study.

In 2014, we also recorded yellow starthistle cover. Of particular interest was the ability of all perennial forage species to suppress yellow starthistle (table 4), including those that showed almost no suppression of annual grass invasion. Yellow starthistle cover was nearly zero in all of the established perennial grass plots even though the abundance of yellow starthistle around the plots made the opportunity of invasion clearly evident. Gulf annual ryegrass and Blando brome were not as successful at preventing yellow starthistle invasion, which was significant because they had been seeded in the same manner as the perennial grasses, creating an equal comparison to evaluate resistance to invasion. This data suggests that seeding perennial grasses, rather than annual grasses, is a viable management approach to controlling yellow starthistle in Northern California's Mediterranean climate.

Effect of soil type

In these trials, soil type had little effect on overall production and cover, suggesting that although the two soil types differed in available water storage, both were adequate for growth of annual and perennial forages. This was unexpected because different soils are typically characterized by dissimilar moisture, chemical and mycorrhizal content, which can directly affect forage production (e.g., Bennett and Doss 1960; Lambert and Cole 1979). However, because we did identify some variety-specific soil responses, further research in annual rangeland systems that tests these forage species in different soil types, including shallower soils, would be of value.

Short- and long-term recommendations

Life cycle (annual or perennial) should be the primary consideration in determining suitable forage choices for either the short or long term. It is not recommended to seed perennial and annual grasses simultaneously. However, if the addition of annuals is desired, sowing them after the perennial grasses are established would ensure the perennials are not outcompeted during the seedling stage (Lodge 2000).

In cases where short-term forage production and weed suppression are management priorities, this work suggests that annual ryegrass and/or soft brome are the most viable options. For longer-term production without reseeding, best forage candidates are mostly perennials, including Flecha tall fescue, hardinggrass (Perla koleagrass, Holdfast, Advanced AT) or Berber orchardgrass, as a mix or a monoculture. CA

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RESEARCH ARTICLE

Cow cooling on commercial drylot dairies: A description of 10 farms in California

A study of 10 California drylots on summer afternoons found diverse heat abatement strategies in place and a wide range of cow respiration rates.

by Grazyne Tresoldi, Karin E. Schütz and Cassandra B. Tucker

Abstract

California summers are hot, compromising the welfare and productivity of dairy cows. To minimize negative effects, producers use shade, fans and sprayed water. However, little is known about how those heat abatement strategies are provided in commercial conditions, nor their effectiveness. Ten dairies with drylots, a common housing system in California, were assessed for strategies provided, and the cows' responses to heat load were observed for 3 days in the afternoon. Dairies were diverse in all aspects. Shade varied in terms of placement (at corral and feed bunk or at corral only) and amount (28 to 74 square feet, or 2.6 to 6.9 square meters, per cow). The quantity of water used to spray cows ranged from 0 to 6.8 gallons (0 to 25.6 liters) per hour per cow. Across dairies, there was a range in the cows' shade use (47% to 98% of herd) and feeding activity (7% to 33% of herd). Respiration rates ranged from 65 (normal) to 95 breaths per minute (very hot) and were positively related to inactivity. Our results indicate that there are opportunities to improve cooling, and consequently dairy cattle welfare, in drylots.

Milk is the most valuable agricultural commodity produced in California, the top dairy-producing state in the country (Sumner et al. 2015). In the western United States, 30% of dairy farms keep about 1.8 million lactating cows in drylots (open, dirt-based pens), where sheltered areas may or may not be available (USDA 2016). Drylots are thought to be advantageous, in comparison to other intensive housing systems (e.g., free-stalls, concrete-floored pens where cows have access to lying areas that are sheltered), because of lower disease prevalence (e.g., lameness and mastitis), better reproductive outcomes (USDA 2010) and lower capital costs (Stokes and Gamroth 1999). Despite the benefits, though, drylots are located mostly in arid areas, where heat load can compromise the profitability and the welfare of cows, especially during summer months.

Heat load reduces cows' feed intake and milk production; reduces fertility; and leads to increased culling and mortality rates (St-Pierre et al. 2003; Stull et al. 2008). Together, these factors cost California dairies over $118 million a year (St-Pierre et al. 2003). This

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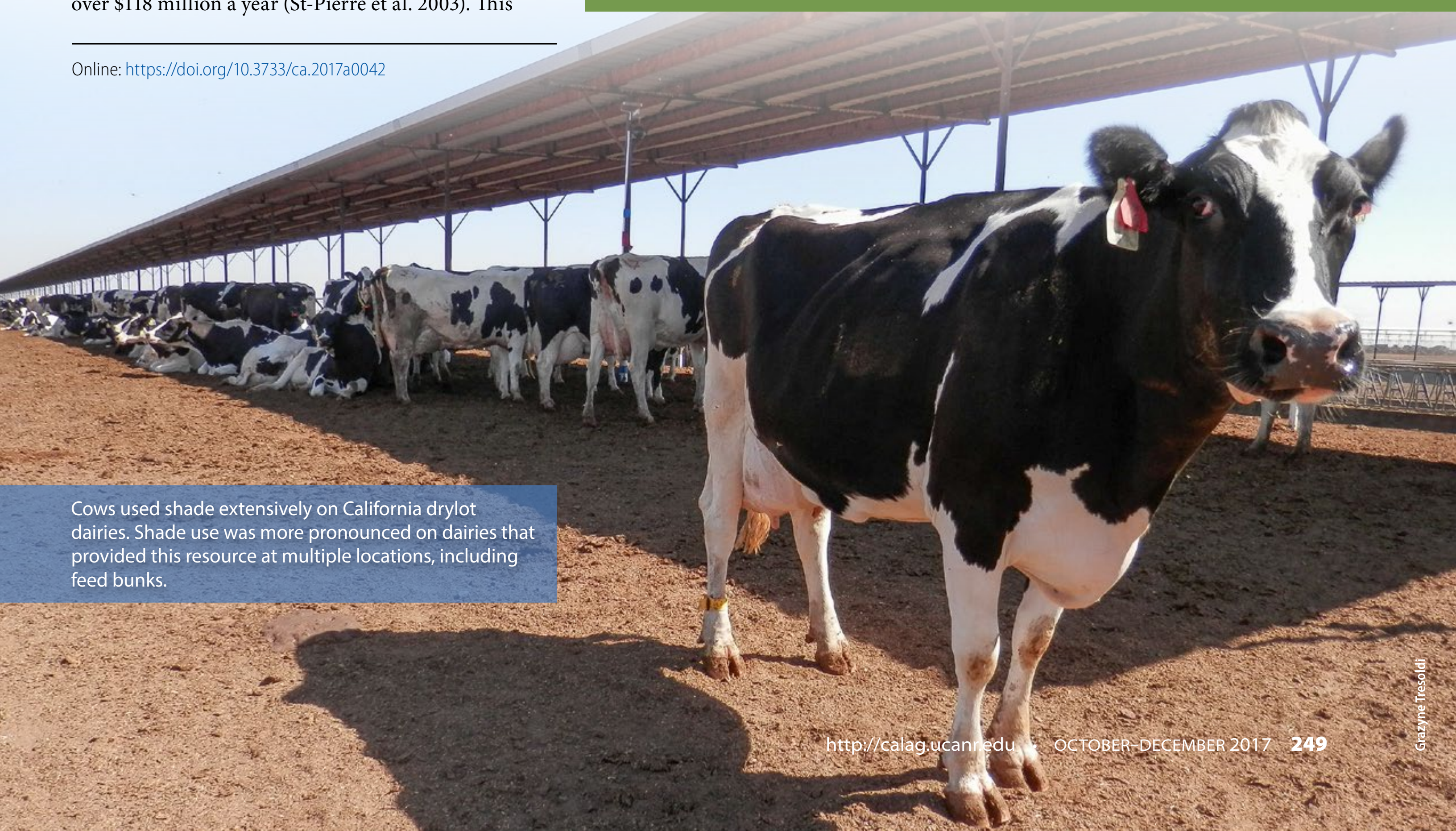


Cows used shade extensively on California drylot dairies. Shade use was more pronounced on dairies that provided this resource at multiple locations, including feed bunks.

Grazyne Tresoldi

cost, moreover, may be underestimated since it does not account for the potential effects of heat load on animal health (e.g., lameness). The cost may be higher on some farms, depending on heat load management strategies adopted and specific environmental conditions (Stull et al. 2008; Urdaz et al. 2006). For example, milk production was reduced when fewer cooling strategies were provided to cows in their home pen (Urdaz et al. 2006).

The negative effects of hot weather can be minimized by providing cows with heat abatement. Shade, fans and sprayed water effectively reduce physiological changes associated with heat load in dairy cows, such as respiration rate and body temperature (Correa-Calderon et al. 2004), and they also cause behavioral changes, such as time spent near water troughs (Schütz et al. 2010).

Although shade, fans and sprayed water are commonly used on commercial dairies (USDA 2010), little is known about how and in what combination they are provided, nor how well they reduce heat load in commercial dairy situations. In addition, knowing how cows respond to heat load may help us to identify when they are hot, so appropriate action can be taken. Our objectives were to describe the provision of heat abatement strategies and cattle responses during summer on California drylot dairies, and to evaluate the relationship between respiration rate and inactivity in cows.

10 dairy farms

During two summers (2013, 2014), 10 dairy farms were assessed in Fresno, Kings and Tulare counties. Farms averaged (mean ± SD) 1,525 ± 912 cows (range of 570 to 3,594) and produced 74.5 ± 5.5 pounds (33.8 ± 2.5 kilograms) of milk per day. On each farm, a pen with the highest-producing cows was selected for observation, because high-yielding cows have the greatest susceptibility to heat stress (Igono et al. 1988). Pens averaged 170 ± 64 cows (80 to 260), 134 ± 39 days in milk (68 to 189), 2.6 ± 0.5 lactations (2.1 to 3.8) and 84.7 ± 11.0 pounds (68 to 105), or 38.4 ± 4.9 kilograms (30.8 to 47.6), of milk per day.

Cows spent most of the afternoon being inactive (i.e., not engaged in any activity) in California drylot dairies. On average, less than 20% of the herd was observed feeding during this period.

Facilities, animal responses

Heat abatement resources (shade, fans, sprayed water), space, feed and drinking water provision were recorded in the housing and milking areas.

Behavioral and physiological measures were taken from the entire group of high-producing cows on each farm, and also from randomly chosen focal animals (n = 10 to 15 per dairy) within this group. Observations were conducted by two to five observers, during 3 consecutive days for 5.6 ± 0.5 hours per day (range of 5 to 6 hours), from 10:45 to 19:00 hours, excluding milking time.

Every 30 minutes, we recorded the number of cows in each location within the pen: corral shelter (underneath the roof, or its shadow, in the middle of the pen), feed bunk shelter (underneath the roof placed over the concrete apron in front of feed), water trough (within two cow body-lengths of the water source) and open area (any other area that was unsheltered). A cow was recorded as using a location when she had one hoof within it, except for open-dirt areas, where she had to have all four hooves in it.

Each high-producing group was monitored twice hourly to determine the number of animals feeding (food visible in the mouth, either chewing or gathering with lips or tongue). Every 10 minutes, focal animals were scanned for activity: feeding, ruminating (chewing without visible feed in the mouth or regurgitating), drinking (touching water in the trough with their tongue or muzzle), walking (traveling on foot), idling (not engaged in any apparent behavior) or other behaviors (e.g., grooming, social interaction).

Data loggers (Hobo Pendant G, Onset Computer Corp., Bourne, MA) were attached to the hind leg of each focal animal to determine lying and standing behaviors at 1-minute intervals (Ito et al. 2009).

Twice hourly, 10 breaths were timed by complete flank movements, then converted into breaths per minute. At the same time, the panting score of each focal cow was recorded on a scale from 0 to 4.5, as defined by Gaughan et al. (2008). Each score was then converted to one-zero sampling for presence and absence of drooling, open mouth and protruding tongue, because a more recent study has shown that some of those scores may not adequately reflect differences in respiration rate (Tresoldi et al. 2016).

To facilitate comparison among dairies, animal responses were calculated as percentage of the group, or percentage of observation times, and averaged by dairy.

All analyses were done in SAS (SAS Institute 2009) using PROC MEANS, except for the comparison between respiration rate and time idle, which was estimated using PROC REG.

Weather measures

A portable weather station (WS-16, Novalynx Corp., Auburn, CA) was placed near the highest-producing pen to record every 5 minutes these factors: air and black globe temperatures (°F), wind speed (mph, measured 8 feet, 2.4 meters, above the ground), relative humidity (%), solar radiation (W per square meter) and precipitation (inches). Temperature-humidity index (Kelly and Bond 1971) and heat load index (Gaughan et al. 2008) were also calculated. In addition, black globe temperature was recorded under the corral shelter at 10-minute intervals (HOBO U23 Pro v2 External Temperature, Onset Computer Corp., Bourne, MA).

During the observation period at seven of the 10 dairies, ground temperature in the most similar adjacent pen (chosen to avoid disturbing the behavior of the observed cows) was recorded at 30-minute intervals at the corral shade, feed bunk and open areas using an infrared thermometer (Autopro ST25, Raytek Corp., Santa Cruz, CA) held 2 feet, 0.6 meter, above the ground.

Heat abatement strategies provided

All dairies provided shade in the corral area; half of them provided shade also at the feed bunk area. The total shade provided ranged from 28 to 74 square feet (2.6 to 6.9 square meters) per cow (table 1). The quantity of shade provided has been shown to affect cows' use of shade and their physiological responses to heat load (Schütz et al. 2010; Schütz et al. 2014; Sullivan et al.

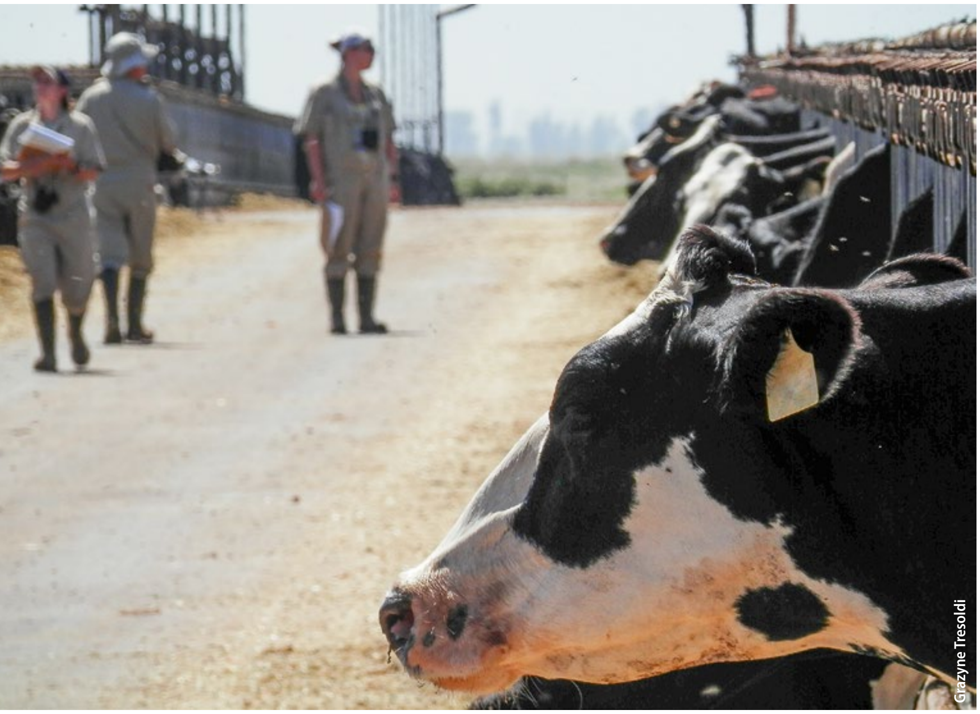
TABLE 1. Space and heat abatement strategies provided at the home pen and milking parlor on 10 California drylot dairies

	Dairy									
Housing characteristics	1	2	3	4	5	6	7	8	9	10
Group size (cows)	140	100	160	80	122	260	145	211	229	251
Pen area (acres)	1.9	1.2	2.0	1.7	1.6	3.3	1.7	2.7	3.8	1.7
Total shade area (% pen surface)	12%	5%	14%	7%	5%	7%	9%	11%	8%	22%
Feed bunk area (% pen surface)	4%	5%	4%	3%	4%	4%	4%	6%	4%	7%
Corral shade area (ft^2/cow)	48	28	49	34	30	41	31	65	59	44
Feed bunk shade area (ft^2/cow)	25	—	25	30	—	—	17	—	—	22
Total shade area (ft^2/cow)	73	28	74	64	30	41	48	65	59	66
Total shade border/cow (ft)	7.9	2.6	8.5	9.2	4.3	3.3	11.8	5.6	5.2	8.2
Feeding space (headlock/cow)	1.0	1.3	1.0	1.1	1.0	1.0	1.0*	1.2	1.1	1.0
Sprayed water delivery method†	S	S	S	—	M	S	M	S	S	S
Flow rate (gal/min)	1.2	0.3	0.6	—	0.1	0.6	0.1	1.0	0.4	0.6
Distance between nozzles (ft)	5.9	6.9	5.9	—	6.6	9.2	7.9	6.9	7.2	6.6
Ratio nozzle/cow	0.3	0.4	0.3	—	0.3	0.2	0.2	0.4	0.3	0.3
Nozzle height from ground (ft)	5.6	5.6	5.6	—	4.9	6.2	7.2	5.2	5.6	5.6
Sprinklers on (min/cycle)	1.0	2.5	2.5	—	1.0	3.5	1.0	3.3	6.0	1.5
Sprinklers off (min/cycle)	3.5	12.0	9.4	—	0	4.0	0	8.0	9.0	3.5
Sprinklers time on (min/hr)	13.3	10.3	12.6	—	60.0	28.0	60.0	17.6	24.0	18.0
Sprayed water (gal/cow/hr)‡	5.1	1.2	2.5	—	2.6	2.9	0.6	6.8	3.6	3.4
Distance from shade to feed bunk (ft)	—	31	—	—	52	54	—	57	57	—
Distance from shade to water source (ft)	0	111	3	3	30	52	3	18	25	8
Water sources (number/pen)	4	2	2	2	2	3	3	4	4	4
Water trough edge (in/cow)	8.5	4.2	2.1	3.1	2.8	2.9	3.7	6.1	4.7	3.0
Milking parlor includes a wash pen	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
Fans used at wash pen	Yes	No	Yes	No	Yes	—	Yes	Yes	Yes	No
Sprinklers used at wash pen	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	No
Fans used at holding area before milking parlor	Yes	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes

* Estimated as 1 headlock = 2 feet per cow.

† S = soaker; M = mister.

‡ Estimated using flow rate and the time water was held on within an hour, during the observation period.



Grazyne Tresoldi

As often as every 10 minutes in the warmest part of each day, observers recorded behavioral and physiological signs of heat load in dairy cows.

2011), but our sample size was not large enough to compare the effects of shade on cow cooling. In our study, the amount provided was within a narrower range than in the only other comparable work with dairy cows, a study of New Zealand pasture-based farms (Schütz et al. 2014), where a range of 0 to 178 square feet (0 to 15.6 square meters) was examined.

All dairies except one sprayed water at the feed line. Spray strategies (i.e., flow rate, number of spray cycles, etc.) were diverse and influenced the volume of potable water used by each dairy (table 1). There was an 11-fold range among the dairies in this study in estimated water sprayed per cow. Considering that these farms sprayed water for at least 6 hours a day, an average California dairy (1,000 lactating cows) may use up to 40,418 gallons (153,000 liters) of water a day to cool cattle during summer. Although the upper range of sprayed water may raise concerns about the use of potable water to cool cows, especially during drought conditions, this resource effectively reduces heat load in dairy cows (Chen et al. 2013, 2016).

No dairies offered fans in the housing area. The heat abatement strategies provided at the milking parlor varied among dairies (table 1). To our knowledge, this is the first study to describe the unique combinations of cooling strategies used on dairy farms.

TABLE 2. Averages of mean or maximum weather conditions during 24 hours and the observation period (5 to 6 hours, 10:45 to 19:00) on 10 California drylot dairies

	24 hours		Observation period	
Measure	*Mean*	*SD*	*Mean*	*SD*
Air temperature (°F)	80.6	12.2	93.5	5.2
Black globe temperature (°F)	91.5	21.0	115.3	7.0
Black globe temperature under shade (°F)	84.3	13.5	97.8	4.3
Solar radiation (W/m^2)	278	306	578	211
Relative humidity (%)	40	20	20	10
Wind speed (mph)	0.8	0.4	1.1	0.4
Temperature-humidity index	72	7	79	2
Heat load index	74	17	91	6
Maximum air temperature (°F)	82.2	12.2	94.8	5.2
Maximum temperature-humidity index	73	6	80	2
Maximum heat load index	77	11	94	6

Microclimates

Weather conditions for 24-hour and observation periods are summarized in table 2. There was no rainfall recorded at the dairies during the study period. Air temperature during the observation period averaged 93.5°F (34.2°C).

Use of the home pen

Pen use by farm is shown in figure 1. On average, during the afternoon, 81% ± 17% (mean ± SD) of the high-producing group on each dairy used shade, which was at least twice as much as found in a New Zealand study conducted when air temperature averaged 73°F (23°C) (Schütz et al. 2014). This and the following results support other literature that demonstrated cows are highly motivated to use shade, especially when it is hot and sunny (Schütz et al. 2008; Schütz et al. 2010).

On dairies where shade was provided in multiple locations, cows extensively used this resource. Cows on these dairies avoided open areas throughout the day (fig. 2), with only 3% ± 2% of the high-producing group in areas with no cooling. In contrast, on dairies where the feed bunk was unshaded, the use of this and other unsheltered areas of the pen increased over time from 15% to 51% of the high-producing group between 13:00 and 17:00 hours (fig. 2).

These results suggest that there was more variable use of space on farms where shade was available only at the corral, and that cows rely on other factors besides weather and shade (e.g., feeding, sprayed water) to make decisions about which location to use. Regarding the use of the area surrounding the water source, only 3% ± 1% of the group was observed at this location during the observation period, which was similar to findings in New Zealand herds (Schütz et al. 2014). The use of this area seems to be affected by weather (Schütz et al. 2010), an idea supported by more cow visits to this area being recorded toward the end of the day.

Surface temperature

During the observation period, dirt temperature in open areas averaged 138°F ± 9°F (59°C ± 5°C); in the corral shade it was 91°F ± 7°F (33°C ± 4°C). At the feed bunk, the temperature of the concrete floor averaged

75°F ± 5°F (24°C ± 3°C) on dairies that provided shade plus sprayed water, and 86°F ± 0°F (30°C ± 0°C) on those that only sprayed water at this area. Similar dirt temperatures were described previously by Sullivan et al. (2011) in both shaded and open areas, and Marcillac-Embertson et al. (2009) at unshaded wet surfaces.

As we expected, blocking solar radiation influenced ground temperatures in both dirt and concrete areas. Ground temperatures fluctuated throughout the day more markedly in open, dirt areas than on other surfaces (fig. 3), and hourly variation in ground temperature was similar (18°F [10°C] on dry dirt) to that described by Mader et al. (2007). Other studies have shown that cows seek areas with cooler ground temperatures during the warmest part of the day (Mader et al. 2007).

Activity

On average, 17% ± 7% of the high-producing group fed (range of 7% to 33%) during the afternoon. A similar average and hourly pattern (data not shown) was observed in a study conducted in a drylot in Texas, where cows had shade at the corral only (Carter et al. 2011). Provision of heat abatement resources, weather (Chen et al. 2013), feeding and milking schedule (DeVries et al. 2003) can all affect feeding behavior and bunk attendance. On dairies that provided shade plus sprayed water at the feed bunk, only 34% of the cows in this area were feeding. This result suggests that cows were using the feed bunk area for cooling, as found previously by Chen et al. (2013).

Focal cows spent most of the observation period (47% ± 9%, on average) not engaged in any specific activity (i.e., idling). The remaining time they spent ruminating (25% ± 6%), feeding (20% ± 8%), drinking, walking, interacting with pen mates or grooming (8% ± 2%). In comparison to cows in a study conducted during winter in Canada, California cows spent slightly less time engaged in feeding and rumination during the afternoon, 25% and 33% of the time, respectively (Schirmann et al. 2012), which can be partially explained by warmer weather in our study.

Cows spend less time feeding when they are hot (Chen et al. 2013). In our study, hot weather may also explain why cows spent a great part of their time inactive, as this response was also positively related with higher respiration rate ($R^2 = 0.75$, $P < 0.01$; fig. 4). When facing high heat load, cows may avoid engaging in activities that increase heat production, or they may simply be unable to engage in other activities due to high respiration rate.

Posture

Cows spent 9 ± 1 hours a day lying down, on average (range of 7.4 to 10.6 hours). Daily averages ranged from 3.9 to 13.2 hours per day for individual cows. In our study, cows spent 1 hour less lying than those housed in

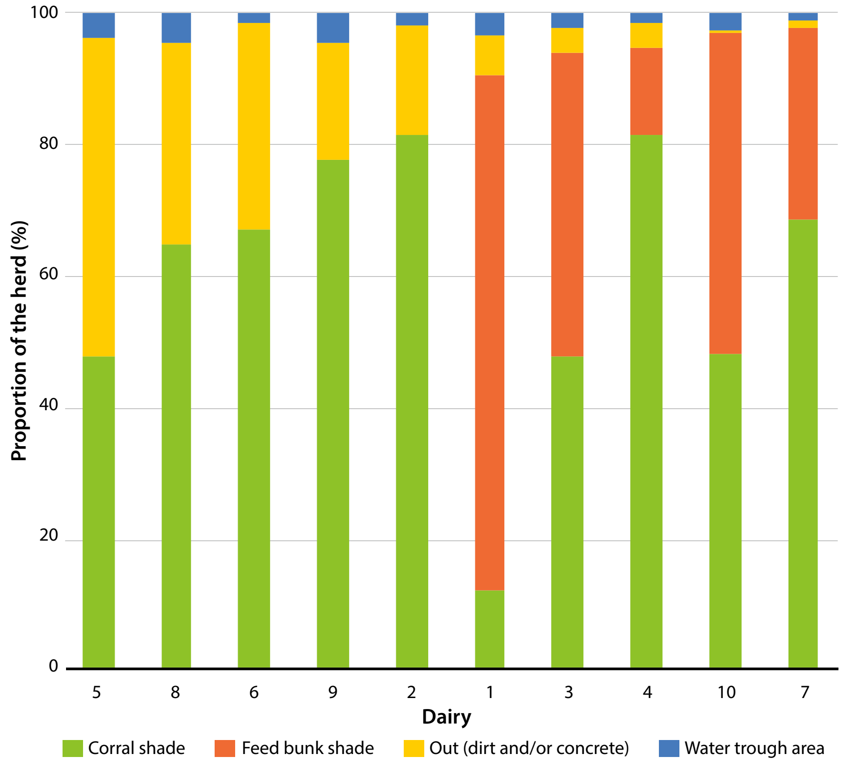


Fig. 1. Proportion of the group using pen locations (average over 3 days of observation). The 10 California drylot dairies are ranked by overall shade use.

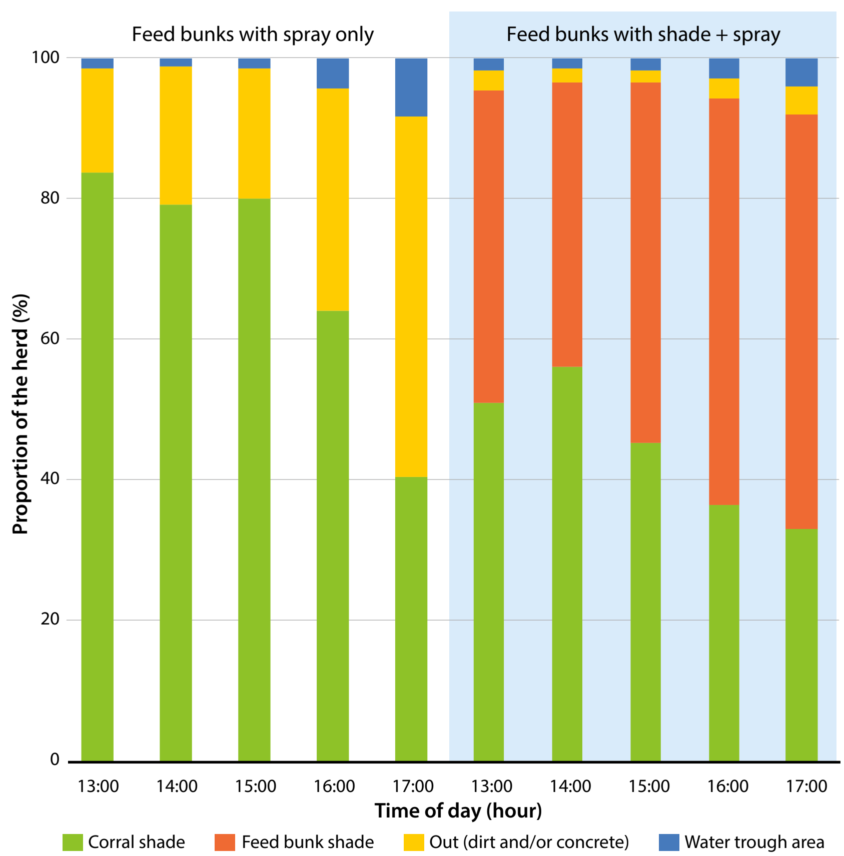


Fig. 2. Proportion (average over 3 days of observation) of the group by pen location and time of day, segregated by heat abatement resources provided at the feed bunk on 10 California drylot dairies.

similar conditions in Texas and New Mexico assessed during cooler conditions (10.2 hours per day; Barrientos et al. 2012). Weather may explain, in part, lower lying times on California dairies because cows spend less time lying in warm weather (Schütz et al. 2010). Individual variation among cows was within the range described by others (Barrientos et al. 2012).

Respiration rate and panting

Farm average respiration rates ranged from 65 to 95 breaths per minute (fig. 5); respiration rates of individual cows ranged from 25 to 147 breaths per minute. These values are within the range described in other studies in drylots during summer (Avendano-Reyes et al. 2012; Correa-Calderon et al. 2004; Tresoldi et al. 2016); however, most of them are much higher than the < 60 breaths per minute obtained in a study designed to maximize cooling in cows (G. Tresoldi, unpublished data).

Higher respiration rates have been associated with panting in dairy cows (Gaughan and Mader 2014; Tresoldi et al. 2016). Differences across farms may be due to the heat abatement resources provided (Correa-Calderon et al. 2004; Avendano-Reyes et al. 2012), while individual variation in respiration rate may be partially explained by use of (or lack of) cooling resources at the dairies (Parola et al. 2012).

Focal cows exhibited drooling (36% ± 13% of observations) more frequently than open mouth (4% ± 3% of observations) and protruding tongue (1% ± 1% of observations). Drooling frequency was similar to values reported previously in cows in California drylots (Tresoldi et al. 2016) and in Australian feedlots (Gaughan and Mader 2014) during summer. However, open-mouth and protruding tongue panting frequencies were lower than reported in those studies. Our results, however, may be underestimated since, in retrospect, we now know we needed to sample every 5 minutes (Tresoldi et al. 2016).

Opportunities to improve cooling and resource use

This is the first study to describe heat abatement strategies and cattle responses to heat load in commercial drylots in California. Given that some dairies achieved better animal responses (e.g., lower respiration rates)

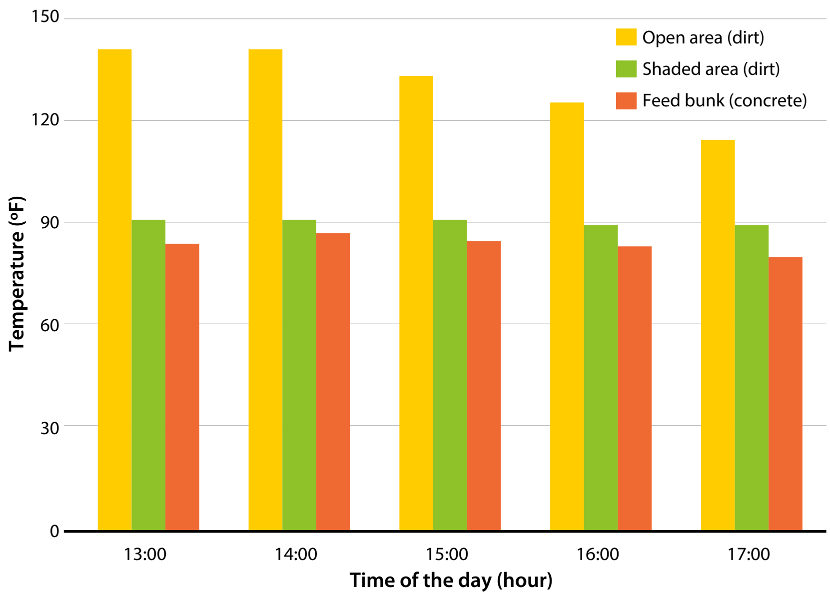


Fig. 3. Ground temperature at pen locations throughout the day (n = 7 drylot dairies, average over 3 days of observation).

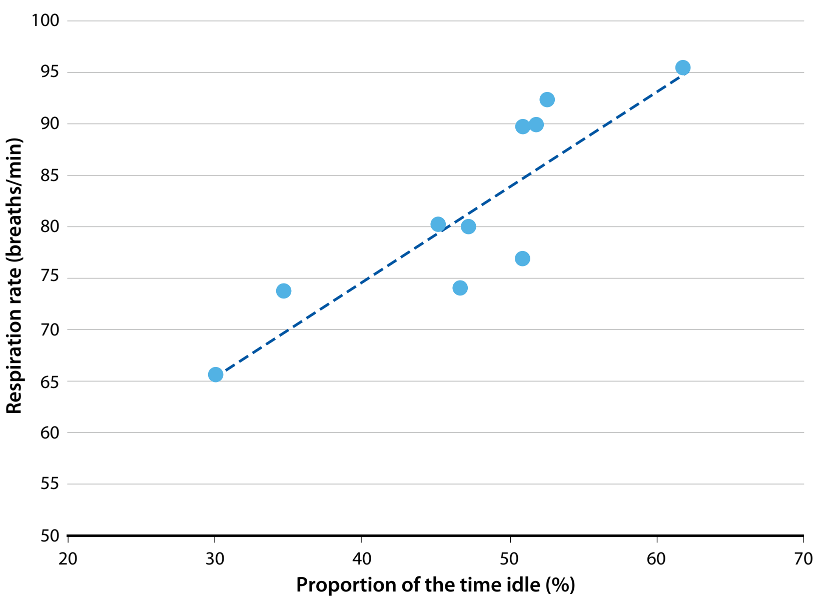


Fig. 4. Relationship between respiration rates and proportion of the time focal cows were idling (i.e., not engaged in any activity) on 10 California drylot dairies (average over 3 days of observation). $R^2 = 0.75$; $P < 0.01$.

Open-mouth panting was usually rare (< 5% of the observations, on average) but indicates that cows were hot. Panting is associated with higher respiration rates.

than others, our results indicate that there are opportunities to improve cooling and, consequently, aspects of cow welfare in California drylots. However, in this study, we could not determine what strategies were associated with better cooling because our sample size was small. Taken together with existing literature, we infer that cooling can be enhanced by adding shade at the feed bunk in complement to spray systems, for example. In addition, the lack of standardization regarding the provision of sprayed water suggests that there is further opportunity to optimize the use of this resource in California dairies. Others have found that increasing the quantity of water sprayed did not necessarily enhance cow cooling in a linear fashion. Our team is now exploring how to better understand how to both optimize cow cooling and the efficiency of water use. CA

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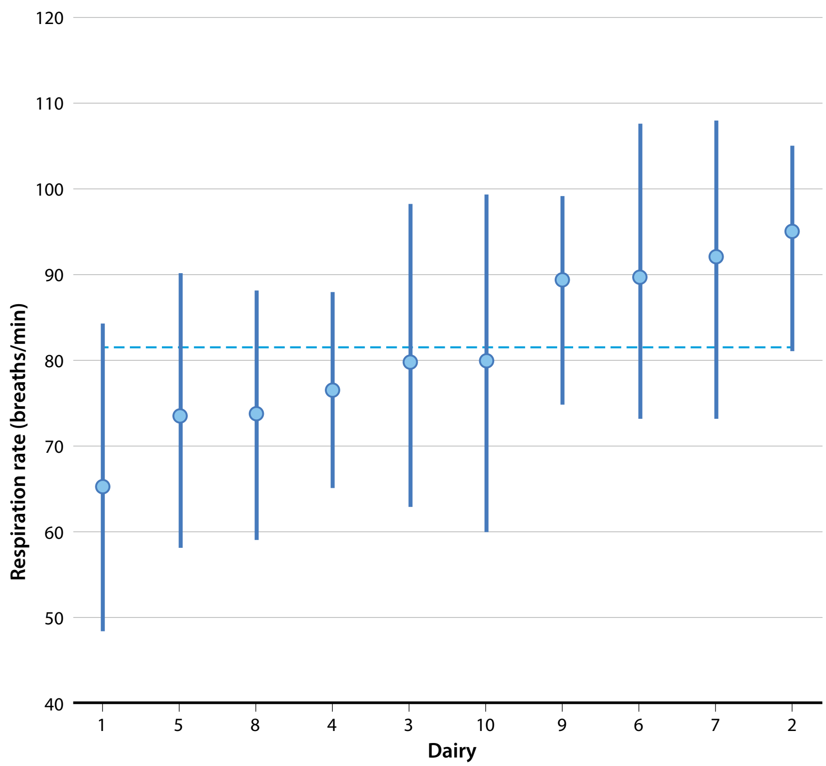

Fig. 5. Mean respiration rates (± SD) ranked for 10 California drylot dairies (average over 3 days of observation). The dotted line represents the overall mean.

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Upcoming events


Will Suckow

Western Alfalfa & Forage Symposium

http://calhay.org/symposium/

Date: November 28–30, 2017
Time: 8:00 a.m. to 5:00 p.m.
Location: Grand Sierra Resort, Reno, NV
Contact: California Alfalfa & Forage Association (916) 441-0635

Lindcove Research and Extension Center Fruit Display and Tasting — Public

http://ucanr.edu/?calitem=379785

Date: December 9, 2017
Time: 9:00 a.m. to 12:00 p.m.
Location: Lindcove Research and Extension Center, 22963 Carson Avenue, Exeter
Contact: Jasmin Del Toro jzdeltoro@ucanr.edu or (559) 592-2408 ext. 151

Elizabeth Grafton-Cardwell


Karen Merrill

Coastal North San Diego County California Naturalist Course

http://ucanr.edu/?calitem=373202

Date: January 9, 2018 –March 13, 2018
Time: 5:30 p.m. to 8:30 p.m.
Location: Buena Vista Nature Center, Oceanside
Contact: Paige DeCino pdecino@preservecalavera.org