APRIL–JUNE 2012 • VOLUME 66 NUMBER 2

California Agriculture

The Morrill Act at 150:

How a land-grant law launched the University of California

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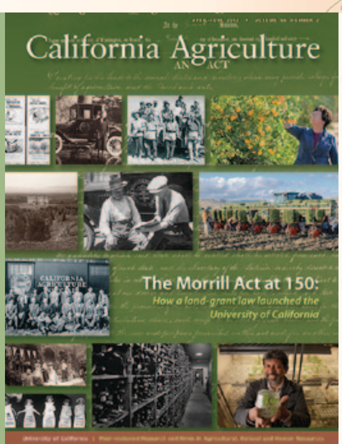


COVER: In 2012, UC celebrates the sesquecentennial of the federal Morrill Land-Grant College Act, which led to the creation of the University of California in Berkeley, the University Farm in Davis and the Citrus Experiment Station in Riverside. In the 21st century, Beth Grafton-Cardwell (top right) studies integrated pest management in citrus at UC Riverside; Abhaya Dandekar (bottom right) pursues a cure for Pierce's disease of grapevines at UC Davis; and conservation tillage methods (center right) developed by UC researchers are being adopted on hundreds of thousands of acres in the Central Valley (see pages 54 and 55).

The Morrill Act at 150:

How a land-grant law launched the University of California

News departments

Research and review articles

Now in print

This article was published online (January-March 2012) on the *California Agriculture* website, and appears after page 75.

Historic photo information:
For full information and credits of historic images on the cover, go to: http://ucanr.org/u.cfm?id=43. *California Agriculture* welcomes any additional information that you can provide about the photos in this issue.

TO OUR READERS: Honoring 150 years of accessible higher education

In 1862, in a nation torn by secession and Civil War, President Abraham Lincoln signed a visionary law that laid the cornerstone of public higher education. The Morrill Land-Grant College Act gave federal public lands to states, allotting 30,000 acres for each Senator and Representative. The total endowment was $7.55 million, then the value of 17.4 million acres. Today, more than 100 land-grant universities serve the nation and the world, including what many believe is the greatest public university in the world, the University of California.

On the 150th anniversary of its passage, we pay tribute to this profoundly democratic law, which made higher education available to those in every social class, and brought practical information to a nation that was then more than 50% farmers. It was followed by other landmark education laws: the 1887 Hatch Act, establishing Agricultural Experiment Stations at universities; a second Morrill Act in 1890, initiating regular funding; the Smith-Lever Act of 1914, establishing Cooperative Extension; and in 1944, the GI Bill. Today, UC's land-grant university thrives as the Agricultural Experiment Stations at UC Berkeley, Davis and Riverside, and in UC Cooperative Extension offices that serve every county.

See pages 40 to 49 for special coverage of the Morrill Act and its role in building the University of California.

— *Janet White*

Letters

Tips for buying and moving firewood safely

Re: "California Firewood Task Force's message: Buy it where you burn it" (October-December 2011): Your article was timely! This past December our department collaborated with Janice Alexander of UCCE Marin County to develop a public service announcement (PSA) regarding the risks of moving firewood and tips on buying firewood. This PSA, along with a few others can be found at: www.youtube.com/user/maringchannel#grid/user/01156AAE4AB13265.

October–December 2011 *California Agriculture*

The movement of firewood has always been a high-risk path to bring invasive and nonnative pests into our backyard. The goldspotted oak borer is just one more example, and more are on their way. All of us must do our part to help prevent their introduction, or detect an infestation at a very early stage before it becomes too costly or impractical to eradicate. Public outreach and education is vital to ensure that we have the greatest chance of success against this ongoing barrage of unwanted and injurious pests.

Stefan Parnay
Deputy Agricultural Commissioner/Director
Marin County Department of Agriculture and Weights & Measures, Novato

Switchgrass clarification

Re: "Switchgrass is a promising, high-yielding crop for California biofuel," by Pedroso et al. (July-September 2011): The article states that switchgrass is no longer listed by the California Department of Food and Agriculture (CDFA) as a noxious weed. This statement is in error. CDFA has never listed switchgrass as a noxious weed and it has been and remains listed as an agricultural crop seed in regulation. Some county agricultural commissioners wanted it listed as a noxious weed, but that never happened.

Stephen Brown
Special Assistant, Permits and Regulations
California Department of Food and Agriculture, Sacramento

Fritz-Metcalf collection now online

The Marian Koshland Bioscience and Natural Resources Library at UC Berkeley has posted the Fritz-Metcalf Photograph Collection, nearly 9,000 images relating to forestry, conservation and the lumber industry in California and the United States (www.lib.berkeley.edu/BIOS/fmpc).

Emanuel Fritz and Woodbridge Metcalf were among the first to join the faculty of the new School of Forestry at UC Berkeley in the early years of the last century. Together they created an extensive collection of photographs taken between 1910 and 1960, documenting their passionate involvement with forestry and the university. The collection itself covers 1906 to 1984, with contributions from other faculty, students and friends of the School of Forestry.

Norma Kobzina
Marian Koshland Bioscience and Natural Resources Library
UC Berkeley

New URL for *California Agriculture*

With this issue, *California Agriculture*'s online address has changed from ".org" to ".edu", better reflecting its status as a University-based academic journal. The prior URL will still function. The new URL is http://californiaagriculture.ucanr.edu.

RSVP

WHAT DO YOU THINK?

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

The Fritz-Metcalf Photograph Collection features images such as this one of Professor Metcalf leading a forestry class on a 12-mile walk to Camp Califorest at Feather River, in 1921.

For 150 years, UC science and agriculture transform California

Mark G. Yudof
President, University of California

Growing up in West Philadelphia, the son of an electrician, I never had much occasion to encounter farm life. Our meat and potatoes came from the grocery store and our vegetables from the frozen food aisle. So one of the great privileges I have enjoyed as president of the University of California is learning about my adopted state's diverse agriculture industry and the amazing bounty it produces.

Having previously served as president of another land-grant college system, the University of Minnesota, I was no stranger to agriculture when I moved here in 2008. But I quickly found that nothing compares to California's agricultural legacy and the forward-thinking leadership of its farmers and ranchers. As UC president I meet regularly with the Advisory Commission on Agriculture and Natural Resources. I have had the opportunity to visit Central Valley farming communities, taste-test a new UC Davis olive oil blend, learn more about almond-growing than any of my city friends could imagine and even get a lesson in lettuce harvesting in the Salinas Valley.

As I have traveled through the state on these eye-opening excursions, I have been reminded many times of the critical contribution agriculture makes to the California economy and the prominent role our university plays in that industry. Whether you're a backyard gardener, a 4-H student, a small family farmer or a major national food producer, chances are what you raise has in some way benefitted from UC innovation and collaboration.

To name just a few examples, about 40% of the strawberries grown in the world come from UC-developed varieties.

UC Davis certifies 95% of the grapevines sold in California, providing our wine industry with a reliable supply of vines. I have even learned that canned fruit cocktail originated at UC when in the 1930s food science pioneer William Vere Cruess came up with a way to keep fruit from going to waste.

Long-standing partnership

From the hundreds of varieties of crops developed to methods of cultivation, irrigation, animal husbandry, pest control, processing and packaging — it is evident that the agriculture industry's long partnership with the university has been a profitable and mutually beneficial one.

Indeed, I would go as far as to say that UC might not have evolved into the world's greatest public university system nor would California agriculture have grown into the $37.5 billion industry it is today if we hadn't teamed up nearly 150 years ago.

The catalyst for that partnership was, of course, the Morrill Land-Grant College Act, signed into law by Abraham Lincoln on July 2, 1862. This issue of *California Agriculture* celebrates the 150th anniversary of that landmark legislation in recognition of the impact it had on the future of California, our university and our nation (see pages 42–49).

It was the early days of the Civil War when Lincoln signed the law introduced by Vermont Congressman Justin Smith Morrill. The law granted federal land for states to fund colleges teaching agriculture and "the mechanic arts." At the time, our country was being split apart, yet Lincoln had the foresight to envision a future of peace and prosperity in a nation united and populated by an educated citizenry.

Robert Durell

In 2010, UC President Mark Yudof (right) viewed harvesting practices designed to ensure freshness and food safety in a Salinas Valley lettuce field, with Jim Lugg (center) of Fresh Express and Tanios Viviani (left) of Chiquita Brands.

Farmers' legislation

The Morrill Act was part of a slate of so-called "farmers' legislation" Lincoln signed that year. Included were the laws that created the U.S. Department of Agriculture and the Homestead Act, which granted plots of land in the West for settlers to farm. He also signed the Pacific Railway Act, which cleared the way to build the transcontinental railroad. You can debate the politics that influenced the creation of these laws and some of the unintended consequences, but there is no question they collectively transformed our country.

With trains connecting East and West, settlers could travel with relative ease to the Western frontier. They could also transport the products of their farming endeavors to markets across the continent.

The railroad opened access to California's fertile valleys, teeming rivers and rich natural resources for a new crop of pioneer families. The Morrill Act opened access to learning for their children and for future generations who might otherwise never have had the opportunity to earn an education.

The nationwide university access the Morrill Act provided was certainly a game-changer in social mobility and economic prosperity. Just as important was the Act's intention to apply scientific research to farming methods and resource stewardship.

Science and agriculture

UC embraced those intentions with a deep and passionate commitment. From humble beginnings at the campus in Berkeley, the University Farm at Davis and the Citrus Experiment Station at Riverside, UC dedicated its resources and knowledge to improving the quality of life and health of all Californians. Nowhere is that dedication so evident as in the mission of the university's Division of Agriculture and Natural Resources. Working side-by-side with California farmers, thousands of UC researchers and educators toil every day to solve the problems of modern agriculture and resource preservation.

The challenges we face together today are far more complex than those California farmers faced in the 19th century. Today we deal with issues like climate change, exotic invasive pests, food security, nutrition and childhood obesity, to name a few. But no matter how daunting the challenges might seem, UC is on the ground in every county — advising, educating and searching for solutions. True to the Morrill Act's philosophy of melding science and agriculture, UC brings to the table the most visionary, industry-transformative research methods.

UC might not have evolved into the world's greatest public university system nor would California agriculture have grown into the $37.5 billion industry it is today if we hadn't teamed up nearly 150 years ago.

In just this one issue of *California Agriculture*, you will find several examples of how UC research works for our state's producers.

One article details the impressive yield increases for corn and tomatoes achieved during an 11-year field study of conservation tillage (see page 55). This cultivation method, which forgoes tilling and leaves residue from the previous crop on the ground, has the potential to reduce soil water evaporation losses in summer by about 4 inches, or 13%.

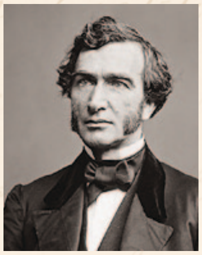
The Bancroft Library, UC Berkeley

Eugene W. Hilgard, a German-American soil scientist, became professor and director of the Agricultural Experiment Station in 1875. During his 30-year tenure, Hilgard established UC as a respected center of agricultural research and guided the college to transfer knowledge statewide via field stations and farmer institutes. Hilgard Hall, dedicated in 1917, currently houses the College of Natural Resources at UC Berkeley.

You can read about why dry matter and fruit acidity should be considered as a quality index for kiwifruit (see page 70), while another article analyzes recent trends in genetic engineering of fruit and nut trees, and suggests that transgrafting may be a promising approach for utilizing biotechnology to address both grower and consumer needs (see page 62).

This is the type of research that ultimately benefits every consumer by increasing the variety and quality of food, keeping supermarket prices down, meeting environmental challenges, promoting nutrition and food safety and contributing to the productivity of one of the state's most important economic engines. Of course, California agriculture has impacts far beyond the borders of our state: The whole world depends on the bounty of California's fields and orchards. UC is proud to contribute the scientific and technological expertise that helped the state's producers become world leaders in the global marketplace.

Despite the budget challenges the university has faced in recent years, our commitment to a healthy and sustainable California agriculture industry is as strong as ever. That partnership we forged nearly a century and a half ago is truly a fundamental cornerstone of California society. We at the university, through the leadership of ANR, look forward to building upon it for many years to come.



Library of Congress

Rep. Justin Smith Morrill of Vermont (circa 1860) proposed the federal land-grant system.

Anthony Berger/Library of Congress

President Lincoln (shown in 1864) signed the Morrill Land-Grant College Act on July 2, 1862.

UC's land-grant mission fuels nation's growth, prosperity

Rose Hayden-Smith
4-H Youth, Family and Community Development Advisor
UC Cooperative Extension, Ventura County
ANR Sustainable Food Systems Strategic Initiative Leader

This year marks the sesquicentennial, or 150th anniversary, of four events key to American agriculture. In 1862, the United States Department of Agriculture (USDA) was created. Three pieces of legislation were also passed that would forever change the face of the nation: the Pacific Railroad Act, the Homestead Act and the Morrill Land-Grant College Act, which created America's land-grant institutions, including the University of California.

In 1862, America was in its second year of the Civil War, which threatened the nation's very survival. It was an unsettled time. Battles such as Shiloh — which would haunt American memory for decades — and Lincoln's preliminary Emancipation Proclamation left Americans feeling uncertain, but also in the case of the North, bravely charting a new direction that expressed optimism despite the war. At that time, farmers made up more than 50% of America's labor force; legislation such as the Morrill Act reflected their importance, and reinforced the economic and social importance of agriculture to the nation's future. The Morrill Act also demonstrated the increasing importance of taking a more scientific approach to agricultural production and education.

M. B. Boissevain/Jack Mason Museum of West Marin History

Agricultural societies were important early supporters of the land-grant system. *Above*, more than 10,000 people attended the Fifth Western Sonoma-Marin Dairy Cattle Show in Valley Ford, in 1927. Stock judges were from the University Farm at Davis, with over $1,800 in cash prizes.

The creation of the USDA (President Lincoln called it "the People's Department") institutionalized agriculture in the federal government; the agency was called "to diffuse among the people of the United States useful information on subjects connected with agriculture." While creation of the USDA was vital to American agriculture, it was the Morrill Act that was truly visionary. It enabled state governments to provide higher education in agriculture, science and mechanical arts. With its passage, all states were given blocks of land by the federal government that could be sold off by legislatures to fund public universities.

Agricultural societies

Farmers have always sought and shared agricultural knowledge. Agricultural organizations, often called societies, were designed to share agricultural knowledge, and they were prevalent in early America. Leaders in Philadelphia formed a society to promote agriculture in 1785; others quickly followed suit. Many of the letters written by General George Washington during the Revolutionary War focused on agricultural practices and production at his plantation. Like fellow founding father Thomas Jefferson, Washington was an agricultural innovator.

Agricultural experimentation was particularly strong among wealthy Southern growers in the period prior to the Civil War, due in part to a decline in soil fertility combined with decreasing cotton prices in the 1840s and 1850s. By the 1860s, there were more than 1,300 agricultural and horticultural societies in the United States; some states were also creating state boards and departments of agriculture. Agricultural fairs (and later, expositions) were popular, and served not only as places to market goods but also as sites for education and demonstration; George Washington encouraged the movement as early as 1796. The United States Agricultural Society was formed in 1851 and enjoyed significant success until the Civil War, when sectional differences made its operation impossible.

Farmers were hungry for knowledge. Publications such as the *American Farmer* (which came to press in 1819) filled some of the gaps. By the end of the 19th century, more than 3,000 agricultural publications had appeared at various times in the United States and Canada; most quickly failed. But through these efforts an increasing amount of information about agriculture was produced and shared, and more farmers were accessing agricultural information. This created a political culture that supported the idea of land-grant legislation.

Land-grant legislation

Justin Smith Morrill introduced the land-grant bill in the U.S. House of Representatives in December 1857; it was accepted by a narrow margin in April 1858. The Senate passed its own version, which was vetoed by President Buchanan, who acceded to Southern interests opposed to the perceived growth of federal power that the Act represented. Later, however, President Lincoln proved favorable to the idea of industrial education (in fact, agricultural education was a repeating campaign theme when he stumped for president). With the Southern congressional members who had opposed the Morrill Act now seceded from the Union, the legislation was reintroduced and signed into law on July 2, 1862.

In September 1862, Iowa became the first state to accept the gift offered by the Morrill Act. By 1870, 37 states had signed on. A second Morrill Act in 1890 gave an additional boost to the land-grant system by fostering institutions serving African Americans in the Southern states.*

In California, the Morrill Act enabled the state to combine federal, state and private funds and efforts (the private College of California was part of the genesis of UC). This led to the creation of the University of California in 1868. Shortly after, a new campus was built on a tract of land near Oakland, called Berkeley. From humble beginnings, UC grew to become one of the world's pre-eminent educational institutions, providing the knowledge and technical education that helped California become one of the world's primary agricultural producers.

ANR Communication Services

During World Wars I and II, UC Cooperative Extension supported the federal Victory Garden (shown) program in California. Nearly a million home vegetable gardens were planted and thousands of animals were raised for food.

The Morrill Act was visionary, but it did not prove an immediate success. It took years for the states to take full advantage of the legislation, and even then, the connection between the production of knowledge at the land-grant institutions and its practical application by farmers was lacking. Some of the problems experienced, including low enrollments and a failure to teach practical agriculture, led to further legislation in the form of the Hatch Act in 1887†, which funded linked experiment stations to provide a practical place to help solve the problems of ordinary farmers. The 1905 State Farm Bill would fund establishment of the University Farm at Davisville in 1906, a teaching farm for UC Berkeley students. The Citrus Experiment Station in Riverside was founded in 1907; it proved vital to Southern California's developing citrus industry. In 1919, the California Legislature designated an existing teacher's college in Los Angeles as UC's southern branch; it became the UCLA campus in 1927 and offered some agricultural programs for decades. As a result of increased enrollment at UC due to the GI bill passed during World War II, the University Farm eventually evolved into the UC Davis campus. Likewise, the Citrus Experiment Station eventually gave rise to the UC Riverside campus. The original campus at UC Berkeley remained the flagship agricultural campus.

Responding to wartime needs

The period around World War I is one of the most interesting in the development of institutions such as UC, in part because of the passage of the Smith-Lever Act in 1914, which provided for "Cooperative Agricultural Extension Work," a federal, state and county funding partnership that gave rise to the Cooperative Extension Service. The importance of scientific agriculture and the role of land-grant institutions in promoting agricultural productivity were highlighted during World War I, when agricultural production and food security were viewed as vital to national security and victory "over there." When the United States entered World War I, national leaders feared an agricultural crisis. Many farmers and laborers were mobilized to war. Foreign labor, used in California, was deemed risky. International allies relied on shipments of U.S. food to avoid mass deprivation and starvation, as most of Europe became a battlefront and agricultural production there plummeted.

Victory gardens. Across the United States and in California, land-grant institutions helped the nation respond to wartime needs. In the quickly urbanizing nation, home food production again became a national priority, even an imperative. UC was involved in providing research, educational resources and training for the army of Victory Gardeners who arose from the civilian population to help raise food on the U.S. home front, encouraging local production and consumption in a national mobilization. It was thought that increased home food production and food conservation efforts would feed civilians, enabling America to increase its agricultural exports to foreign allies; this proved to be true.

School gardens. UC's groundbreaking efforts in school garden work and agricultural education, much done in the decade prior to World War I — including a program called the California Junior Gardeners offered in conjunction with the Berkeley School District — enabled a national program called

M.B. Boissevain/Jack Mason Museum of West Marin History

Cooperative Extension supports youth via 4-H, as well as nutrition and community development programs. Early in the 20th century, 4-H was an innovative way to introduce new agricultural technologies to farming communites. *Above*, the Tomales Joint Union High School Club, with leader Charles Hampton (left), raised and sold pigs in Marin County in 1924.

* Corrected by *California Agriculture* April 13, 2012, after press run: "African Americans in the Southern states," not "African Americans and Native Americans."

† Corrected by *California Agriculture* April 16, 2013, after press run: "in 1897" not "in 1887."

the U.S. School Garden Army (USSGA) to gain traction and engage tens of thousands of urban and suburban youth in school, home and community gardening efforts across the state. At Ann Street Elementary School in Ventura, where teachers had previously received school gardening instruction from UC, students raised 2 tons of potatoes.

Nearly a century later, UC remains a national leader in school, home and community gardening work. UC advances research about the importance of agricultural and nutrition education and helps homeowners, schools and communities launch gardening efforts. Nearly 5,000 UC Master Gardener volunteers in 44 California counties provided 258,000 hours of service to California communities in 2010. Urban agriculture thrived in the form of national Victory Gardens during World War I and World War II. Today UC supports urban gardening through programs such as the UC Cooperative Extension Los Angeles Common Ground Program and its Grow LA Victory Garden Initiative. Farm advisors and campus-based specialists work with small producers to find new markets closer to home, through Community Supported Agriculture (CSA) and Farm-to-School programs.

Food conservation. During World War I, UC Extension agents also served as local food administrators, helping California communities conserve food by suggesting alternative foods on wheatless and meatless days, and in rationing scarce products such as sugar. During this period, UC hired new Cooperative Extension agents to work with youth and to help women learn best practices in food preservation. UC-trained Master Food Preservers do the same today. In counties 100 years ago, farm advisors worked with agricultural producers, in partnership with local farm bureaus and county government, to boost California's agricultural productivity. They do the same today, helping producers conduct field trials of new varieties, develop markets for new products, reduce pesticide use, improve water use efficiency, reduce impacts on water quality, and remain viable and competitive despite ever-changing conditions.

Women's Land Army. UC played an instrumental role in one of World War I's more controversial efforts, the Women's Land Army (WLA), which sought to address labor shortages by deploying young women, mostly urban and suburban and many college-educated, to work as agricultural laborers on the nation's farms. UC employed young women first to help conduct an assessment of agricultural labor in the state, and then trained them for agricultural work at the University Farm at Davisville. These young women proved critical to California growers during World War I, and some women used their work in the WLA to press for national suffrage.

Special Collections, General Library, UC Davis

UC nutrition programs have long encouraged healthy lifestyles while promoting California agriculture. *Above,* a Picnic Day float on the University Farm at Davis, circa 1939, featured the nutrient "fairies" in milk.

Land settlements. During this period, UC professor Elwood Mead worked closely with the State of California to organize a novel land settlement project at Durham, in Butte County, to create a utopian agricultural community. Its first year proved successful, and a second settlement, specifically for returning war veterans, was organized at Delhi, a few miles from Turlock. Today, UC farm advisors once again work with returning veterans as part the USDA's Beginning Farmers and Ranchers effort. As the nation faces a potential crisis inherent in the aging of the American farmer, UC farm advisors train beginning and new farmers, many of them veterans, women and immigrants, to become producers, assuring California's agricultural future and enhancing the security of the world's food supply.

The Bancroft Library, UC Berkeley/Ban PIC 1966-034-FALB

Under the leadership of UC professor Elwood Mead, the state purchased the Durham Tract in 1918, near Chico. The utopian agricultural community of Durham, *above,* was so successful that a second, called Delhi, was organized near Turlock for returning veterans.

Post–World War II growth

In June 1944, President Roosevelt signed the Servicemen's Readjustment Act, also known as the GI Bill of Rights. This legislation matched the Morrill Act in its vision and national impact. Returning veterans boosted enrollment at UC, creating conditions for the state's phenomenal economic and social growth. Land-grant institutions such as UC proved to be the economic engine of the nation in the 20th century, creating a robust middle class, providing upward mobility for millions of Americans, and assuring America's pre-eminence in agriculture and science. They also provided a place where the nation's promise of equality could be achieved, in part, through accessible public education.

It is impossible to overstate the importance of the GI bill nationally and to the California economy. Nearly 8 million returning veterans participated nationally in the program in the first decade. During this period, UC trained farmers, engineers, teachers, doctors, scientists and others who helped boost California's economy and college enrollment. (U.S. college enrollment grew to nearly 30% by the late 1960s, up from less than 10% in the pre-war years).

In California, UC's research and agricultural education programs provided the basis for durable economic growth that has made our state one of the world's largest economies. The story of UC is writ large on California's cultural, economic and physical landscape, but it is also a personal story to many of us.

My connection to UC dates back to the mid-1960s, when my father — who received two degrees in the "mechanic arts" at a land-grant institution under the GI Bill — moved our family to California, in large part because of the vision of higher education presented by the state. Like earlier pioneers, we made our way West, not in a covered wagon but in a Ford station wagon. Like pioneers of the past, we were drawn by dreams of prosperity and the brighter future that the Golden State promised.

I grew up knowing from my father that I would attend UC, where I would receive the world's best public education. He was right on both counts. Each day, I reap the benefit of that education. I also reap the benefits of UC research and extension work in myriad ways, whether through the selection of California-grown fruit at the local grocery store (the variety patented by a UC scientist), or when taking my daughter to the local family practice clinic that is part of the UCLA Medical School's teaching program in my community.

National Archives

During both World Wars, UC played an important role in the Women's Land Army, which addressed the nation's agricultural labor shortage.

UC has evolved from a single campus to 10 campuses spanning the state, which make significant economic contributions statewide. According to an independent 2011 economic impact analysis, UC generates $46.3 billion in economic activity annually and contributes $32.8 billion toward California's gross state product. For every $1 of taxpayer investment, UC leverages and produces nearly $14 in economic output, while supporting one in every 46 jobs in the state.

UC research has fueled national and international prosperity, but it also remains a local institution in a very real sense. Through UC's Cooperative Extension program, it supports agricultural producers, youth through 4-H and nutrition programs, natural resource managers and landowners and communities.

UC Master Gardener volunteers enable urban and suburban populations to engage in home food production and community beautification through gardening. UC advisors and volunteers instruct youth, teachers and parents in nutrition and the health benefits of consuming fruits and vegetables. Some lemons grown with advice from a UC farm advisor in an orchard several miles from my home are shipped around the globe; others stay locally, and are used by a small business to produce a coveted limoncello liqueur that is featured in local restaurants. UC connections are global and local, and every place in between.

ANR Communication Services

In 1943, UC began administering the federal Emergency Farm Labor Project in California, which deployed youth, immigrants and other volunteers to areas where harvest assistance was needed. UC and USDA also provided training, transportation and housing assistance.

Service to land and citizens

With agricultural research investment declining, agricultural productivity threatened by a number of factors (including limited water and climate change), and the world's population expected to increase at a dramatic pace, what California can produce is desperately needed.

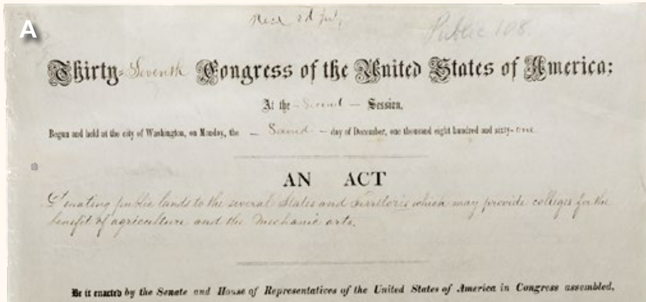
We tend to take for granted a safe, plentiful and inexpensive food supply, which helps to assure our nation's social and political security. But continued investment is required to sustain the vision of the Morrill Act, to help all Americans reap the promise of abundance our physical geography offers. How will we chose to support the land-grant mission in the next 150 years?

ANR Communication Services

Nutrition paper dolls, circa 1930, were part of a national Extension campaign.

The mission of UC and the land-grant institutions, both at home and abroad, remains larger than our collective imagination. We were a nation of farmers at origin: we are still a nation of farmers at heart. The frontier as once envisioned may be gone, but the real frontier — the pursuit of knowledge — awaits our further exploration.

1862–1918



National Archives

The Bancroft Library, UC Berkeley

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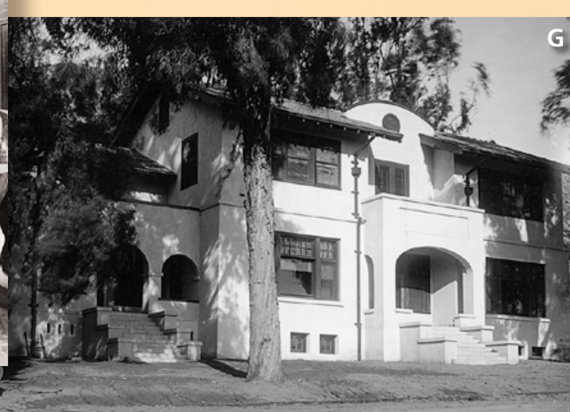


Special Collections & Archives, UC Riverside Libraries

Early days: 1862–1918

A. The Morrill Act was signed into law by President Lincoln in 1862.

B. Among the first UC buildings was South Hall (left), first home of the College of Agriculture; it still stands on the UC Berkeley campus, just southwest of the Campanile. The 1873 image shows South and North Halls, looking west toward the San Francisco Bay.

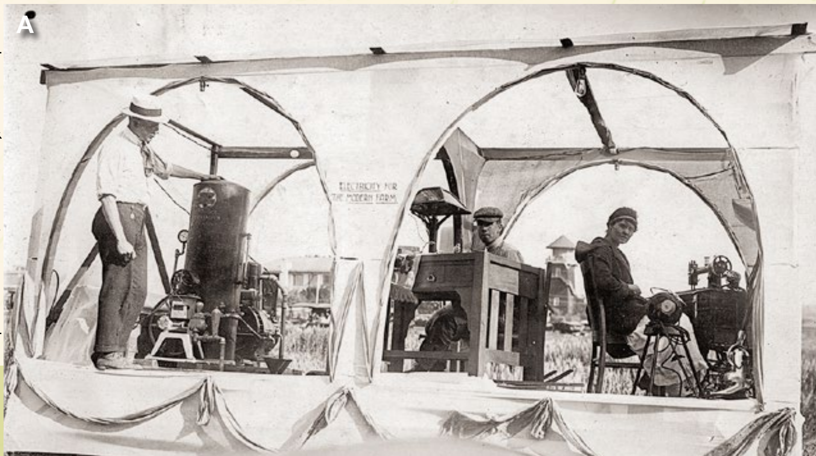
C. A lecture classroom in South Hall, shown in 1898, was filled with students. The College of Agriculture was in the basement.

D. The University Farm was situated on 776 acres in Davisville, Yolo County — 75 miles north of Berkeley. Three buildings from this image, circa 1910, are still in use at UC Davis: North Hall, South Hall and the Cottage.

E. Since its inception in 1909, when the University Farm invited the community to view its new dairy barn, Picnic Day in Davis has grown into the largest student-run event in the nation. Shown is a cow parade, circa 1920.

F. From its earliest days, UC extended agricultural knowledge throughout California. In 1909, an agricultural demonstration train toured the state with animal husbandry displays.

G. After citrus growers, including John Henry Reed, lobbied for a research station, California established the Citrus Experiment Station in 1907 on 23 acres at the base of Mount Rubidoux, overlooking Riverside.


Special Collections, General Library, UC Davis/uap-01722


Special Collections, General Library, UC Davis/uap-01396

Research takes root: 1919–1945

A. A Picnic Day parade float at the University Farm in Davis featured a farm electrification demonstration, circa 1920.

B. From 1922 to 1934, Thomas Tavernetti, in a field of millet, was assistant dean of agriculture at the University Farm, which was designated as UC Davis in 1959.

C. At UC Berkeley, Ansel F. Hall constructed a relief model of Yosemite Valley in 1921. Hall went on to become the first park naturalist of Yosemite National Park.

D. In the 1930s, a researcher in the Citrus Experiment Station's Division of Plant Pathology studied citrus fruit quality. The station became UC Riverside in 1954.*

E. The 1920s are often considered the "golden age" for extension, with outreach helping many families achieve better livelihoods. In San Diego County, a farm advisor posed in his Model T.

F. UC Berkeley's Division of Forestry was established in 1913, with field camps in the Sierra Nevada. In 1926, advisors visited Whitaker's Forest; the image was taken by Woodbridge Metcalf, UC Berkeley forestry faculty from 1914–1956.

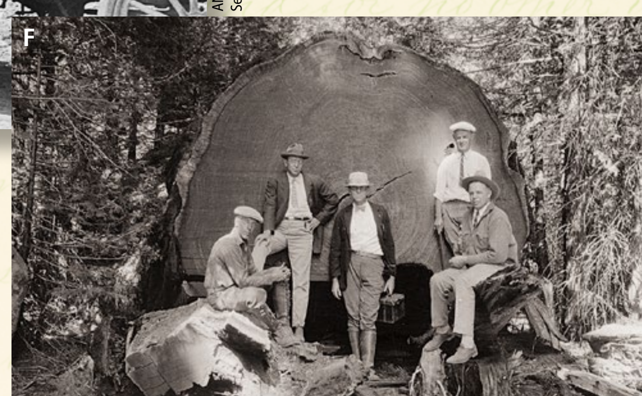
G. During the 1930s, chemical methods to control citrus pests were tested in a large fumigator at the Citrus Experiment Station in Riverside.

* Corrected by *California Agriculture* April 13, 2012, after press run: "in 1954" not "in 1959."


Fritz-Metcalf Collection/UC Berkeley/lib.berkeley.edu/BIOS/fmpc


Special Collections & Archives, UC Riverside Libraries

ANR Communication Services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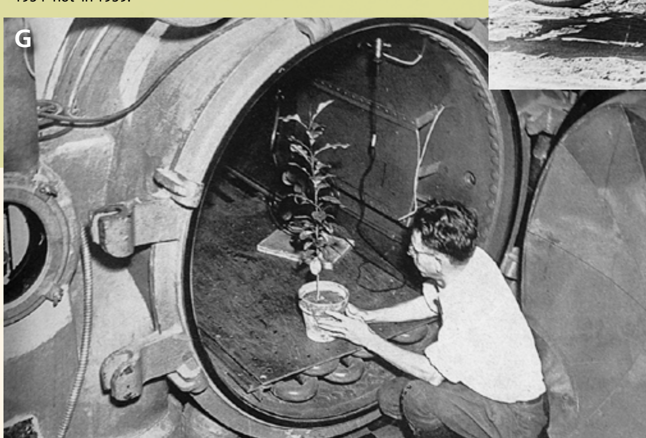
Golden Book of California: 1860–1936

Ansel Adams Fiat Lux Collection, UCR/CMP

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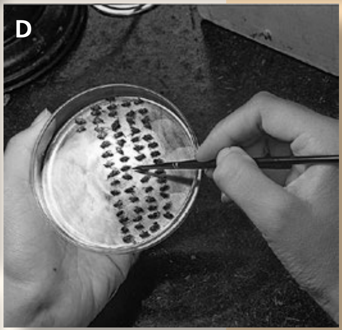
Ansel Adams Fiat Lux Collection, UCR/CMP



Ansel Adams Fiat Lux Collection, UCR/CMP

Ansel Adams/Special Collections, General Library, UC Davis

Jack Kelly Clark/UC Statewide IPM Program

Jack Kelly Clark

Gary Andersen

Postwar years: 1946–2000

A. The School of Veterinary Medicine was the first professional school at UC Davis; the first classes were in September 1948.

B. Extension enologist George Cooke is seen in the distance (in 1966)* in the cellars of the enology building at UC Davis, where research and outreach has been instrumental in building the state's $18.5 billion wine industry.

C. In 1966†, watershed experiments were conducted at Hopland Research and Extension Center, one of 10 RECs operated by UC ANR. The centers represent the state's diverse growing conditions and natural ecosystems.

D. UC Riverside entomology professor Vern Stern made critical contributions to IPM science; in 1966, lygus bugs, an important cotton pest, were segregated in his lab.

E. UC Berkeley and UC Davis biologist and geneticist G. Ledyard Stebbins (center) led an agricultural field trip, circa 1967.

F. UC Davis entomology professor Frank Zalom directed the UC Statewide IPM Program for 16 years; circa 1990, he placed a trap to monitor for oriental fruit moth.

G. The IMPACT (Integrated Management of Production in Agriculture using Computer Technology) system was established at UC Davis in 1979 (shown in 1981).

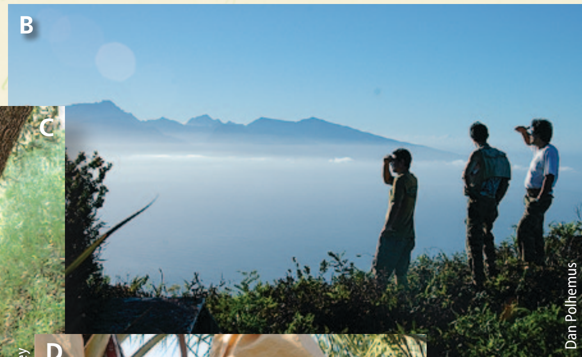
H. In 1987, UC Berkeley plant pathologist Steven Lindow received permission to field-test genetically altered *Pseudomonas syringae* (known as "ice minus" bacteria) as a frost-preventive on potatoes in the Tulelake area.

I. UC has published peer-reviewed research and news in *California Agriculture* journal continuously since 1946.

* Corrected by California Agriculture April 13, 2012, after press run: "(in 1966)" not "(in 1960)."
† Corrected by California Agriculture April 13, 2012, after press run: "In 1966" not "In 1960."

Research highlights

James Block



Dan Polhemus

Matteo Garbelotto Lab, UC Berkeley

Carlos Puma/ UCR Strategic Communications

Recent research highlights

A. Peggy Lemaux (second from right) examines sorghum in a UC Berkeley greenhouse; Lemaux was named the nation's first biotechnology advisor in 1990.

B. Botanists led by Jean-Yves Meyer (center) look out from Mt. Tohiea on the Polynesian island of Moorea, during a plant-collecting expedition. UC Berkeley researchers are barcoding an entire tropical ecosystem on Moorea.

C. Matteo Garbelotto, forest pathology specialist at UC Berkeley, co-discovered the agent responsible for sudden oak death and is working to stem its spread.

D. UC Riverside entomology professor Thomas Perring investigates carob moth, a key pest of ripening date fruit.

E. UC Riverside entomologist Beth Grafton-Cardwell's work targets IPM and biocontrol solutions for citrus pests.

F. Carole Meredith, professor emerita of viticulture and enology at UC Davis, uses DNA analysis to determine the heritage of wine grape varieties.

G. Medical ecologist Rob Atwill, who leads the Western Institute for Food Safety at UC Davis, tests water samples for disease-causing microbes that could be transferred between livestock, wildlife and humans.

H. UC Davis plant scientist Abhaya Dandekar and colleagues have fused two genes to engineer resistance to Pierce's disease of grapevines.

I. UC school garden studies, curricula and projects have introduced thousands of students across the state to important science and health concepts. The California Master Gardener Handbook, published by ANR Communication Services, is a top seller.

Carlos Puma/ UCR Strategic Communications

UC Davis

Karin Higgins

Gregory Urquiaga

Suzanne Paisley

About *California Agriculture*

University *of* California
Agriculture and Natural Resources

California Agriculture is a quarterly, peer-reviewed journal reporting research and reviews, published by the University of California Agriculture and Natural Resources (ANR). The first issue appeared in 1946, making *California Agriculture* one of the oldest, continuously published, land-grant university research journals in the country. There are about 17,000 print subscribers. The electronic journal logs about 6 million page views a year.

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

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

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

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

Rejection rate. The rejection rate has ranged between 20% and 25% in the last 3 years. In addition, associate editors and staff sent back 24% of manuscripts for revision prior to peer review.

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

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Report seeks solutions for nitrate in drinking water

A new report by UC Davis researchers, commissioned by the California State Water Resources Control Board and released in mid-March, is the first comprehensive scientific investigation of nitrate contamination of drinking water in high-risk areas of California.

Titled "Addressing Nitrate in California's Drinking Water," the report defines the extent of the problem, recommends clean-up strategies and outlines possible funding mechanisms.

"Cleaning up nitrate in groundwater is a complex problem with no single solution," said Jay Lund, director of the Center for Watershed Sciences at UC Davis. "This report should help inform discussions among drinking water, waste discharge and agricultural interests, and local governments on this issue."

Nitrogen in organic and synthetic fertilizers has dramatically increased crop production in California. However, excess nitrate applied on the surface can over many decades seep into groundwater. Almost one in 10 people living the areas studied, among the state's most productive agriculturally, risk dangerous nitrate levels in their drinking water, which have been linked to some illnesses.

UC Davis scientists examined data from wastewater treatment plants, septic systems, parks, lawns, golf courses and farms in the Tulare Lake Basin and Salinas Valley, areas that include Fresno, Bakersfield and Salinas. Their report calls for a statewide effort to integrate water-related data collection by various state and local agencies.

UC scientists are developing methods to reduce nitrate levels in irrigation runoff in order to farm more efficiently and protect drinking water in rural areas.

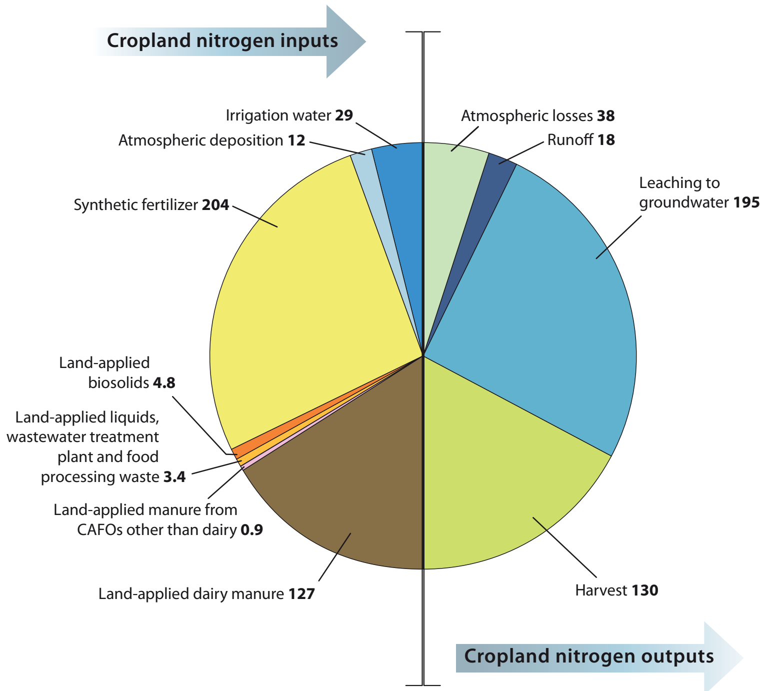
Thomas Harter, UC Cooperative Extension specialist in the department of Land, Air, and Water Resources at UC Davis, said the report bolsters efforts by scientists with UC Agriculture and Natural Resources (ANR) to help growers manage nitrogen more effectively and, in turn, improve drinking water for future generations in the Tulare Lake Basin and Salinas Valley.

"This report defines the extent and costs of the problem, for the first time, and outlines how we can address it," said Harter, the report's lead author. "We hope it provides the foundation for informed policy discussions."

Scientists with ANR have been working to ensure that Californians have access to safe drinking water while the state's farmers can grow enough food to meet the world's increasing demand. Examples of related ANR research currently under way include:

- Best management practices to optimize water applications and minimize nitrate leaching in irrigated crops.
- A quick test to measure soil nitrate in the field so that growers can match fertilizer rates with plant needs.
- Nutrient planning tools that help dairy operators decide how to most efficiently manage manure applications to their silage crops.
- A new test, based on plant gene expression, that more accurately reflects the availability of nitrogen in the soil.
- The use of cover crops to prevent nitrates from moving out of crop fields and into groundwater.
- Adjustments to field length to reduce irrigation levels, and conservation tillage to help farmers better utilize nitrogen on dairies and in field crops (see page 55).
- Information and resources to enable dairy operators to comply with state and federal regulations.

—Editors



Cropland input and output of nitrogen (gigagram N/yr) in Tulare Lake Basin and Salinas Valley, 2005. The left side shows total N inputs to 3.12 million acres, not including alfalfa. The right side shows total N outputs with leaching to groundwater estimated by difference between known inputs and outputs. *Source: Viers JH et al. 2012. Nitrogen Sources and Loading to Groundwater. Tech Rep 2 in: Addressing Nitrate in California's Drinking Water. UC Davis Center for Watershed Sciences.*

For more information:

Addressing Nitrate in California's Drinking Water report
http://groundwaternitrate.ucdavis.edu

ANR Healthy Crops, Safe Water
http://ucanr.edu/News/Healthy_crops,_safe_water

UC leads effort to protect California forests from catastrophic fire

Fire has always been a part of California's Sierra Nevada ecosystem, but over the past 100 years, a national fire suppression policy has disrupted the natural order.

"By studying fire scars on tree rings, scientists have confirmed that before fire suppression, the Sierra Nevada's mixed conifer forests burned every 15 to 35 years. The forests were more open and didn't have as much ground fuel," said Susie Kocher, UC Cooperative Extension advisor in the Central Sierra, a forestry expert. "Today's overstocked forests are primed for catastrophic fire."

In 2005, the U.S. Forest Service, UC and other state and federal agencies signed a memorandum of understanding to create the Sierra Nevada Adaptive Management Project (SNAMP). SNAMP researchers are studying forest management and documenting modern, sustainable techniques that will return forest environments to a more natural density. A unique funding partnership — involving the California Department of Water Resources, the Forest Service, private foundations and other sources — provided about $15 million.

"Climate change is giving us an even longer and drier fire season," Kocher said. "Adapting forest management to make Sierra Nevada forests more fire resilient is an urgent task."

Humans and forest fire

Human impacts on the forests of California's Sierra Nevada can be almost imperceptible in the short run, but profound over time. The consequences of forest management decisions made 100 years ago are still felt today, and changes in management being made now will shape the forest, wildlife, watersheds and nearby communities long into the future.

About 75 California spotted owls have been banded in the Last Chance study area.

For eons, intermittent fires regularly pruned low shrubs, killed small trees and converted forest duff to ash. Low-intensity burning was also part of Native American culture. But through most of the 20th century, natural forest fires were quickly suppressed. The new, fire-suppressed landscape, rife with vegetation, can fuel less frequent but all-enveloping infernos that destroy whole communities in their paths.

USDA research found that fire size and the area burned in the western United States has risen substantially since the early 1980s and are now at or above values from before the 1940s, when fire suppression became national policy. Also, a large area of California and western Nevada experienced an increase in high-severity fire between 1984 and 2006.

Forest Service partners with UC

The U.S. Forest Service is responsible for more than 20 million acres in California, including striking vistas, rich wildlife habitat and invaluable watersheds, much of it adjacent to rural communities. The agency was charged by Congress with managing the nation's forests for multiple uses — water, forage, wildlife, wood and recreation. However, historical missteps eroded the agency's credibility among some forest community residents and people dedicated to protecting Sierra wildlands and wildlife. Management projects were contested in court at every turn, to the point that fire hazard management, especially if it involved removing large trees, was essentially at a standstill.

In the mid-2000s, the Forest Service, along with state partners, turned to UC to document the effects of an integrated, science-based, vegetation management strategy that would modify landscape-scale fire behavior to reduce the size and severity of wildfires. UC was asked to serve as a neutral third party, to research key management issues and increase public participation in all aspects of fuel management strategy.

"UC was chosen because of its credibility on all sides of Sierra forest management debates," said Richard B. Standiford, who as associate vice president for UC Agriculture and Natural Resources negotiated UC's involvement in SNAMP; he is now UC Berkeley Cooperative Extension specialist, a forest management expert. "We wanted to try a completely new approach, to integrate science and public participation from the start so forest management plans could move forward."

Adaptive management is a learn-by-doing approach, which allows managers to take action without complete information about a system. For SNAMP that meant scientists would collect and analyze pretreatment data, then the Forest Service would choose and carry out forest fuels treatments, including tree and brush removal and prescribed burns. During and after the treatments, scientists conduct research and report the results back to the Forest Service and the public to improve future fuels reduction treatments.

"In a scientifically sound adaptive management program, management is done as part of experimental treatments," said UC Berkeley environmental sciences professor John Battles, principal investigator for the multiteam project. "In SNAMP, we have tried to stay true to this vision while having scientists interact directly with stakeholders about all aspects of the scientific approach."

A female Pacific fisher and kit were monitored in the Sugar Pine study area.

Reducing fire danger

The Forest Service's goal is to diminish fire danger on 100% of an area by reducing trees and brush on about 20% to 30% of the landscape. This strategy is based on the theory that disconnecting areas with fuel concentrations will reduce the intensity of fire and so increase the percentage of trees and vegetation that survive. Two sites in the western Sierra Nevada were selected for the study: the Sugar Pine Project in the Sierra National Forest south of Yosemite National Park and the Last Chance Project in the Tahoe National Forest.

"Our project sites represent the major bio-geographical features of the Sierra Nevada," Battles said. "These mixed conifer forests offer suitable control and treatment watersheds and mature forest habitat for the wildlife species we wanted to study. They are also large enough to support landscape-scale research and planning by local Forest Service rangers."

In 2011, the Forest Service implemented three fuel reduction treatments in strategically placed areas of the Last Chance Project, including mechanical thinning and prescribed fire, as well as some treatments in the Sugar Pine Project. All treatments in both areas should be completed in 2012.

SNAMP includes six research and outreach teams, with 12 principal investigators and representatives from UC Berkeley, UC Merced, UC Cooperative Extension and the University of Minnesota. Each team has made progress toward their goals:

Fire and forest health. The fire and forest health team is investigating the effects of strategic fuel treatments on fire behavior and tree and forest health, and documenting fire histories for the two study areas. The team has collected data on tree size and species, analyzed hundreds of tree core samples and compared growth patterns of live and dead trees. They predict that the Forest Service treatments, when completed, will be effective at moderating wildfire behavior. Initial evidence suggests that forest thinning for fire control will improve tree growth even under adverse environmental conditions, such as drought.

California spotted owl. This team is surveying the Last Chance study site and nearby areas for owls and monitoring their breeding status. California spotted owls select habitats that have large trees and high canopy cover. The team has identified 75 owls in 48 territories within the study area. Using monitoring data, initial findings suggest that the owl population is in overall decline. The team is conducting a retrospective analysis on the history of land use and vegetation, considering all observable changes in owl habitat, to identify potential causes for the population decline.

Pacific fisher. The Pacific fisher research team is studying whether the small, weasel-like animal's population in the southern study area is stable or decreasing, and why. To date, the team has used radio collars and aerial telemetry to track the movements and dispersal of 103 individual Pacific fishers in and around the Sugar Pine area. By retrieving carcasses, the team has identified the top causes of mortality as disease and predation from bobcats, mountain lions or coyotes. Other causes are roadkill, starvation and accidental exposure to rodenticides.

Water. The water team is investigating the daily impacts of the fuel treatments on water quantity and quality. Treatments may affect patterns of snow buildup or melt, and stream flow timing. This data is fed into computer models to determine potential trends in stream discharge and sediment loading or snow accumulation and snowmelt rates. Using different parameters, such as a reduction in leaf area index, the team is modeling the effects of fuels treatments on stream flows and evapotranspiration rates.

Spatial analysis. The spatial team is mapping the forest before and after the Forest Service's vegetation treatments and measuring forest habitat characteristics across treated and untreated sites. Remote sensing of both study areas was done with lidar (light detecting and ranging), which works by emitting a light pulse toward the ground from a plane. Lidar allows scientists to record areas of bare earth, slope, aspect, elevation and canopy cover and produce two- and three-dimensional maps. The team can detect individual trees from a lidar data-point cloud, and they have used this data to characterize habitat for the wildlife teams.

UC Berkeley forest ecologist John Battles shows a SNAMP workshop participant how to read a tree ring core, near Forestville.

Public participation. The public participation team uses strategic facilitation and outreach to support the progress of adaptive management in the two project areas. The team hosts meetings, field trips, lectures, annual conferences and public presentations. It reaches a large and diverse population with submissions to blogs, industry publications and traditional media outlets, and maintains the SNAMP website. The team also researches how various public participation initiatives contribute to the adaptive management process and decision-making about Sierra Nevada forests. The team is hosting a public meeting on June 22 in Sacramento to develop recommendations and receive input on concluding the project in 2014.

— Jeannette Warnert

For more information:

Sierra Nevada Adaptive Management Project
http://snamp.cnr.berkeley.edu

Conservation tillage achieves record acreage, yields

Between 2008 and 2010, Central Valley farmers switched to conservation tillage on more than 344,000 acres used to grow row crops such as corn and wheat silage; meanwhile, in their 11th year of field research, UC scientists studying no-tillage practices achieved record yields in cotton and tomato.

A survey conducted in 2010 found that the amount of farmland under conservation tillage statewide grew by nearly 20% to nearly 1 million acres compared to a similar survey conducted in 2008, and by nearly 50% since surveying began in 2004.

Conservation tillage, a suite of low-impact cultivation practices that include leaving crop residues such as corn stalks in fields and planting new crops on top, significantly decreases the number of tractor passes needed to prepare fields for planting. This results in dramatically lower fuel, labor and maintenance costs for farmers — and less dust and diesel pollution in the air.

Photos: Sustainable Conservation

Planting with conventional tillage, *left*, generates dust; with conservation tillage, *right*, residues left on the surface prevent soil erosion and protect air quality.

"No-till makes sense as a means for lowering production costs, and cutting dust and potentially greenhouse gas emissions," said Jeffrey P. Mitchell, head of the UC Conservation Agriculture Systems Initiative (CASI), which conducted the survey with the nonprofit organization Sustainable Conservation.

"No-till also improves soil functions, such as increased carbon storage, greater stability of soil aggregates, increased porosity and water infiltration, and a larger population of earthworms" (see page 55).

The survey is part of an ongoing comparison of annual row-crop acreage farmed under a variety of tillage methods in nine Central Valley counties (Fresno, Kern, Kings, Madera, Merced, Sacramento, San Joaquin, Tulare and Yolo). Crops surveyed included silage, grains, tomatoes, cotton, dry beans and melons.

Farmers using conservation tillage also reported reductions in operating costs from 30% to 40% each year. Since 2004, farmers have saved more than $75 million, the survey found, and nearly half of all row-crop acreage in the San Joaquin Valley is now farmed using conservation tillage.

For more information:

Conservation Agriculture Systems Initiative
http://ucanr.org/CASI

Sustainable Conservation
http://www.suscon.org

Record no-tillage yields achieved in 2011

UC scientists for the first time achieved the same yields in cotton and tomato research plots managed under conservation tillage as they did on adjacent plots using conventional tillage practices.

"After toiling for more than a decade, we've finally succeeded in putting the pieces together this past season," said Mitchell, UC Cooperative Extension specialist in the Department of Plant Sciences at UC Davis. A cropping systems expert, Mitchell is based at the Kearney Agricultural Research and Extension Center in Parlier.

Researchers harvested 3.4 bales per acre of cotton and 53 tons per acre of processing tomatoes using no-tillage techniques. Plots managed with conventional tillage practices averaged about 3.4 bales per acre for cotton and 49 tons per acre for tomatoes.

The research was conducted at the UC West Side Research and Extension Center near Five Points. Mitchell and his Five Points team are part of CASI, a diverse group of more than 1,800 farmers, industry representatives, UC and other academic faculty, and Natural Resource Conservation Service and other public agency members.

Scientists established the cotton crop by direct seeding into beds that had not been touched since the preceding tomato crop, except by two herbicide sprays. The 2011 tomato crop was established with a no-tillage transplanter following the 2010 cotton crop, which had only been shredded and root-pulled under a waiver granted by the California Department of Food and Agriculture's Pink Bollworm Eradication Program.

The benefits of no-tillage farming have been recognized by researchers and farmers in other regions, such as the U.S. Great Plains and the Pacific Northwest, much of Canada and large areas of South America.

UC researchers estimated that switching to no-tillage reduced expenditures by about $135 per acre for the tomato crop and about $40 per acre for cotton. "These benefits start to pile up pretty fast once longer-term and broader sustainability goals are factored in," Mitchell said.

— *Jeannette Warnert and Editors*

No-tillage and high-residue practices reduce soil water evaporation

by Jeffrey P. Mitchell, Purnendu N. Singh, Wesley W. Wallender, Daniel S. Munk, Jon F. Wroble, William R. Horwath, Philip Hogan, Robert Roy and Blaine R. Hanson

Reducing tillage and maintaining crop residues on the soil surface could improve the water use efficiency of California crop production. In two field studies comparing no-tillage with standard tillage operations (following wheat silage harvest and before corn seeding), we estimated that 0.89 and 0.97 inches more water was retained in the no-tillage soil than in the tilled soil. In three field studies on residue coverage, we recorded that about 0.56, 0.58 and 0.42 inches more water was retained in residue-covered soil than in bare soil following 6 to 7 days of overhead sprinkler irrigation. Assuming a seasonal crop evapotranspiration demand of 30 inches, coupling no-tillage with practices preserving high residues could reduce summer soil evaporative losses by about 4 inches (13%). However, practical factors, including the need for different equipment and management approaches, will need to be considered before adopting these practices.

Jeffrey P. Mitchell

Conservation tillage allows growers to plant directly into fields that contain residue from prior crops. *Above,* tomatoes are transplanted into cover crop residues (triticale, rye and pea) in Five Points.

Improving water use efficiency is an increasingly important goal as California agriculture confronts water shortages. Changing tillage and crop residue practices could help.

Crop residues are an inevitable feature of agriculture. Because no harvest removes all material from the field, the remaining plant matter, or residue, accumulates and is typically returned to the soil through a series of mixing and incorporating operations involving considerable tractor horsepower (Upadhyaya et al. 2001), an array of tillage implements (Mitchell et al. 2009) and cost (Hutmacher et al. 2003; Valencia et al. 2002).

Managing residues to essentially make them disappear is the norm in California. Concerns about crop pathogens are exacerbated when organic materials accumulate on the soil surface (Jackson et al. 2002), and farmers believe that they need "clean" planting beds to make the seeding and establishment of subsequent crops easier and efficient. Residue management practices in California are also influenced by tradition; until recently, they had not changed significantly for 70 years (Mitchell et al. 2009).

In regions of the world where no-tillage systems are common — such as Brazil, Argentina, Paraguay, Canada, Western Australia, the Dakotas and Nebraska — generating and preserving residues are an indispensable part of management and major, even primary, goals of sustainable production (Crovetto 1996, 2006). Value is derived from residues in several ways: they reduce erosion (Shelton, Jasa et al. 2000; Skidmore 1986), provide carbon and nitrogen to soil organisms (Crovetto 2006) and reduce soil water evaporation (Klocke et al. 2009; van Donk et al. 2010), along with other advantages and drawbacks (see box, page 56).

Residue amounts vary widely in cropping systems (Mitchell et al. 1999; Unger and Parker 1976). While the weight of the residues may be important, most often the percentage of soil cover or the thickness of residues is used in assessing or distinguishing their benefits (Shelton, Smith et al. 2000; USDA NRCS 2008). From research back in the Dust Bowl era, soil scientists developed relationships between the amount and architecture of residues, including crop stubble, and the reductions in soil loss due to wind (Skidmore 1986) and water (Shelton, Jasa et al. 2000). Over time, 30% or more residue cover was associated with significant reductions in soil loss, and this level of cover became an important management goal in areas where soil loss was a problem, such as the Great Plains, Pacific Northwest and southeastern United States (Hill 1996). Eventually, 30% cover became the target linked to the definition of conservation tillage and also to the residue management technical practice standard that the U.S. Department of Agriculture's Natural

Online: http://californiaagriculture.ucanr.edu/landingpage.cfm?article=ca.v066n02p55&fulltext=yes
DOI: 10.3733/ca.v066n02p55

Resources Conservation Service has used for decades to evaluate conservation management plans (USDA NRCS 2008).

Soil water evaporation

Crop residues reduce the evaporation of water from soil by shading, causing a lower surface soil temperature and reducing wind effects (Klocke et al. 2009; van Donk et al. 2010). A number of studies from both irrigated and rain-fed regions around the United States where no-tillage is used have reported annual irrigation savings of as much as 4 to 5 inches (10 to 13 centimeters) (Klocke et al. 2009). Crop residues are left in the field under mechanized overhead irrigation systems. When irrigation wets the soil surface, evapotranspiration (ETc), which is the combination of transpiration and soil water evaporation, occurs. Transpiration, water moving into and through crop plants to the atmosphere, is essential for growth and crop production. Soil water evaporation, on the other hand, is generally not useful for crop production, although it does slightly cool the crop canopy microenvironment (Klocke et al. 2009).

Two processes govern soil water evaporation. When the soil is wet, evaporation is driven by radiant energy reaching the soil surface; this is called the energy-limited phase. Once the soil dries, evaporation is governed or limited more by the movement of water in the soil to the surface; this is the soil-limited phase. Subsurface drip irrigation, which typically keeps the soil surface dry, generally greatly reduces soil water evaporation (Allen et al. 1998). Irrigation systems such as furrow and overhead that frequently leave the soil surface wet can result in an evaporation loss of about 30% of total crop evapotranspiration (Klocke et al. 2009), depending on irrigation frequency.

At Kansas State University's Southwest Research and Extension Center, near Garden City, Kansas, full-surface residue coverage with corn stover and wheat stubble has been shown to reduce evaporation by 50% to 65% compared to bare soil with no shading (Klocke et al. 2009). The type of residue, though, is important, as residues from crops such as cotton and grain sorghum, which produce less material, would need to be concentrated to impractical levels to achieve evaporation decreases comparable to those obtained by typical residues from irrigated wheat (Unger and Parker 1976).

Converting to no-tillage has also been shown to reduce irrigation water needs because soil water evaporation is reduced (Pryor 2006). Conventional intercrop tillage typically involves a number of tillage passes; this is the case, for example, in the spring between winter wheat or triticale and corn seeding in San Joaquin Valley dairy silage production systems, or virtually any conventional crop rotation in which spring tillage is performed (Mitchell et al. 2009). Research in Nebraska has shown that these tillage operations dry the soil before planting to the depth of the tillage layer and that typically 0.3 to 0.75 inch (0.8 to 1.9 centimeters) of soil moisture may be lost per tillage pass (Pryor 2006). In Nebraska, switching from conventional tillage to no-tillage under center-pivot irrigation has been shown to save 3 to 5 inches (8 to 13 centimeters) of water annually, with an added savings of $20 to $35 per acre from pump costs (Pryor 2006). Water savings of 8 inches (20.3 centimeters) annually have been documented when conventional tillage under furrow irrigation was converted to no-tillage under overhead irrigation.

The water conservation value of crop residues and conservation tillage (Mitchell et al. 2009) has not been evaluated in the warm, Mediterranean climate of California. The objective of our study was to determine the effects of residues and no-tillage on soil water evaporation in California conditions.

Tillage studies

To determine the effects of intercrop tillage on soil water storage, we conducted

Glossary

Conservation tillage: As defined by the Conservation Agriculture Systems Initiative, a wide range of production practices that deliberately reduce primary intercrop tillage operations such as plowing, disking, ripping and chiseling, and either preserve 30% or more residue cover (as in the classic Natural Resources Conservation Service definition) or reduce the total number of tillage passes by 40% or more relative to what was customarily done in 2000 (Mitchell et al. 2009).

Conventional, or traditional, tillage: The sequence of operations most commonly or historically used in a given geographic area to prepare a seedbed and produce a given crop (MPS 2000).

No-tillage, or direct-seeding: Planting system in which the soil is left undisturbed from harvest to planting, except perhaps for the injection of fertilizers. Soil disturbance occurs only at planting by coulters or seed disk openers on seeders or drills (Mitchell et al. 2009).

Residues: Plant materials remaining on land after harvesting a crop for its grain, fiber, forage and so on (Unger 2010).

Strip-tillage: Planting system in which the seed row is tilled prior to planting to allow residue removal, soil drying and warming and, in some cases, subsoiling (Mitchell et al. 2009).

Advantages and drawbacks of agricultural residues

Advantages	Drawbacks
Increase infiltration and storage of rainfall	Decrease surface soil temperatures
Reduce sealing of surface soil	Increase some crop diseases
Reduce runoff	Retain more surface soil water, which can restrict access to field
Reduce water erosion	Reduce herbicide effectiveness
Reduce soil water evaporation	Create challenges for seeding and crop establishment
Provide habitat and food sources for earthworms	
Increase snow trapping and subsequent water storage from melted snow	

studies in 2009 and 2010 at the UC West Side Research and Extension Center in Five Points. We monitored the surface water content in a Panoche clay loam soil during the transition from wheat harvest to corn seeding under no-tillage and standard tillage. Each treatment plot consisted of fifteen 5-foot-by-300-foot beds and was replicated three times in a randomized complete block design. Following wheat silage harvest in late April of each year, the no-tillage plots were left undisturbed, while the standard tillage plots were disked twice, chiseled to an approximate depth of 1 foot and disked again before being listed to recreate 5-foot-wide planting beds for corn.

Surface soil water content in the top 0 to 5 inches and 0 to 8 inches (0 to 12 and 0 to 20 centimeters) of soil was monitored during this transition between crops, using time-domain reflectrometry (TDR) (Hydrosense, Campbell Scientific, Logan, UT) instrumentation that had been calibrated for the experimental soil and gravimetric water content techniques. Water content sampling consisted of about 12 TDR readings made in the outer 6 inches of randomly selected bed tops in each plot and four to six 3-inch-diameter soil cores collected in similar areas and composited for each gravimetric water content measurement. Soil bulk density was determined at the start of each study.

To account for possible changes in soil bulk density resulting from standard tillage, two 3-inch-diameter soil cores per plot were collected, dried and weighed following the disking operations. These density determinations were then used with the gravimetric water content measurements to calculate soil volumetric water content (SVWC). Percentages of wheat straw and corn stover residue cover were determined using the line-transect method (Bunter 1990).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A 2-year study at the UC West Side Research and Extension Center in Five Points compared soil water content in tilled (right, subsoil ripped) and no-tillage (left) plots.

Residue studies

The effects of wheat straw residues on soil water evaporation were determined in one study in 2009 and two studies in 2010. These studies were also conducted in a Panoche clay loam soil at the UC West Side Research and Extension Center. Before each study, the field was prepared by disking, land planing and ring rolling to create uniform and level conditions throughout. Soil in the entire experimental field had been similarly managed before each study in terms of previous cropping and tillage. Residue and bare-soil treatment plots measured 65.8 by 75.1 feet and were replicated four times in a randomized complete block design.

The residue plots were established by manually placing wheat straw on them to an approximate height of 4 inches (10 centimeters); the straw was collected from a uniform crop that had been grown and chopped as for silage in the study field before the start of each study. An overhead, hose-fed, eight-span, lateral-move irrigation system (Model 6000, Valmont Irrigation, Valley, NE) fitted with Nelson (Walla Walla, WA) pressure-regulated nozzles at 48 inches above the soil surface and 5-foot spacing was used to apply 2.5 inches (6.4 centimeters) of water to each plot in the 2009 study and 1.2 inches (3.0 centimeters) to each plot in the 2010 studies. This system's nozzle and hose configurations provided Christensen application uniformities (CUs) of 93%.

Surface soil water content (in the top 0 to 5 and 0 to 8 inches of soil) was monitored daily, using TDR and gravimetric water content techniques. In 2009, monitoring was done for 14 days before irrigation and 7 days after, and in 2010, monitoring was done only for 7 days after. Each daily sampling consisted of about 15 TDR readings collected along both sides of two transects in each plot and four soil cores 4 inches (10 centimeters) in diameter taken in similar areas of each plot and composited for gravimetric water content measurements. Soil bulk density measurements were made for each study using the compliant cavity method (USDA NRCS 1996).

Aboveground air temperatures (1 meter above the soil surface) and soil temperatures at 0.4, 3.4 and 7.9 inches (1, 10 and 20 centimeters) below the soil surface were determined every 15 minutes during the second study in 2010, using HOBO Pro v2 data-logging sensors (Spectrum Technologies, IL). Percentage canopy cover was determined by placing a LI-191 Line Quantum Sensor (LI-COR, Logan, UT) in full sun and then below the residue at six locations in each residue plot and calculating the amount of photosynthetically active radiation that had been intercepted by the residue.

TABLE 1. Soil volumetric water content at depths of 0–5 and 0–8 inches in conventional tillage plots (before and after tillage) and no-tillage plots, 2009 and 2010

	2009		2010	
Tillage system	Before	After	Before	After
	%		%	
0–5 in (0–12 cm)				
Conventional	20.7a*	12.8b	20.0a	11.9b
No-tillage	19.9a	22.5a	20.9a	20.2a
0–8 in (0–20 cm)				
Conventional			23.5a	13.7b
No-tillage			21.7a	23.4a

* Values are means of four replications. Means within a column followed by the same letter are not significantly different at $P = 0.05$ according to Fisher's Protected LSD.

Less evaporation with no-tillage

In both years, the five tillage passes performed in the conventional plots — over about 5 days after wheat chopping and before corn seeding — reduced the SVWC in the soil's top 5 inches (13 centimeters) (table 1). The reduction was 7.9%

in 2009 and 8.1% in 2010; the SVWC in the no-tillage plots remained unchanged. When the SVWC was recorded in the top 8 inches of the soil in 2010, we found it was reduced by 9.8%, or 0.77 inch, in the tilled plots. Extrapolating the reduction in the top 5 inches to a 1-foot depth, which more closely matches the actual depth of tillage, suggests that the soil water losses from tillage might have been 0.93 inch (2.4 centimeters) in 2009 and 0.96 inch (2.4 centimeters) in 2010.

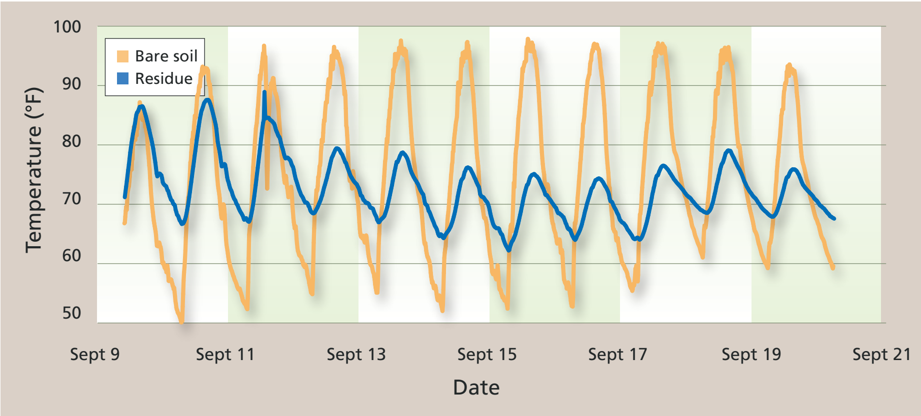

Fig. 1. Maximum soil temperature (°F) at 1 centimeter below soil in bare-soil and residue-covered plots, 2010 evaporation study.

TABLE 2. Soil volumetric water content in bare-soil and residue treatments at depths of 0–5 and 0–8 inches, 2009	Sept. 4	Sept. 10	Sept. 18
	%		
0–5 in (0–12 cm)			
Bare soil	45.0b*	23.4b	16.7b
Residue	48.2a	37.2a	34.4a
0–8 in (0–20 cm)			
Bare soil	43.6a	26.7b	21.6b
Residue	45.6a	35.8a	33.4a

* Values are means of four replications. Means within a column followed by the same letter are not significantly different at $P = 0.05$ according to Fisher's Protected LSD.

TABLE 3. Soil volumetric water content in bare-soil and residue treatments at depths of 0–5 and 0–8 inches, first and second 2010 studies	Aug. 3	Aug. 4	Aug. 10
	%		
0–5 in (0–12 cm)			
Bare soil	7.0a*	34.4a	15.2b
Residue	8.3a	35.3a	24.4a
0–8 in (0–20 cm)			
Bare soil	7.1a	29.8a	15.6b
Residue	7.9a	29.6a	27.7a
	Sept. 9	**Sept. 11**	**Sept. 18**
	%		
0–5 in (0–12 cm)			
Bare soil	7.7a	42.5a	22.0b
Residue	8.7a	43.2a	30.0a
0–8 in (0–20 cm)			
Bare soil	8.6a	37.7b	19.2b
Residue	8.1a	32.4a	22.9a

* Values are means of four replications. Means within a column followed by the same letter for a given soil depth are not significantly different at $P = 0.05$ according to Fisher's Protected LSD.

In 2009 and 2010, the percentage residue cover (75% and 95%, respectively) in the no-tillage plots was many times higher than in the tilled plots (7.5% and 6.0%, respectively). Although no-tillage management eventually will improve the soil's water-holding characteristics, our studies had not been in place long enough to produce such a change. It is likely that the differences in SVWC between the tilled and no-tillage plots resulted from increased soil-water evaporation in the tilled plots relative to the no-tillage plots.

Impact of residues

In the residue studies, we applied wheat straw residue to a depth of about 4 inches (10 centimeters), which is comparable to application rates in other residue studies (Klocke et al. 2009; Unger and Parker 1976) and to levels of residue accumulation recently measured in sustained tomato and cotton conservation-tillage systems at the same research site and also in related corn and tomato conservation-tillage studies on the UC Davis campus (Mitchell et al. 2005). The soil coverage was over 95% in each of the three studies.

Residues reduced near-surface daily maximum soil temperatures, measured under the residues at 0.4 inch (1 centimeter) below the soil surface, by up to 20°F relative to bare-soil conditions during the second 2010 study (fig. 1). At the end of each of the three studies, our recordings showed that more water was retained in the soil under the residues than in the bare-soil plots (tables 2 and 3). The amount of retained water in the soil at the end of the studies could have been affected by evaporation losses, initial SVWC and percolation losses. Numerical simulation of water flow in the control volume — using HYDRUS 1-D software and data from the 2010 studies — indicated that the effect of percolation losses on the difference in evaporation losses between the residue and bare-soil plots was negligible (Singh et al. 2011).

Differences in SVWC between the bare-soil and residue plots at the shallow depth (top 5 inches) were greatest in the 2009 study, when 0.83 inch (2.1 centimeters) more water was retained in the residue than in the bare-soil plots. In the first

2010 study, the difference was 0.43 inch (1.1 centimeter) and in the second 2010 trial, 0.38 inch (0.97 centimeter) (data not shown). A portion of this difference in SVWC between residue and bare-soil crops was caused by the different initial SVWC in the plots. Accounting for the initial SVWC, the change in SVWC due to evaporation was 0.68 inch (1.7 centimeters) in 2009, 0.37 inch (0.9 centimeter) in the first 2010 study and 0.33 inch (0.8 centimeter) in the second 2010 study. The particularly high number for the 2009 study was a result of the longer evaporation estimation period — 2 weeks rather than 7 to 8 days as in the other two studies; the change in SVWC for 1 week during the 2009 study was 0.50 inch (1.3 centimeters). The changes in SVWC between treatments at the greater depth (top 8 inches) ranged from 0.33 inch (0.8 centimeter) to 0.89 inch (2.3 centimeters) when differences in initial SVWC were accounted for.

As shown in other studies, the evaporation rate from bare soil after initial wetting is greater than from soil under residues. Residues shield the soil surface from solar radiation. Likewise, air movement at the soil surface is reduced under residues, resulting in a lower evaporation rate (van Donk et al. 2010). However, if the soil under residues is not rewetted by irrigation or rainfall, evaporation will continue and after many days can exceed that from bare soil.

In our studies, about 0.06 to 0.08 inch (0.15 to 0.2 centimeter) of the initial applied water was retained in the residue itself (fig. 2). This water, however, almost completely evaporated within about 2 days. These recordings match quite closely the results of studies in Nebraska, where 0.08 to 0.1 inch (0.2 to 0.3 centimeter) of water evaporated from residue after wetting events (van Donk et al. 2010). They indicate that evaporation losses from residues can be significant, particularly if irrigation or rainfall is light and frequent. Evaporation of 0.1 inch from an 0.5-inch (1.3-centimeter) application is a 20% loss, which is significant (van Donk et al. 2010). Heavier or less-frequent irrigations would be more effective in decreasing the proportional water loss from residues; however, concerns about runoff at high application rates may limit an irrigator's option to do that. In this regard, no-tillage offers an advantage: sustained no-tillage allows higher irrigation rates before runoff, because changes in soil structure and porosity result in higher infiltration rates (Pryor 2006).

The water evaporation rate from plots with residue (example at right) was consistently lower than from bare-soil plots (left) after overhead irrigation, in Five Points.

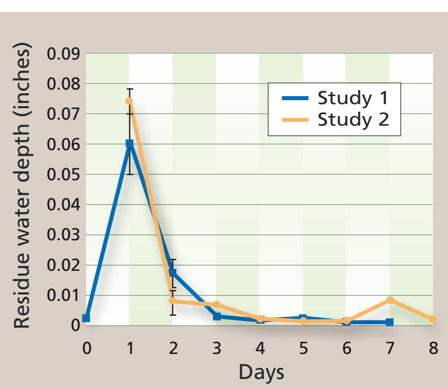

Fig. 2. Amount of water in residue during 2010 evaporation studies.

Water conservation

The general finding that residue cover tends to reduce soil water evaporation relative to bare soil has been consistently shown in a wide range of studies (Crovetto 1996; Klocke et al. 2009; Unger and Parker 1976; van Donk et al. 2010). The water conservation value of residues, however, remains controversial for a number of reasons (van Donk et al. 2010). In some U.S. regions, the harvest of residues for animal feed or as a source of cellulose for domestic biofuel production is increasing. Because maintaining residues has long been a conservation goal and a primary means for reducing erosion, research is now under way in these areas to evaluate the impacts of crop residue removal and develop recommendations for sustainable removal rates (Andrews 2006) and to better quantify both the agronomic and economic effects of residues on components of the soil water balance (van Donk et al. 2010).

Predicting or projecting the season-long impacts of residue cover relative to bare soil is complicated and depends on a number of interacting factors, including soil type, planting date, crop type, crop spacing, irrigation frequency and potential evapotranspiration. Work by Klocke et al. (2009) in Kansas suggested that residues may reduce energy-limited evaporation by 50% to 65% compared with evaporation from bare soil with no shading.

Our study is limited because we did not have a crop growing in the field when the measurements were taken. To compare our findings with recent similar studies that have included a transpiring crop, we estimated the longer-term impacts of having residues in a field relative to bare soil using data from our study and the following assumptions: (1) bare soil in our three studies evaporated about 84% more water than the soil with residues; and (2) for a typical summer crop produced in the Five Points region, evapotranspiration is about 30 inches.

We used two different data sources to estimate the longer-term water conservation potential of residue-covered versus bare soil. Data from Garden City, Kansas, indicated that evaporation was about 30% of evapotranspiration for a center-pivot-irrigated corn crop (Klocke et al. 2009). In addition, unpublished data from B. R. Hanson suggested that evaporation on furrow-irrigated tomatoes in California as a percentage of evapotranspiration is more like 15%. Under these two scenarios, an 84% reduction in evaporation under residues would correspond to 2.1 inches (5.3 centimeters) more water lost from bare soil than from under residues if evaporation were 15% of evapotranspiration, and 4.1 inches (10.4 centimeters) if evaporation were 30% of evapotranspiration. This extrapolation is remarkably close to the 3.5 to 4.1 inches (9.0 to 12.4 centimeters) of water savings from leaving residues on cornfields in west-central Nebraska (van Donk et al. 2010) and the 2.9 inches (7.5 centimeters) of water savings in Nebraska on irrigated cornfields with growing-season crop residues (Klocke et al. 2009).

Prospects for California

Improving the water use efficiency of crop production by increasing the amount of water that is transpired by a crop relative to the amount that is evaporated by the soil has been identified as a management goal for California agriculture (Burt et al. 2002; Hsiao and Xu 2005). Transitioning from tillage and residue management practices used in California today to high-residue, no-tillage practices may partially accomplish this goal, according to our studies and similar recently published studies in Nebraska and Texas. In our studies, coupling no-tillage with high-residue preservation practices could reduce soil water evaporative losses during the summer season by about 4 inches (10.2 centimeters), or 13%, assuming a seasonal evapotranspiration demand of 30 inches. In Texas, a study of strip-till cotton grown in wheat residues, compared to cotton under conventional tillage, showed decreased soil water evaporation, increased crop transpiration and an increase in water use efficiency of 37% (Lascano et al. 1994).

Coupling no-tillage with high-residue preservation practices could reduce soil water evaporative losses during the summer season by about 4 inches.

However, a number of practical factors will need to be addressed before any wholesale transformation to no-tillage, residue-preserving production can be envisioned in California; these include the relative ease with which a farm's existing cropping mix might be converted to no-till, the need for and cost of new equipment and the learning curve for new management practices. Also, more research is needed on water balance and crop productivity under no-tillage and high-residue field conditions.

Certain California cropping systems, such as dairy silage and small grain rotations, may initially be more amenable to being converted to no-tillage and to maintaining sufficient residue amounts than others. Surveys conducted by the Conservation Agriculture Systems Initiative, for instance, have documented that high residue levels are achieved in sustained no-tillage and strip-tillage dairy silage fields. Long-term studies with conservation tillage and cover-cropped tomato and cotton rotations in Five Points, and conservation-tillage corn and tomato in Davis, have also demonstrated the ability to maintain high residue levels while

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No-tillage corn grows in triticale and corn residues in Turlock.

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In Five Points, soil is disked to incorporate residues — the conventional practice. Transitioning to reduced-tillage practices could significantly improve water use efficiency in California agriculture.

sustaining productivity (Mitchell et al. 2005; Mitchell et al. in press).

The use of cover crops to provide relatively high surface residue levels has also been tried commercially in tomato fields in the western San Joaquin Valley in recent years. Transitioning to such management systems, however, has required considerable planning, know-how and persistence. The reductions in soil water evaporation that have been shown here add to the list of benefits of conservation-tillage systems for California producers (Mitchell et al. 2009; Mitchell et al. in press).

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For more information:

Conservation Agriculture Systems Initiative
http://ucanr.org/CASI

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In Firebaugh, fresh-market tomatoes will be planted directly into a triticale cover crop that has been treated with herbicides.

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Research and adoption of biotechnology strategies could improve California fruit and nut crops

by Victor M. Haroldsen, Gabriel Paulino, Cecilia L. Chi-Ham *and* Alan B. Bennett

California's fruit and nut tree crops represent one-third of the state's cash farm receipts and 70% of U.S. fruit and nut production. Advances in crop biotechnology and genetic engineering could help protect these valuable crops from pests and diseases and improve productivity. However, due to the difficulty of genetically engineering woody tree crops, as well as intellectual property concerns, regulatory hurdles and public perceptions about genetic engineering, biotechnology has not gained a foothold in this area of agriculture. Our survey of published genetic engineering research and issued field trial permits between 2000 and 2011 revealed that citrus and grape are the focus of most current work, and that walnut — not the more widely planted almond — is the focus among nut crops. Matching publicly funded genetic engineering research projects to a survey of the industry's top needs, we found that far less than half of the funded research has focused on the top-identified pest and disease threats. The most promising genetic engineering technology for fruit and nut tree crops may be transgrafting, which could address consumer concerns and benefit growers.

Okanagan Specialty Fruits

Genetically engineered field crops such as corn and soybeans are widely planted in the United States, but few fruits or nuts have been commercialized. Okanagan Specialty Fruits of Canada is seeking regulatory approval for its genetically engineered Arctic apple (right). This apple's browning genes were replaced with nonbrowning apple genes that produce too little polyphenol oxidase to trigger browning (left). The nonbrowning trait can be introduced into any apple variety.

Biotechnology is a unique avenue for incorporating innovations into crop plants. In general, growers have a vested interest in adopting technologies that can raise crop yields by reducing disease pressure or improving growth conditions, yet growers remain skeptical of genetic engineering innovations due to the uncertainty of consumer and market acceptance (Mulvaney et al. 2011). On a global scale, however, transgenic crops are making an impact: in 2010, transgenic crops contributed an estimated $10.7 billion in direct global farm income, while providing a reduction of 86.2 million pounds (10.2%) of pesticide usage and proffering an associated 21.8% reduction in the environmental impact quotient, a "field value per hectare" metric that takes into account toxicity and environmental exposure data related to individual pesticides (James 2010).

Currently marketed genetically engineered crops mainly consist of large-acreage row crops such as cotton, soybean, corn and canola. To date, genetically engineered fruit and nut trees include only virus-resistant papaya (*Carica papaya*), which significantly benefited the Hawaiian industry (Gonsalves 2004), and a more recently approved, but not yet commercialized, plum pox virus–resistant plum (*Prunus domestica*). The challenge remains to extend the benefits that biotechnology can deliver to a broader range of agriculturally important crops.

According to the U.S. Department of Agriculture's (USDA) Economic Research Service, California was the number one exporter of agricultural commodities in the United States in 2010; the state's total cash farm receipts, including exports, were $37.6 billion, of which one-third were fruits and nuts (USDA ERS 2011). In 2010, California contributed over $13.2 billion to the total $20.9 billion U.S. fruit and nut market (USDA NASS 2011).

In agriculture, biotechnology involves the insertion of one or more specific genes into a plant to impart a new characteristic or trait. These new traits can endow the modified plant with better resistance to insects, herbicides, disease or environmental stressors such as drought. An example of one of the most widespread applications of agricultural biotechnology is the use of glyphosate-tolerant (Roundup Ready) soybeans.

Often cited as the "birthplace of biotechnology," California has remained relatively open to biotechnology and genetic engineering innovations in agriculture. Since 2000, the USDA Animal and Plant Health Inspection Service has issued

Online: http://californiaagriculture.ucanr.edu/landingpage.cfm?article=ca.v066n02p62&fulltext=yes

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more than 1,100 environmental release or interstate movement permits for genetically engineered crops in California, more than twice the number issued in any other U.S. state (USDA APHIS 2011).

In a state where agriculture plays such an important role in the economy and where the biotechnology industry has such a strong presence, we sought to determine the status of biotechnology applications in a subset of California specialty crops: the top 10 woody fruit and nut crops, by production value. To gain a general overview of this status, we first examined the number of peer-reviewed publications that described genetic engineering technologies among these crops. Next, to assess the research priorities supported by industry, we surveyed individual fruit and nut crop advisory boards, obtained input from UC Cooperative Extension advisors and the UC Fruit and Nut Research and Information Center, as well as the UC Statewide Integrated Pest Management (IPM) Program website. This information allowed us to assess the most pressing pest- and disease-related issues for these crops. We then examined which issues were being addressed using biotechnology by assessing the number of related scientific publications and genetic engineering field permits for each fruit and nut crop. Lastly, we looked at the concept of transgrafting fruit and nut trees on to genetically engineered rootstock, how this could benefit growers, and the regulatory hurdles this technology may face.

Top 10 fruit and nut crops

California's fruit and nut tree crops consist of 35 species, ranging from almond to walnut and including a number of berries (USDA NASS 2011). We analyzed and ranked these crops in terms of value. Excluding strawberry (*Fragaria x ananassa*), the top 10 woody fruit and nut crops had a cumulative production value of $10.86 billion in California, representing 77% of total U.S. production (fig. 1).

In 2010, California produced 14.8 million tons (13.4 million metric tons) of fruits and nuts, 60% of the U.S. utilized production (the amount of a farm's crop that is sold), with citrus (*Citrus* spp.) and grape (*Vitis vinifera*) comprising the majority of this amount (fig. 2, table 1). California was a major producer of almond (*Prunus dulcis*), walnut (*Juglans regia*), pistachio (*Pistacia vera*), avocado (*Persea americana*), plum (*Prunus domestica*), peach (*Prunus persica*) and grape, accounting for 76% to 100% of all U.S. production for each (fig. 2, table 1). California citrus accounted for one-third of U.S. production volume and 44% of total U.S. production value at $1.3 billion in 2010 (fig. 1). Additionally, 9% of the total top 10 U.S. fruit and nut products was exported in 2010, 60% of which were produced in California. Almond, walnut and pistachio contributed most to total U.S. export value, tallying $3.24 billion of $3.78 billion in exports in 2010 (USDA ERS 2011).

Improved crop management and agronomic practices have helped attain high levels of productivity for major crops such as wheat, rice and maize (Oerke and Dehne 2004). Crop protection has also played an integral role in maintaining productivity in the face of challenges by viruses, bacteria and fungi. The use of biotechnology in protecting crops from disease and pests promises even greater potential for productivity. Implementing

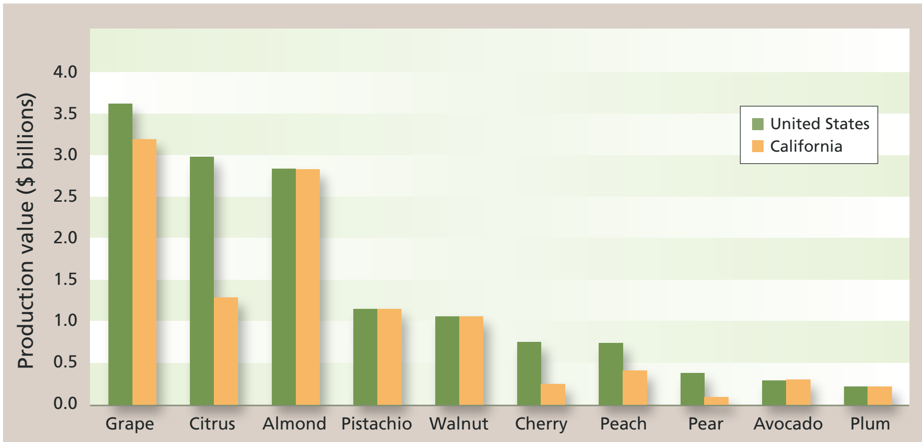

Fig. 1. Production value of top 10 woody fruit and nut tree crops in the United States and California, 2010. Crops are ranked in descending order of U.S. production value.

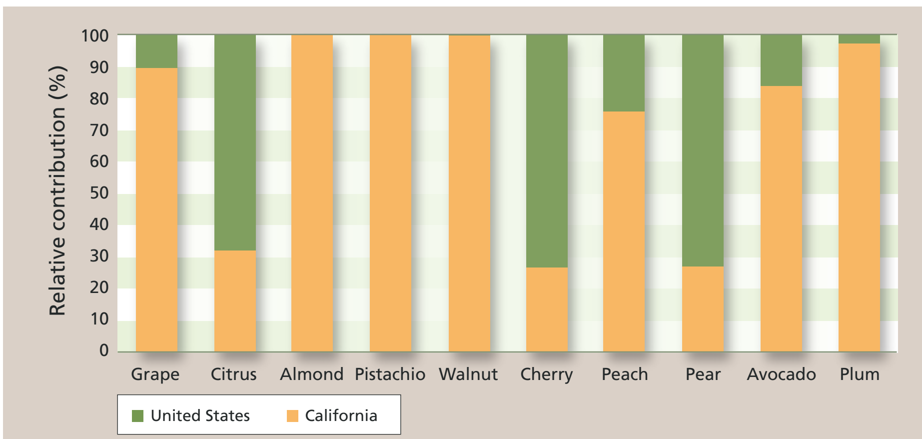

Fig. 2. Relative contribution of California production to total U.S. production of top 10 woody fruit and nut crops, 2010. Crops are listed left to right in descending order of U.S. production value.

TABLE 1. Export tonnage and value for top 10 California woody fruit and nut crops, 2010

	Grape*	Citrus	Almond	Pistachio	Walnut	Cherry	Peach	Pear	Avocado	Plum
U.S. production (1,000 tons)	7,412	11,734	1,414	261	503	348	1,364	814	149	531
Exported (%)	< 1	10	71	66	43	17	4	1	14	13
Export value ($ millions)	11.7	293.1	2,021.8	766.9	453.2	129.9	30.8	2.7	43.9	30.0

* Crops listed left to right in descending order of U.S. production value.

biotechnology strategies might help growers realize substantial yield gains similar to those that have been documented for other genetically engineered crops during the last decade (James 2010). Underscoring the significance of this potential, in 2009, 75% of the $10.7 billion in estimated economic benefits from genetically engineered soy, maize, cotton and canola were due to yield gains alone (James 2010). It remains to be seen what sorts of yield gains would be possible for genetically engineered fruits and nuts.

Survey of public research

Using keyword searching in ISI Web of Knowledge and OvidSP CAB Abstracts databases, over 4,400 international, English-language, scientific publication entries were obtained, and 139 of these were compiled and reviewed in detail.

The scientific publications that we examined described genetic engineering strategies related to improving general agronomic properties such as drought, salinity or temperature tolerance; the modification of flowering time or plant architecture; herbicide resistance; product quality traits; and bacterial, fungal, insect and viral resistance. We examined only strategies demonstrating potentially useful applications for the fruit and nut industry; we did not consider publications that solely addressed genetic engineering methods or involved genes unrelated to agricultural productivity.

The number of permits giving permission to field-test noncommercial, genetically engineered plants was obtained from various USDA agencies from 2000 to 2011. We recognize that given the long time frames for developing and deregulating transgenic fruit and nut trees (transgenic plum has taken nearly 20 years, for example), field permits for research are frequently renewed and often overlap. The way in which field permit data is submitted makes it extremely difficult to follow the process of a single transgenic crop that is being developed, so we cannot be certain of the extent of this overlap. However, the continual renewal of permits indicates, at the very least, that research on specific crops continues to move through the regulatory chain.

Our survey showed that research publications and field permits related to genetic engineering were concentrated in the highest-value crops, except for almond, which ranked third in U.S. production value (fig. 1) yet had only one publication and no field permits (fig. 3). Given the large production value of grape and citrus, we were not surprised that there were more scientific publications and field permits for these crops than for those with lower production value. The lower-value crops pistachio, avocado, cherry and peach had too few genetic engineering–related publications or field trials for us to accurately evaluate them.

These plums genetically engineered to resist the plum pox virus have received regulatory approval in the United States but have not yet been commercialized.

Almond is lagging far behind other crops in relation to biotechnology-based research; however, taking into account the large export market for almonds (table 1) and the unfavorable international perception of genetically engineered products, it is understandable that this industry may be hesitant to explore the potential of transgenic technologies at present. Major trading partners such as Japan and the European Union will not import genetically engineered crop products. Interestingly, 43% of U.S. walnuts were exported last year and walnuts ranked third in overall export value, yet this sector is taking the lead within the nut tree industry, with several genetic engineering publications and field permits.

Both citrus and grape had a similar total number of field permits plus publications — the top two in this study. However, grape genetic engineering research had nearly twice as many field permits as publications, while citrus had only one-third as many field permits as publications. This suggests that grape research has been more effectively translated from the laboratory to the field. This may be due, at least in part, to support for the grape industry to find innovative solutions to potentially devastating diseases. In recent meetings of the Pierce's Disease Board, the magnitude and significance of Pierce's disease to the California grape and wine industry were central to discussions, and research results that directly addressed combating Pierce's disease were underscored as vitally important (CDFA 2007). Industry encouragement and incentives may be paramount to ensuring that research enters the translational pipeline to field evaluation and ultimately to commercial implementation.

Industry needs and public research

Economic losses due to pests and diseases in fruit and nut tree crops are not reported consistently on an annual basis. However, based on the results from other major crops, losses may approach 32%, with potential losses as high as 67% if integrated pest management practices are

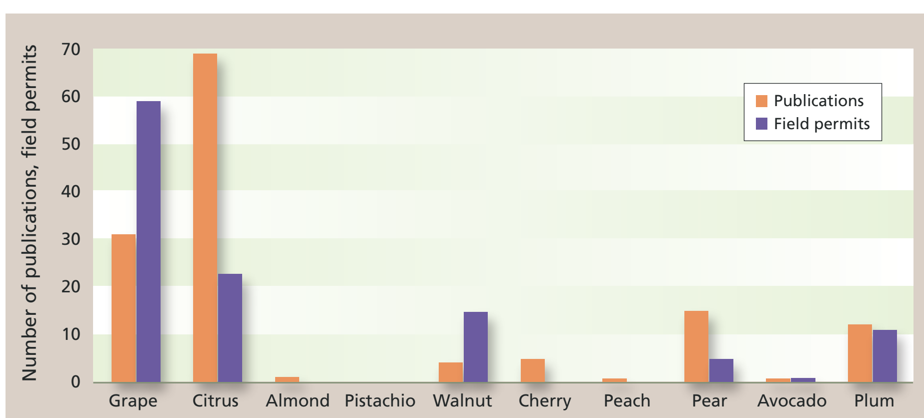

Fig. 3. Number of scientific publications and field permits in public databases for genetically engineered fruit and nut crops, 2000–2011. Crops are shown left to right in descending order of U.S. production value.

not used (Oerke and Dehne 2004). Under a worst-case scenario, this represents a potential $3.5 billion to $7.3 billion loss for California's fruit and nut sector. With such a large fraction of California's agricultural economy dependent on consistent yields of these crops, pest- and disease-related losses directly affect the financial viability of the state's agricultural sector.

Since public-private partnerships are intrinsic to California agriculture, we investigated if industry pest and disease priorities were aligned with genetic engineering research being performed at public institutions. Through personal communications with fruit and nut advisory boards and UC Cooperative Extension advisors, we identified the most pressing pest- and disease-related issues that threaten California fruit and nut crops (table 2). Additionally, we reexamined the 139 scientific publications previously mentioned and assigned them to research categories.

Our results indicated that most genetic engineering research in fruit and nut trees was focused on pest- and disease-related issues (fig. 4), with the other major focus on agronomic properties, such as early-flowering phenotype or salinity tolerance. Surprisingly, only 5% of genetic engineering research was devoted specifically to insect resistance. In contrast, researchers working on major row crops such as cotton and maize tend to use insect-resistance traits — such as technologies based on Bt (*Bacillus thurengiensis*) — as a significant portion of their genetic engineering portfolio.

The two crops with the greatest amount of research, citrus and grape, had 62 pest- or disease-related publications describing genetic engineering strategies (figs. 5A and 5B, table 2). Publications were classified as disease and pest related if the genetically engineered trait targeted a fungus, bacteria, insect or virus. The publications data column in table 2 shows the number of peer-reviewed publications that describe genetic engineering strategies for a crop's top-identified diseases and pests; the second column shows the number of publications describing genetic engineering strategies for all diseases and pests, not just the top-identified problems. For example, citrus had 42 publications that used genetic engineering to target a pest or disease, but only 13 of those were directed toward citrus canker, one of its top-identified diseases.

The grape and citrus industries have identified the most critical pests and diseases to bring under control. Citrus greening, or huanglongbing (HLB), is high on the list. It is one of the most serious disease threats in citrus to emerge in recent years, with no known effective control other than to remove infected trees. Although it is not known to have entered California, HLB is present in several southeastern states, and strict quarantine controls are currently the only way to keep it at bay (USDA APHIS 2010). With such a devastating disease looming, the need to find and implement solutions, whether conventional or biotechnology-based, cannot be overstated.

Comparing pest and disease concerns identified by industry members to published research topics, we found that far less than half of the published genetic engineering research has focused on the top-identified threats (table 2). Recognizing the time frames involved in fruit tree research, it is possible that ongoing research simply has not been published yet. If industry needs and public research efforts are aligned, we would expect that after a lag period, genetic engineering research related to many of these pests and diseases will be published in the near future. Citrus and grape may have the highest number of pest and disease issues being addressed because of the involvement of commodity funding organizations such as the Citrus Research and Development Foundation and the Pierce's Disease/Glassy-winged Sharpshooter Board. Interactions between

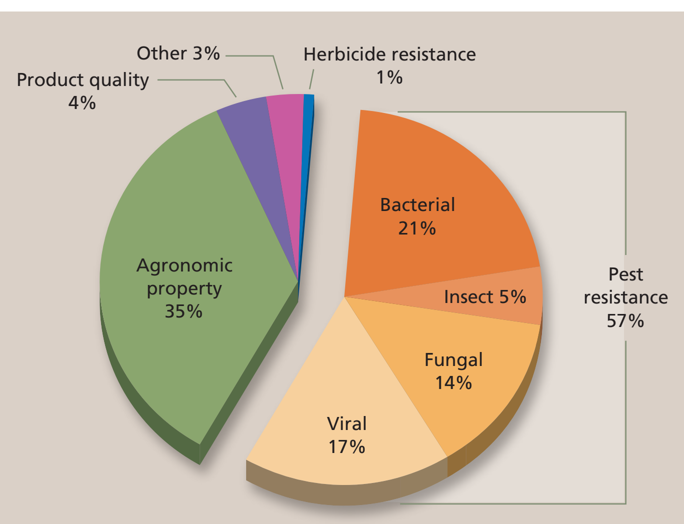

Fig. 4. Categories of genetic engineering research found in publications for the top 10 woody fruit and nut crops (*n* = 139).

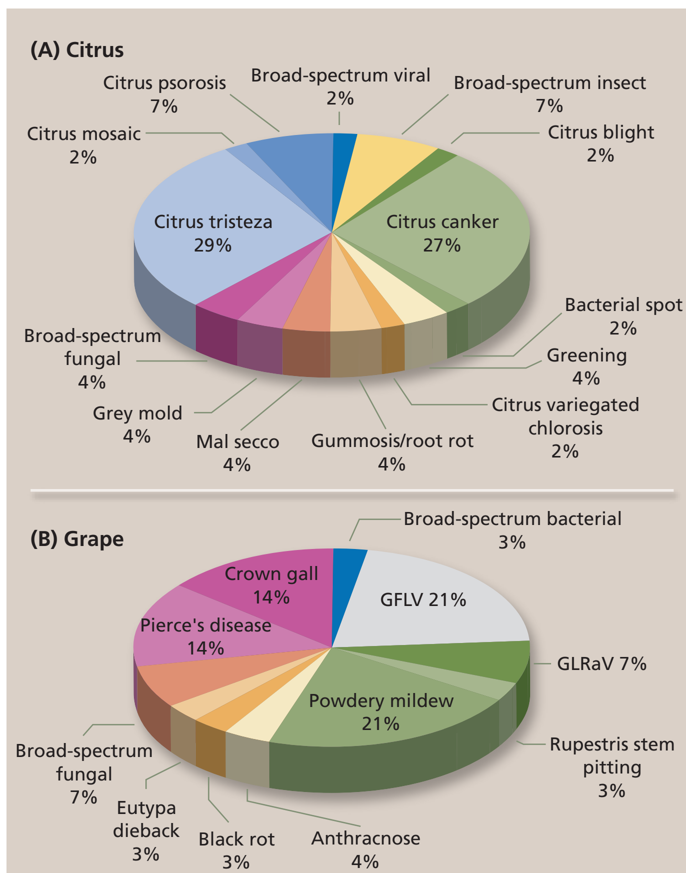

Fig. 5. Detailed analysis of research in genetic engineering–based publications on (A) citrus (*n* = 42) and (B) grape (*n* = 20).

TABLE 2. Top-identified pests and diseases of top 10 California woody fruit and nut crops, and related genetic engineering (GE) publications, 2000–2011

		GE-based publications	
Crop*	Disease†	On disease‡	Generally pest related§
Grape	Powdery mildew	6	20
	Pierce's disease	4	
	Eutypa dieback	1	
	Mealybug	0	
	Nematode	0	
Citrus	Canker	13	42
	Greening (HLB)	2	
	Phytophthora root rot	2	
	Asian citrus psyllid	0	
	Thrips	0	
Almond	Anthracnose	0	1
	Brown rot	0	
	Rust	0	
	Scab	0	
	Shot hole	0	
Pistachio	Alternaria late blight	0	0
	B. panicle/shoot blight	0	
	Verticillium wilt	0	
Walnut	Crown gall	1	2
	Blackline	0	
	Walnut blight	0	
	Phytophthora crown/root rot	0	
Cherry	Canker	1	2
	Fruit rot	0	
	Powdery mildew	0	
Peach	Brown rot	0	0
	Leaf curl	0	
	Peach twig borer	0	
	Rust	0	
	Sour rot	0	
Pear	Fireblight	6	8
	Codling moth	0	
	Mites	0	
	Root rot	0	
	Scab	0	
Avocado	Amored scales	0	1
	Dothiorella complex	0	
	Phytophthora	0	
	Thrips	0	
	Mites	0	
Plum	Brown rot	0	9
	Omnivorous leafroller	0	
	P. syringae	0	
	Oriental fruit moth	0	

* In descending order of U.S. production value.
† Based on information provided by fruit/nut advisory boards, UC Cooperative Extension advisors and the UC Fruit and Nut Research and Information Center.
‡ Genetic engineering–related publications addressing that specific disease or pest.
§ All genetic engineering–related publications for pests and diseases of that crop.

the private and public sectors appear to be important in aligning scientific and industry research priorities.

Transgrafting fruit trees

Given the severity of diseases such as HLB that have no known conventional controls, it is imperative to consider alternative methods to assist in crop protection. The concept of transgrafting — a blend of a common agronomic technique and modern biotechnology — was introduced nearly a decade ago. Transgrafting is the grafting of a transgenic rootstock with a conventional wild-type scion; it introduces genetic engineering innovations into commercial settings while maintaining a non–genetically engineered fruit or nut (Escobar et al. 2001; Lev-Yadun and Sederoff 2001). Transgrafting allows industry to benefit from transgenic traits while potentially mitigating consumer concerns about genetically engineered crops. Regulatory and consumer concerns over the flow of genetically engineered pollen may also be decreased in properly maintained transgrafted orchards, since it is the wild-type scion, not the genetically engineered rootstock, that flowers and produces pollen (COGEM 2006; Lev-Yadun and Sederoff 2001).

From an industry or commercialization perspective, achieving regulatory approval of a single rootstock is preferable to seeking approval for multiple scion cultivars, given the estimated regulatory cost of $7 million to $15 million for each approval process (Kalaitzandonakes et al. 2006). A single, approved, genetically engineered rootstock could be used with several different scion cultivars, including scions that are resistant to genetic engineering and in certain cases scions from other species (for example, an almond scion might be grafted onto a plum rootstock).

Transgrafting applications that are moving toward commercialization include a crown gall–resistant walnut rootstock (see photo, page 67) (Escobar et al. 2002) and a grape rootstock that produces pear polygalacturonase–inhibiting protein (Aguero et al. 2005), which confers a moderate level of resistance to Pierce's disease. These applications address root or xylem pests and diseases, but future applications will likely target traits aimed at consumer needs such as increased nutritional value or improved flavor characteristics.

Public-private partnerships will be critical to moving promising technologies such as transgrafting into the market, especially because in comparison to row crops, fruits and nuts are minor-acreage specialty crops, making them less attractive to private investment. Nearly all fruit and nut trees grown on a commercial scale are currently grafted, so using genetically engineered rootstocks is technically feasible for this industry.

Intellectual property strategies

The regulatory status of transgrafted crops is unclear (see sidebar, page 68), necessitating innovative research and development strategies. Transitioning biotechnology from publicly funded research and development to commercial applications will require an intellectual property strategy to access and protect agricultural innovations (Mou and Scorza 2010). Perhaps to the advantage of fruit and nut tree crops, public institutions have been more involved in transgenic research of specialty crops than of commodity crops such as maize or soy, which could facilitate the process, since intellectual property and innovations have traditionally been shared more readily between public institutions (Graff et al. 2004).

In the past decade, several public-sector initiatives have been launched to support the development of new biotechnology crops. For example, PIPRA, a nonprofit organization, was established at UC Davis by the Rockefeller and McKnight foundations to facilitate access to patented and proprietary technologies for the development and commercialization of agricultural crops, primarily in developing countries, but also for public entities (Atkinson et al. 2003). The USDA APHIS Biotechnology Quality Management System was established in 2007 to help technology developers with the tools needed for regulatory compliance and to facilitate regulatory clearances.

In vitro **wild-type (left) and transgenic (right) walnut microshoots, 5 weeks postinoculation with crown gall–inducing virulent** ***A. tumefaciens*** **strain 20W-5A. The wild-type microshoot exhibits tumor growth, while tumors are absent from the transgenic microshoot. (Permission to reprint photos obtained from RightsLink Copyright Clearance Center.)**

Public perception

Strategies based on biotechnology or genetic engineering have the potential to address many of the pest and disease problems in fruit and nut tree crops, but consumer and export-market resistance have hampered their progression and implementation (Mou and Scorza 2010). If perceived risks to personal health and the environment could be reduced, or if the benefits of biotechnology and genetic engineering were targeted to consumers (second-generation traits, such as better tasting or more nutritious fruits) instead of farmers (first-generation traits, such as herbicide- or drought-tolerant crops), there is a greater possibility that consumers would accept fresh genetically engineered products (Astrid 2009; Huffman and Rousu 2006; Lusk et al. 2004). Only 4% of the genetic engineering research on fruit and nut trees that we surveyed was directed toward product quality (fig. 4), including producing taste-modifying proteins, modifying juice quality, decreasing seed set and producing anthocyanin, an antioxidant. One of the first genetically engineered fruit products aimed at consumers instead of producers is a nonbrowning apple developed in Canada that will not discolor after it is sliced. Okanagan Specialty Fruits is currently petitioning for its regulatory approval in the United States (see photo, page 62).

In general, genetically engineered crops are discussed in terms of their first- and second-generation traits, and it may be beneficial to the future regulatory process to divide transgrafting applications in a similar fashion. For example, a transgraft with first-generation traits would have a scion free of any transgenic DNA and also of any transgenic components (protein, mRNAs and siRNAs) above a predetermined threshold. A transgraft with second-generation traits would have a scion free of transgenic DNA, but the scion would have received translocated transgenic products such as insecticidal proteins or siRNAs to combat certain bacterial or viral diseases. Or its second-generation genetic engineering traits could modulate scion or fruit development or influence its organoleptic properties, such as flavor, scent, texture or color.

Abbreviations

sRNA = small, noncoding RNAs;
siRNA = small, interfering RNA or silencing RNA;
mRNA = messenger RNA

We expect that because of their ability to transport transgenic products to wild-type scions, second-generation transgrafts would likely receive regulatory scrutiny similar to that of current genetic engineering applications. However, if second-generation traits are incorporated into transgrafted crops, consumers may re-evaluate the perceived risk/benefit relationship that these products can offer (Astrid 2009; Huffman and Rousu 2006). Since transgrafted crop scions are free of transgenic DNA, and consumers are less resistant toward second-generation traits from genetically engineered crops (Bernard et al. 2009), it is likely possible that second-generation transgrafted products would have a better chance of being marketable relative to their “traditional” genetically engineered counterparts.

Looking forward

Fruit and nut tree crops are a multibillion-dollar industry in California, and if current trends persist, the industry will continue to grow. Land-grant universities with agricultural roles, such as UC Berkeley, UC Davis and UC Riverside, have a general mission to give back to society by identifying and addressing the agricultural, environmental and ecological needs of industry, government agencies and the community — not only on a local level, but globally as well. As the industry grows, new threats to agriculture, as well as solutions, will emerge. We anticipate that genetic engineering technologies will be a part of that future, but progress has been slow. Given the estimated cost to deregulate a genetically engineered crop variety, it comes as no surprise that the majority of crops that have moved forward are high-value commodities. Furthermore, since specialty crops such as grape and citrus do not need to be replanted every year like maize and soybean, collecting ongoing revenue from seed sales would be less lucrative.

A recent broad survey of all genetically engineered specialty crops found that adjustments to current regulatory

In Hawaii, papaya has been genetically engineered to resist ringspot virus: infected plants on (left), virus-resistant (right).

requirements might be necessary if commercialization of these crops is to become a reality (Miller and Bradford 2010; Mou and Scorza 2010). In the survey, conducted between 2005 and 2008, research publications identified 78 different specialty crops and more than 250 traits; however, none of the crops had received complete regulatory approval or been commercialized (Miller and Bradford 2010).

While the lengthy regulatory approval process may account for some of these delays and market failures, public approval and consumer and export-market acceptance will remain the ultimate hurdles in the marketplace success of genetically engineered specialty crops (Astrid 2009; Huffman and Rousu 2006; Lusk et al. 2004). The degree of market acceptance varies, with some markets being more affected than others by international attitudes about genetic engineering.

Transgrafting presents a potential way to address consumer acceptance issues and allow the fruit and nut tree industries to realize some of the possible benefits of genetic engineering technology. To move transgrafting technologies toward implementation efficiently and effectively, scientists and legislators must establish clear lines of communication and create supportive regulatory frameworks. Moreover, industry backing will be paramount given the long time frames and costs related to genetic engineering. Ultimately, however, consumer education and attitudes toward transgrafting will be a pivotal aspect. It is important that all of these factors are addressed if specialty crops, such as fruit and nut trees, are to profit from the benefits biotechnology can provide.

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Regulatory status of transgrafted plants is unclear

by Victor M. Haroldsen, Gabriel Paulino, Cecilia L. Chi-Ham *and* Alan B. Bennett

The regulatory implications of using transgrafted plants are currently unknown. A plant's vascular system can selectively transport across graft junctions endogenous elements such as full-length RNAs, sRNAs, proteins, hormones, metabolites and vitamins, and even elicit epigenetic effects, heritably changing the way genes are expressed without changing the actual DNA sequence. However, not all of these elements are transported freely, and they either require specific molecular signals or cellular transporters to aid in their movement through a plant's vascular system.

These transfers are understood to a degree (Haroldsen et al. 2012), but what is less clear is how the movement of these elements from transgenic rootstocks to scions might affect the regulatory approval process for a transgrafted plant — a product developed using transgenic tools and yet not containing transgenic DNA in the scion product. It cannot be said with certainty if transgenic RNAs, sRNAs or proteins produced in rootstocks may make their way to the nontransgenic scion. Furthermore, some of these elements may have short half-lives, making it difficult to determine by testing whether the final crop was produced using a transgraft.

There is no precedent within the regulatory framework coordinated by the U.S. Department of Agriculture, U.S. Food and Drug Administration and U.S. Environmental Protection Agency regarding how a transgrafted, genetically engineered rootstock and wild-type scion might be regulated. U.S. regulation identifies genetically engineered crops through a product-based policy; that is, if the final product contains transgenic material, then it is considered genetically engineered. However, even if scions are shown to be free of transgenic DNA, since transgrafted crop products are new to consumption, it is likely that safety assessments will be required prior to their market release. They would potentially, however, be classified as a conventional and not genetically modified food in the United States.

Conversely, in the European Union, if biotechnology tools are used in the process of developing a crop, then they fall under EU legislation for genetically engineered crops. In this case, regardless of whether the final transgrafted crop product contains transgenic material (DNA, RNA or proteins) or not, it would be classified as genetically modified. For example, German authorities decided in 2010 that any grapes or wine produced from transgenic rootstocks must be labeled as genetically engineered (Heselmans 2011).

This international policy difference will put EU regulators in a difficult situation in the future, when importing crops harvested from transgrafted plants produced in the United States. How will they identify a nontransgenic crop product that has been developed using transgenic tools? How can they be certain that crops imported from countries such as the United States are not genetically engineered (by EU

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definitions) when testing may not differentiate between conventionally grown crops and those from transgrafted plants? While the European Union may elect to implement process monitoring of new technologies to ensure proper labeling, documenting every step of the production process and tracking the final products of transgrafted crops, it would be difficult to guarantee the genetically engineered status of imports from outside the European Union.

To address this difficulty, and assuming tests can be developed that easily and robustly detect the presence or absence of transgene elements in the final crop, a threshold limitation could be established. The EU threshold for allowable levels of "adventitious mixing" of genetically engineered seed into conventional seed is 0.9%. The expectation for transgrafted crops, in particular first-generation transgrafts (see page 67), is that any transgenic DNA, mRNA, siRNA or protein would fall below the 0.9% level. While current EU legislation would likely need to be revised, it is possible that EU regulators would allow transgrafted fruit or nut products to enter the European Union, so long as transgenic material was below the 0.9% threshold. While strictly conjecture, at the least, this sort of threshold limitation should be included in discussions of alternatives to current regulatory requirements.

In the United States, transgrafting applications will likely be dealt with on a case-by-case basis as they are introduced into the regulatory process (C. Wood, USDA Biotechnology Regulatory Services, personal communication, September 2010). This would be in line with suggestions by the Dutch scientific advisory committee on genetically modified organisms (COGEM 2006). In anticipation of regulatory scrutiny, it will be important for scientists to gather experimental information determining to what degree transgenic elements move across the graft junction in different plant species and different types of coding and noncoding genetic constructs.

Unlike plant model systems, such as *Arabidopsis* sp., analyses of genetic material from fruit and nut crops tend to be compounded by high levels of phenolic compounds, polysaccharides and other secondary metabolites. Nevertheless, laboratory experiments have been carried out in walnut, grape and tomato regarding the mobility of transgenic elements, and the results are in the process of being published. This information should assist regulatory bodies in determining what portion of the scion, if any, should be regulated.

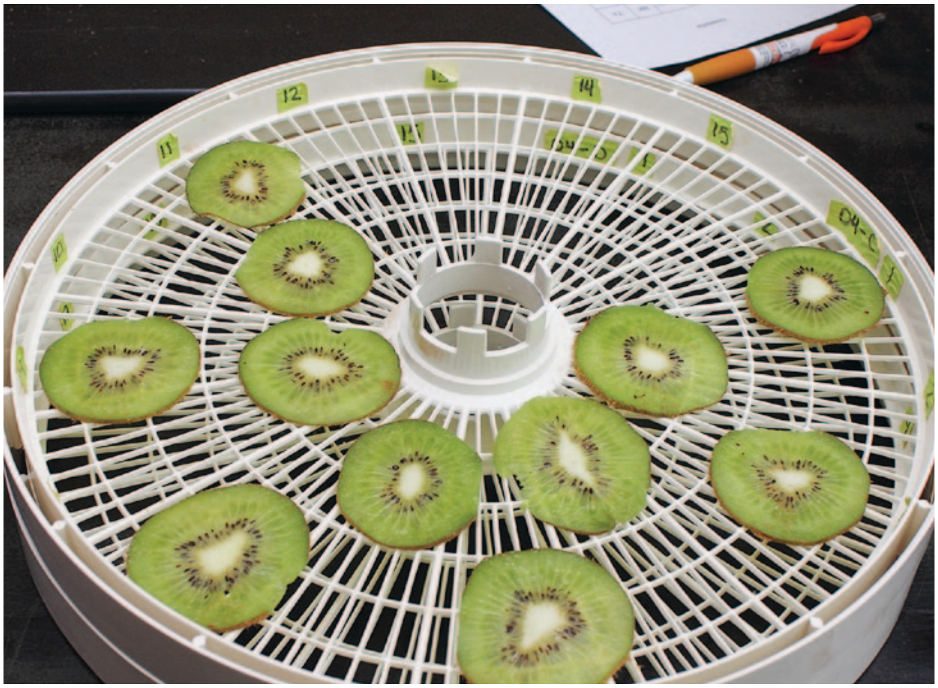
To illustrate these issues, imagine that a transgrafted orange is developed with transgenic siRNA in the rootstock that wards off nematodes. Tests on the scion leaf material do not reveal the presence of siRNA, but when the fruit is tested transgenic siRNA is detected. However, tests also show that after the oranges are harvested, the transgenic siRNA decreases over a short time to nondetectable levels. In the United States, after regulatory approval the oranges would not be required to be labeled as genetically engineered. If these sames oranges were exported to the European Union, siRNA would be undetectable in tests regardless of the transgraft, but under EU legislation they would be classified and labeled as genetically engineered. So unless the U.S. seller directly informs the importer that the oranges were grown with a transgraft, they would have no way of knowing since the siRNA is undetectable after picking. This example highlights the difficulties arising from policy differences, which could hamper the future commercialization of transgrafting technologies currently in the developmental pipeline.

RESEARCH ARTICLE

New quality index based on dry matter and acidity proposed for Hayward kiwifruit

by Gayle M. Crisosto, Janine Hasey, Jorge A. Zegbe *and* Carlos H. Crisosto

Researchers from various countries have proposed using dry matter at harvest as a worldwide quality index for Hayward kiwifruit, because it includes both soluble (sugars and acids) and insoluble (structural carbohydrates and starch) solids and doesn't change during postharvest handling. Our consumer tests in 1999 and 2008 indicated that dry matter and ripe titratable acidity are related to in-store consumer acceptance of kiwifruit. In most California seasons, when ripe titratable acidity was less than 1.2%, only a dry matter greater than or equal to 15.1% was required for consumer acceptability. Our 6-year quality attribute survey of California kiwifruit at harvest and from cold storage demonstrated that dry matter and ripe soluble solids concentration were highly variable among vineyards and seasons, but ripe titratable acidity values varied more among seasons than between vineyards. Our results provide strong evidence that dry matter would be a reliable quality index candidate for California kiwifruit, especially if ripe titratable acidity were factored in.



In research analyzing the role of various fruit quality attributes in consumer acceptance, kiwifruit slices were dried in a dehydrator in order to measure dry matter content.

Measuring the soluble solids concentration of kiwifruit juice at harvest is the official method of assessing its maturity in most kiwifruit-producing countries, including New Zealand, Italy, France, Greece, Chile, Japan and the United States (Beever and Hopkirk 1990; Crisosto and Mitchell 2002). A refractometer is used to make the simple and fast measurement of the concentration of soluble solids such as sugars, organic acids, phenolic compounds and pectins. Minimum harvest maturity standards for Hayward kiwifruit (*Actinidia deliciosa* [A. Chev.] C. F. Liang and A. R. Ferguson) are enforced in several countries including the United States, ranging from 5.5% to 6.5% soluble solids concentration at harvest (HSSC) (Beever and Hopkirk 1990; Crisosto and Mitchell 2002). This range assures a minimum consumer acceptance (greater than or equal to 12.5% ripe soluble solids concentration) and adequate storage potential to avoid flesh breakdown, which occurs when soluble solids are less than 6.2% at harvest (Crisosto and Crisosto 2001).

Kiwifruit is usually harvested when mature but unripe, then kept in cold storage for up to 6 months. Ripening starts at various points in the distribution chain on the fruit's way to the consumer (Ritenour et al. 1999). Ripening time depends on how long the fruit has been stored at 32°F, and whether it has been preconditioned with ethylene. Kiwifruit harvested with less than 6.2% soluble solids concentration develop flesh breakdown by 3 months in storage at 32°F. Soluble solids increase slowly during cold storage as starch is converted to sugars, but the complete conversion occurs when the kiwifruit is ripened.

At harvest, a mature, unripe kiwifruit has a high content of starch and soluble sugars, but soluble solids concentration readings do not take starch into consideration because it is insoluble. Therefore, soluble solids concentration measurements do not accurately predict final soluble sugars after ripening. As ripening and softening progress during the kiwifruit's postharvest life, starch is hydrolyzed to soluble sugars and consequently the soluble solids concentration increases.

The sweetness, eating quality, consumer acceptance and repeat purchases of kiwifruit are strongly associated with the concentration of soluble sugars (Burdon et al. 2004; Crisosto and Crisosto 2001; Harker et al. 2009; Jordan et al. 2000; Rossiter et al. 2000). Following an in-store consumer test, UC researchers proposed a soluble solids concentration after ripening (RSSC) of 12.5% as the minimum quality index for early-marketed California kiwifruit (Crisosto and Crisosto 2001).

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Hayward kiwifruit dominate California production, and they are marketed worldwide. California growers export little, but fruit is shipped to the Southern Hemisphere (New Zealand and Chile) and Italian markets when local crops are out of season, and California receives imports from these countries as well. This globalization has created economic advantages for early- and late-harvest kiwifruit sales, when fruit availability is low and prices are high. However, the incentive to harvest early or to hold fruit in long-term storage can result in low-quality kiwifruit in the market, reducing repeat purchases and overall demand.

To more reliably assure flavor quality, researchers from various countries including New Zealand have proposed, in addition to the harvest maturity index, the use of dry matter concentrations as a voluntary quality index, which would be measured at harvest and/or shipment to market. Dry matter readings include starch and are highly correlated with ripe soluble solids concentration (Beever and Hopkirk 1990; Harker et al. 2009; Jordan et al. 2000), and they do not change during cold storage (Crisosto et al. 2009). New Zealand and Chile have started using a minimum dry matter standard for retail marketing and wholesale trade. However, as yet, there is no agreement on the minimum dry matter level that should be established as a quality index.

To develop a quality index for Hayward kiwifruit, we studied the relationships among dry matter, ripe soluble solids concentration, ripe titratable acidity (RTA) and consumer acceptance. We also investigated dry matter variability in kiwifruit at harvest and from cold storage from several California growing regions, and we surveyed imported kiwifruit during the U.S. low-availability season (March to May and August to November).

In-store consumer survey

During the 1999 and 2008 kiwifruit growing seasons, we surveyed groups of 142 and 124 consumers, respectively, at a major supermarket in Fresno County. Each consumer was presented with three ripe Hayward kiwifruit samples from California vineyards at targeted dry matter levels (14.0% to 15.9%, 16.0% to 17.9% and ≥ 18.0%). To ripen the previously cold-stored kiwifruit samples (1 to 5 weeks storage at 32°F [0°C]), cold kiwifruit were exposed to 100 parts per million ethylene for 12 hours, following the preconditioning protocol (Ritenour et al. 1999). This process was carried out 2 to 3 days prior to the consumer test, and the kiwifruit were allowed to ripen at 68°F (20°C) until they reached 2 to 3 pounds-force (1 pound-force equals 4.45 Newtons) flesh firmness (Crisosto and Crisosto 2001).

Flesh firmness and dry matter were measured on the day of the test before the consumers tasted the samples, and juice was extracted from the remaining fruit after tasting on the same day of the test, using previously described methods (Crisosto and Crisosto 2001; Crisosto, Hasey et al. 2008). A kiwifruit sample consisted of a 0.25-inch-thick slice, halved, cut perpendicular to the long axis of the fruit, adjacent to the location where the slice for dry matter assessment was taken. The consumer responses were recorded using a 9-point hedonic scale (1 = dislike extremely, 9 = like extremely). Consumer acceptance was measured as a degree of liking and expressed as a percentage (Lawless and Heymann 2010).

Fruit quality attributes survey

During the 2006 and 2007 growing seasons, samples of 10 to 15 kiwifruit, replicated three times, were collected at six different maturity stages (harvest dates) from the same vineyards: three in the San Joaquin Valley (southern region) and three in the Sacramento Valley (northern region). All kiwifruit samples from these vineyards — and commercial cold-storage facilities and retail stores in California for the low-availability season survey — were immediately transported to the F. Gordon Mitchell

Glossary

Dry matter: The ratio of the weight of a test sample after drying to the fresh weight of the test sample, expressed as a percentage. Kiwifruit dry matter at harvest is composed of both starch and soluble sugars as well as organic acids, minerals, pectins and other components.

Soluble solids concentration: A measurement consisting primarily of soluble sugars, as well as soluble pectins, and organic, amino and ascorbic acids. Measured using refractometers or hydrometers.

Starch: A white, tasteless, solid carbohydrate $(C_6H_{10}O_5)_n$ occurring in the form of minute granules in seeds, tubers and other parts of plants. Measured by potassium iodide test or other chemical tests.

Titratable acidity: A measure of the total amount of acid present expressed as a percentage of the predominant acid, as determined by titration or chemical tests in a laboratory.

Carlos H. Crisosto

At the F. Gordon Mitchell Postharvest Center in Parlier, UC Davis master's student Jiaxuan Liu juiced kiwifruit collected from vineyards across the Central Valley, as well as imported fruit.

Postharvest Center at the Kearney Agricultural Research and Extension Center in Parlier, California, for fruit quality assessments.

Fruit quality attributes measured at harvest included flesh firmness, soluble solids concentration, titratable acidity and dry matter (Crisosto, Hasey et al. 2008). Soluble solids concentration and titratable acidity of ripened fruit were measured as described by Crisosto and Crisosto (2001).

In addition to the vineyard survey, kiwifruit samples of three replicates of 10 to 15 kiwifruit were collected directly from commercial cold-storage facilities in California during 1998, 1999, 2006, 2007, 2008 and 2009 for dry matter determinations. Imported kiwifruit samples from Chile and New Zealand (three replications of 10 kiwifruit) were collected for dry matter determinations directly from California retail stores in 2009 and 2010.

Quality and consumer acceptance

Dry matter. The in-store consumer tests showed that dry matter content significantly influenced the degree of liking in both seasons (tables 1 and 2). In the 1999 growing season, consumers rated kiwifruit from "like slightly" (6.1) to "like moderately" (7.1). The percentage of consumers who said they "like" (score > 5.0) the kiwifruit varied from 71% to 87% depending on dry matter, while the percentage of consumers who chose "dislike" (score < 5.0) ranged between 6% and 26%. Only a few consumers (3% to 6%) chose "neither like nor dislike" (table 1). Degree of liking was significantly higher (6.6 to 7.1) and acceptance was approximately 85% for kiwifruit with dry matter greater than or equal to 16.1% than for kiwifruit with dry matter less than 16.1%.

These results demonstrate that consumer acceptance of kiwifruit is affected by dry matter and acidity levels.

The in-store consumer test results for the 2008 growing season were similar to the 1999 results (table 1). Consumers rated kiwifruit from "dislike slightly" (4.6) to "like slightly-moderately" (6.5). The percentage of consumers who said they "like" the fruit varied from 35% to 76%, increasing as dry matter increased, while the percentage who said they "dislike" the fruit decreased from 50% to 20% as dry matter increased. "Neither like nor dislike" was chosen by 4% to 15% of consumers (table 1).

Ripe titratable acidity. Dry matter and ripe titratable acidity, which is associated with sourness, significantly influenced the degree of liking in the 2008 consumer test, but not in the 1999 test. In 2008, the F-ratio for ripe titratable acidity was significantly higher than for dry matter. (A significant F-ratio means that there is at least one significant difference among means being compared.) As a result, we divided the data set into two classes for further analysis using dry matter and ripe titratable acidity as combined factors on degree of liking. With the same dry matter levels, one class had a ripe titratable acidity greater than or equal to 1.2% and the other less than 1.2% (table 2).

Consumers rated kiwifruit with ripe titratable acidity greater than or equal to 1.2% from "dislike slightly" (4.4) to "like

TABLE 1. Relationship between dry matter, as a percentage of fresh weight, and consumer acceptance of Hayward kiwifruit, 1999 and 2008

Dry matter	n*	Degree of liking†	Consumer acceptance: Like	Neither like nor dislike	Dislike
			....	%	....
1999					
≤ 15.0	34	6.1b‡	70.6	2.9	26.5
15.1–16.0	33	6.3b	72.7	3.1	24.2
16.1–17.0	114	6.6ab	81.6	5.3	13.1
17.1–18.0	174	7.1a	87.4	6.3	6.3
> 18.0	213	6.9a	86.4	6.1	7.5
LSD 0.05		0.6			
P > F		< 0.0001			
2008					
≤ 15.0	20	4.6b	35.0	15.0	50.0
15.1–16.0	82	5.1b	48.8	6.1	45.1
16.1–17.0	84	6.1a	65.5	11.9	22.6
17.1–18.0	80	6.3a	71.3	7.5	21.2
> 18.0	106	6.5a	76.4	3.8	19.8
LSD 0.05		0.8			
P > F		< 0.0001			

* Number of samples.
† 1 = dislike extremely, 2 = dislike very much, 3 = dislike moderately, 4 = dislike slightly, 5 = neither like nor dislike, 6 = like slightly, 7 = like moderately, 8 = like very much, 9 = like extremely.
‡ Mean separations within a column were by Fisher's LSD test ($P \leq 0.05$). Mean values followed by the same letters were not significantly different.

TABLE 2. Consumer acceptance of Hayward kiwifruit at different levels of dry matter, as a percentage of fresh weight, and ripe titratable acidity (RTA), as a percentage of citric acid, 2008

Dry matter	n*	Degree of liking†	Consumer acceptance: Like	Neither like nor dislike	Dislike
			....	%	....
RTA ≥ 1.2%					
≤ 15.0	14	4.5b‡	35.7	7.2	57.1
15.1–16.0	58	4.4b	34.5	8.6	56.9
16.1–17.0	46	5.6a	54.3	17.4	28.3
17.1–18.0	26	5.7a	65.4	0	34.6
> 18.0	30	5.7a	63.3	0	36.7
LSD 0.05		1.2			
P > F		0.01			
RTA < 1.2%					
≤ 15.0	6	4.5b	33.3	33.3	33.3
15.1–16.0	24	6.8a	83.3	0	16.7
16.1–17.0	38	6.7a	78.9	5.3	15.8
17.1–18.0	54	6.5a	74.1	11.1	14.8
> 18.0	76	6.8a	81.6	5.2	13.2
LSD 0.05		1.2			
P > F		0.05			

* Number of samples.
† 1 = dislike extremely, 2 = dislike very much, 3 = dislike moderately, 4 = dislike slightly, 5 = neither like nor dislike, 6 = like slightly, 7 = like moderately, 8 = like very much, 9 = like extremely.
‡ Mean separations within a column were by Fisher's LSD test ($P \leq 0.05$). Mean values followed by the same letters were not significantly different.

slightly" (5.7), and acceptance ranged from 34% to 65%. A high percentage of consumers (28% to 57%) said they "dislike" these kiwifruit. In this high titratable acidity class, degree of liking was significantly higher for kiwifruit with dry matter greater than or equal to 16.1% (acceptance ranged from 54% to 65%) than with dry matter less than 16.1%.

Consumers rated kiwifruit with ripe titratable acidity less than 1.2% from "dislike slightly" (4.5) to "like moderately" (6.8), and acceptance ranged from 33% to 83%. A high percentage of consumers (13% to 33%) said they "dislike" these kiwifruit. The degree of liking was significantly higher for kiwifruit with dry matter greater than or equal to 15.1% (acceptance ranged from 74% to 83%). In this class, the percentage of consumers who said they "dislike" the fruit decreased from 33% to 13% as dry matter increased. In contrast, consumers who chose "neither like nor dislike" varied among dry matter classes, ranging between 0% and 33% (table 2). These results demonstrate that consumer acceptance of kiwifruit is affected by dry matter and acidity levels.

Quality at harvest and after ripening

2006 samples. In the 2006 growing season, the average dry matter of kiwifruit sampled from the three San Joaquin Valley vineyards (A, B, C) increased from 14.6% to 16.2% between Sept. 14 and Oct. 23. During this sampling period, harvest soluble solids concentrations ranged between 5.1% and 6.6%, and harvest titratable acidity was between 1.8% and 2.0%. After ripening to a flesh firmness of 2 to 3 pounds-force (9 to 13.5 Newtons), the kiwifruit exhibited average ripe soluble solids concentrations between 10.4% and 13.1% and titratable acidity between 0.4% and 1.1%. (Data in this section is not shown; it is available from authors upon request.)

Minimum quality indexes (dry matter ≥ 15.1% and soluble solids concentration ≥ 6.2%) are important to consider at harvest because they can predict consumer acceptance. For instance, vineyard A reached the minimum dry matter by Sept. 14 and the minimum harvest soluble solids concentration by Oct. 2, with titratable acidity at harvest of 2.0%. However, vineyard A exceeded a ripe soluble solids concentration of 12.5% by Sept. 25, and its ripe titratable acidity was lower than 1.2%. Vineyard B met the minimum quality indexes at harvest and after ripening in the last harvest (Oct. 23). Vineyard C did not reach the minimum quality indexes during this harvest season.

Some 4,200 acres of kiwifruit are harvested annually in California. In this study, dry matter content at harvest, coupled with ripe titratable acidity, was a reliable consumer acceptance indicator.

Average dry matter at harvest of kiwifruit grown in the Sacramento Valley vineyards (D, E, F) increased from 16.1% to 17.9% between Sept. 15 and Oct. 23. Soluble solids concentrations at harvest increased from 5.4% to 7.0% during this time, and titratable acidity ranged between 1.8% and 2.0%. After ripening kiwifruit to a flesh firmness of 2 to 3 pounds-force (9 to 13.5 Newtons), average soluble solids concentration and titratable acidity varied between 11.8% and 13.3%, and 0.5% and 1.2%, respectively. Vineyard D fruit had the highest dry matter on the first harvest date (Sept. 15); dry matter was the same in the three vineyards for the rest of the harvest dates.

The minimum quality index of dry matter greater than or equal to 15.1% was observed on the first harvest date (Sept. 15) for the three Sacramento Valley vineyards. However, none of the fruit from these vineyards reached the minimum quality index for soluble solids concentration until the last two harvest dates. After ripening, fruit from vineyard D had soluble solids concentrations greater than or equal to 12.5% on all harvest dates, except the third harvest date. Fruit from the other two vineyards had ripe soluble solids concentrations greater than or equal to 12.5% by the fourth harvest date, while titratable acidity remained less than or equal to 1.2%.

2007 samples. In the 2007 growing season, average dry matter at harvest (16.1% to 16.8%) and soluble solids concentrations at harvest (5.6% to 7.7%) and when ripe (13.3% to 14.5%) of kiwifruit grown in the San Joaquin Valley vineyards increased consistently between Sept. 27 and Oct. 22. (We did not measure titratable acidity at harvest or after ripening on fruit from these vineyards.) Vineyard A fruit had dry matter consistently higher on all harvest dates than fruit from vineyards B and C. Vineyard C fruit had consistently the lowest dry matter and harvest and ripe soluble solids concentrations on all harvest dates, but harvest soluble solids concentrations were similar in the three vineyards on the fourth harvest date (Oct. 22). Fruit from vineyard A met the minimum quality index for dry matter and soluble solids concentration by the first (Sept. 27) harvest date, and fruit from vineyard B met it by the second (Oct. 4) harvest date. Vineyard C fruit did not meet the minimum quality index for dry matter on any harvest date, and it met the minimum quality index for soluble solids concentration on the last harvest date (Oct. 22). After ripening, vineyards A and B fruit met the minimum quality index for soluble solids concentration on the first harvest date (Sept. 27), while vineyard C fruit met that value by the third harvest (Oct. 11).

Similar results were observed in the three vineyards in the Sacramento Valley during 2007, although the values were higher compared with those in the San Joaquin Valley. Also, titratable acidity decreased from harvest to ripening, with a smaller decrease in 2006 than in 2007.

Seasonal variation. After two consecutive growing seasons, the data suggest that variation in dry matter and other fruit quality attributes depends on harvest time (Crisosto et al. 2007, 2009; Crisosto, Garibay et al. 2008), growing area (Crisosto et al. 2007, 2009; Crisosto, Garibay et al. 2008), vineyard and year. For these six vineyards, dry matter variability was higher among vineyards than between seasons, and ripe titratable acidity variability was low among vineyards but high between seasons.

Our 6-year California kiwifruit quality attribute survey demonstrated that dry matter and ripe titratable acidity were highly variable among seasons, with ripe titratable acidity values varying more among seasons than dry matter (fig. 1).

Proposed kiwifruit quality index

Based on our studies, we propose a minimum quality index of dry matter greater than or equal to 16.1% when ripe titratable acidity is greater than or equal to 1.2%, and 15.1% when ripe titratable acidity is less than 1.2%, to maximize consumer satisfaction.

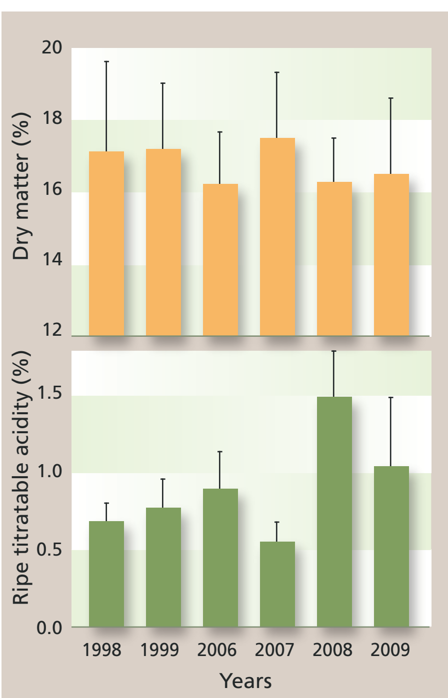

Fig. 1. Seasonal variation in dry matter and ripe titratable acidity of Hayward kiwifruit. Vertical bars on mean values indicate standard deviations.

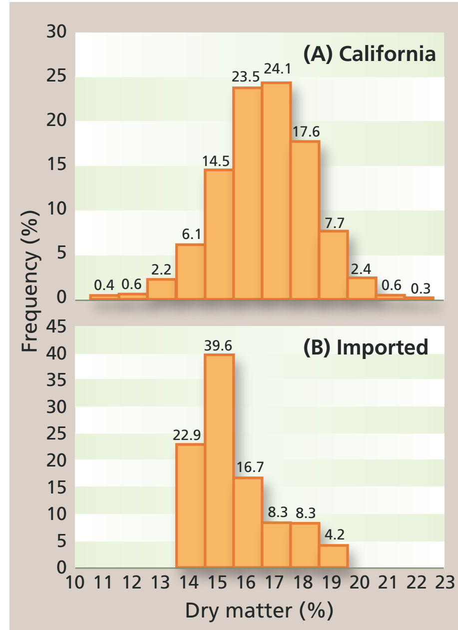

Fig. 2. Dry matter distribution of Hayward kiwifruit for (A) California harvest and cold-storage samples in 1998, 1999, 2006, 2007, 2008 and 2009 growing seasons (n = 3,156) and (B) imported samples collected from commercial cold-storage facilities and retail stores during the 2009 and 2010 U.S. low-availability season (March to May and August to November) (n = 48).

During the six growing seasons of harvest and cold-storage sample collection from California vineyards (n = 3,156), dry matter ranged from 11% to 22% with an average of 17.1% and a standard deviation of 1.6% (fig. 2A). Of these samples, 76.2% and 90.7% exceeded our proposed minimum quality indexes of dry matter greater than or equal to 16.1% and 15.1%, respectively. In the imported kiwifruit collected in 2009 and 2010 (n = 48), dry matter ranged between 14% and 19%, with an average of 16.0% and a standard deviation of 1.4% (fig. 2B). Of these imported samples, 37.5% and 77.1% exceeded our proposed minimum quality indexes of dry matter greater than or equal to 16.1% and 15.1%, respectively.

Although the influence of ripe titratable acidity on consumer acceptance has been previously documented (Crisosto and Crisosto 2001; Rossiter et al. 2000), the direct impact of dry matter and ripe titratable acidity together on kiwifruit acceptance (table 2), using single-fruit measurements, has not been previously reported. In our study, kiwifruit with high ripe titratable acidity (≥ 1.2%) required high dry matter (≥ 16.1%) for consumers to "like" the fruit; for kiwifruit with ripe titratable acidity less than 1.2%, a minimum dry matter of 15.1% was adequate for consumer acceptance.

This effect of ripe titratable acidity may be explained by the fact that high dry matter is associated with sweetness (Burdon et al. 2004; Jordan et al. 2000), which may balance a sourness perception, as reported in kiwifruit and mango (Harker et al. 2009; Malundo et al. 2001). When fruit is perceived to be less sour (ripe titratable acidity < 1.2%), consumers are less demanding for high soluble sugars, or dry matter content, and they "like" kiwifruit with dry matter greater than or equal to 15.1%.

Crisosto and Crisosto (2001) reported that total organic acid content, in terms of titratable acidity at harvest, was relatively stable across harvest seasons. Similar to that study, we noticed a decrease in ripe titratable acidity between harvest and ripening in both years of our fruit quality attributes survey (data not shown). In 2006, titratable acidity decreased 54% from harvest to ripening, and in 2007 it decreased 70%. The high ripe titratable acidity observed during the in-store consumer test in the 2008 growing season may explain the high dry matter level (and indirectly the ripe soluble solids concentration) needed for consumers to like the kiwifruit when ripe titratable acidity was greater than or equal to 1.2% (table 2).

Therefore, in terms of marketing, dry matter would be a more accurate tool than soluble solids concentration alone for controlling minimum quality at harvest, and for meeting export and import requirements. As only minor changes in dry matter occur during postharvest handling, kiwifruit with low consumer acceptance — either harvested early in the season or from potentially low-quality vineyards (dry matter < 15.1%) — could be detected. In our study, differences in dry matter among kiwifruit sources remained constant throughout the cold-storage period. This lack of dry matter change is an advantage over the soluble solids concentration maturity index currently in place.

In some commodities, soluble sugars and organic acids (important components of dry matter) are reduced during cold storage because of respiratory activity. The kiwifruit's low metabolic respiration favors the maintenance of dry matter and soluble sugars, as well as a low water loss potential when fruit is kept at 32°F (0°C) and with relative humidity of 90% to 95%. Kiwifruit's respiration rate is less than or equal to 2 milliliters carbon dioxide per kilogram per hour at 32°F (0°C), whereas the rates for other commodities, such as peach and apple, are about 1.5 and 3.0 times higher, respectively, at the same temperature (Ritenour et al. 1999).

Dry matter content should not be used as the sole index at harvest, since storage potential tests at different dry matter levels have not been investigated extensively. To assure long cold-storage potential, we recommend that the new dry matter quality index be used with the current harvest maturity index between 6.2% and 6.5% soluble solids concentration (a minimum of 6.2% is required to avoid flesh breakdown during long-term cold storage of 3 to 6 months).

Our proposed dry matter quality index would segregate out kiwifruit of low consumer quality either harvested early in the season or from low-quality vineyards. While the dry matter values may not be reached during early harvests (September, in California), some exceptions could be allowed depending on growing area, vineyard management and weather conditions in particular years, as suggested by other authors (Burdon et al. 2004; Crisosto and Crisosto 2001).

Our data indicated that there was strong variation from one season to the next in attributes such as dry matter, harvest and ripe soluble solids concentrations, and harvest and ripe titratable acidity. Among these attributes, ripe titratable acidity had the lowest variability within a season. These differences in kiwifruit quality attributes from year to year, coupled with consumer acceptance, highlight the need to segregate kiwifruit based on consumer acceptance. Because the proposed minimum dry matter quality index is based on single-fruit measurements and consumer acceptance, it would allow single-fruit segregation during packaging without regard to population variability, perhaps using postharvest technologies such as near-infrared sensors (Slaughter and Crisosto 1998).

Even though there were highly significant correlations between dry matter and soluble solids concentration in our studies, we do not recommend the use of dry matter as a maturity index. A maturity index is used to define when a given commodity has reached the stage of development that after harvesting and postharvest handling (including ripening, where required) its quality will be at least the minimum acceptable to the consumer. This maturity index may be an enforced standard; a quality index is a guide that is used voluntarily to assure a certain level of quality. Previously published information demonstrated that immature or overmature kiwifruit, with maturity based on harvest soluble solids concentration, can develop senescent breakdown — the breakdown of tissues or the development of granular, mealy or soaked tissues during long cold-storage periods (Crisosto and Crisosto 2001).

Our studies demonstrate that dry matter is a reliable consumer quality index, but not a reliable maturity index, so harvest decisions should still include harvest soluble solids concentration and firmness to protect kiwifruit in long-term storage or marketing conditions. Studies are needed to understand the potential limitations of dry matter in predicting long-term cold-storage performance.


California Kiwifruit Commission

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RESEARCH ARTICLE

Citrus growers vary in their adoption of biological control

by Kelly A. Grogan *and* Rachael E. Goodhue

In a spring 2010 survey, we investigated the characteristics that influenced whether California growers controlled major citrus pests with beneficial insects. We also performed statistical analysis of growers' reliance on* Aphytus melinus*, a predatory wasp, to control California red scale. The survey results suggest that growers with greater citrus acreage and more education are more likely to use biological control. Marketing outlets, ethnicity and primary information sources also influenced the extent of reliance on beneficial insects. In Probit model analysis, respondents with greater citrus acreage were more likely to incorporate* A. melinus *into their pest management, as well as those with more education and higher-valued crops. Information sources and growing region also had statistically significant effects.

Jack Kelly Clark/UC Statewide IPM Program

Growers in the main citrus-growing regions of California were surveyed about their pest control practices and their use of biological control for four important pests. *Above*, an orange grove at UC's Lindcove Research and Extension Center, near Visalia in the Central Valley.

Although many university extension programs emphasize integrated pest management (IPM), it has been unevenly adopted across regions and crops, and chemical control is still the primary method in much of the United States (Smith and Kennedy 2002). Encouragingly, many California citrus growers have incorporated biological control (biocontrol) — the use of predaceous, parasitic or pathogenic organisms — into their IPM programs. At the peak, in 1997, about 30% of citrus growers used biological control in the San Joaquin Valley, which contains the majority of California citrus acreage (Morse et al. 2006). Little data on citrus growers' biological or cultural pest-control decisions exist. To fill this gap and help Cooperative Extension programs promote the increased use of biological control, we surveyed California citrus growers in spring 2010 regarding their pest management decisions and analyzed the extent to which they used beneficial insects to help control the major citrus pests: California red scale, citrus red mite, citrus thrips and cottony cushion scale.

We surveyed growers in California's main citrus-growing regions, as categorized by UC Cooperative Extension (UCCE): the San Joaquin Valley (mainly the southeastern portion), Coastal-Intermediate (San Luis Obispo County to the San Diego-Mexico border), Interior (western Riverside and San Bernardino counties and inland areas of San Diego, Los Angeles and Orange counties) and Desert (Coachella and Imperial valleys) (UCCE 2003). We also included growers in the relatively small Northern citrus-growing region (Glenn and Butte counties).

Natural enemies of citrus pests

We inquired in detail about the use of biological control agents for four important citrus pests.

California red scale. California red scale sucks on plant tissue, damaging fruit, leaves, twigs and branches. Damaged fruit receive lower prices from packinghouses (Grafton-Cardwell et al. 2009). A parasitic wasp, *Aphytus melinus*, lays its eggs under California red scale, a primary citrus pest in the San Joaquin Valley and the Coastal-Intermediate and Interior regions. When the egg under the scale hatches, the larva eats the scale and the scale dies. Produced by commercial insectaries, *A. melinus* can be purchased and released relatively inexpensively (Fake et al. 2008; O'Connell et al. 2010; UC IPM 2003). Some pesticides that control California red scale and other pests, such as citricola scale and a variety of ant species, negatively affect the wasp. Selective pesticides such as narrow range oil or the insect growth regulator pyriproxyfen have little effect on *A. melinus*, so the naturally occurring population is conserved.

Reliance on control provided by *A. melinus* in the San Joaquin Valley is hampered by climatic factors that impede its reproduction (Hoffmann and Kennett

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1985; Kennett and Hoffmann 1985; Luck 1995; Yu and Luck 1988). Other natural enemies include the parasitic wasps *Aphytis lingnanensis* and *Comperiella bifasciata*, which help control red scale in the Coastal-Intermediate and San Joaquin Valley regions, respectively. Several lady beetles also consume red scale (Grafton-Cardwell et al. 2009).

Citrus red mite. Citrus red mite, a primary pest in the San Joaquin Valley and Interior regions, feeds on citrus leaves, damaging them and causing leaf drop and twig dieback (Grafton-Cardwell et al. 2009). Several species in the *Euseius* genus of predatory mites, including *E. tularensis*, help control citrus red mite by consuming the pest. *Euseius* mites, when sufficient populations exist, are quite effective at reducing citrus red mite (Kennett et al. 1979; McMurtry et al. 1979).

Citrus thrips. Citrus thrips puncture and feed on the rind of citrus, leaving scars that get larger as the fruit grow (Grafton-Cardwell et al. 2009). Several studies suggest that *Euseius* also provides some control of citrus thrips (Congdon and McMurtry 1988; Grafton-Cardwell et al. 1995, 1999; Grafton-Cardwell and Ouyang 1995a). However, Jones and Morse (1995) found evidence that thrips control by *E. tularensis* is limited. Unlike *A. melinus*, *E. tularensis* is not commercially available (Weeden et al. 2007). *Euseius* population levels tend to be higher on new growth, so growers can encourage populations through pruning, which stimulates new growth (Grafton-Cardwell and Ouyang 1995b). They can also conserve *Euseius* populations by applying only selective pesticides, such as abamectin and spinosad (Success), when necessary for citrus thrips control (Grafton-Cardwell et al. 1995; Khan and Morse 2006).

Cottony cushion scale. In the late 19th century, cottony cushion scale, an invasive pest, threatened to eliminate the California citrus industry. Cottony cushion scale reduces tree health by feeding on phloem sap from twigs, leaves and branches (Grafton-Cardwell et al. 2009). Entomologists went to Australia, where cottony cushion scale originated, to find its natural enemies. In winter 1888-1889, the vedalia beetle (*Rodolia cardinalis*) was brought to California and released, and cottony cushion scale was under full control in areas of release by fall 1889 (Weeden et al. 2007).

Vedalia beetle spread throughout the state's citrus-growing regions and completely controls cottony cushion scale, unless its populations are suppressed or eliminated by the application of pesticides that are toxic to it. Vedalia beetle is not sold commercially. However, few adults are required to establish a population; UC Pest Management Guidelines recommend collecting vedalia beetles at any stage of development from other orchards (Grafton-Cardwell et al. 2009).

Citrus grower survey

We obtained citrus grower addresses from agricultural commissioner offices in 18 counties, which together contain 99.3% of California citrus acreage (USDA 2008). The survey was mailed on March 18, 2010, to 3,959 growers, and a reminder postcard was mailed on April 15, 2010. Of these, 348 surveys and an additional 28 postcards were undeliverable. Eighty-eight people responded that they did not produce citrus, no longer produced citrus, were in the citrus industry but had no acreage, or had less than 1 acre of citrus production for personal use. Additionally, three farm managers who managed several farms each consolidated information on all their acreage onto one form. As a result, we mailed 3,480 surveys to individuals who presumably had citrus production in 2009 and could have responded. Of these, 429 growers responded by June 3, 2010, a 12.3% response rate.

The Northern region had 3.7% of respondents and 0.5% of reported acreage; the San Joaquin Valley had 35.9% of respondents and 67.2% of reported acreage; the Coastal-Intermediate region had 51.0% of respondents and 25.8% of reported acreage; the Interior region had 7.9% of respondents and 5.7% of reported acreage; and the Desert region had 1.4%

Photos: Jack Kelly Clark/UC Statewide IPM Program

California red scale sucks on plant tissues and damages citrus fruit, leaves and branches. *Left, Aphytis melinus,* a parasitic wasp, oviposits in the scale. *Right,* the parasitized scale shows the *A. melinus* exit hole. The presence of this biological control agent may limit the need for insecticide applications.

of respondents and 0.9% of reported acreage. No responses were received from Imperial or Kern counties, but all other counties with citrus acreage reported by the USDA were represented. The distribution of respondent acreage across counties in the survey was close to USDA estimates for Tulare and Santa Barbara counties, a little high for Madera and Ventura counties, and a little low for Fresno and Kern counties (table 1).

The survey was nine pages with 35 questions, including filling in tables of information, multiple-choice and open-ended questions. The survey was administered in 2010, and all the questions asked about the prebloom-to-harvest season of 2009. One section addressed the management of four major citrus pests (California red scale, citrus red mite, citrus thrips and cottony cushion scale) and whether any insecticides were applied if the pest was present. We asked about the presence of three important natural enemies; the degree of grower reliance on these natural enemies for pest control; and natural enemy releases during the season. Other questions addressed the implementation of cultural control methods, such as dust reduction, pruning, cover crops and sources of pest control information.

Other sections inquired about characteristics of the operation, including the amount of citrus acreage, acreage of other crops and livestock numbers, prices received and how much citrus was sold to various outlets. The final set of questions addressed demographics, experience and the share of agricultural and citrus production in the household's total income.

Pest presence and biological control usage

Citrus thrips. Citrus thrips was the most common pest, with 54.8% of respondents reporting it present (table 2). Citrus thrips was most common in the San Joaquin Valley and least common in the Coastal-Intermediate region. Respondents were more likely to rely on insecticidal control for citrus thrips than other pests; 30.6% of all respondents (more than half of those with citrus thrips present) applied at least one insecticide for this pest, and insecticidal control was most common in the San Joaquin Valley.

California red scale. California red scale was the second most common pest, with 47.7% of all respondents reporting its presence (table 2). The pest was most common in the Northern

TABLE 1. Survey respondents' citrus acreage, 2009, and 2008 USDA county citrus acreage

County	Respondents' reported acreage 2009*	Percentage of total acreage reported	USDA county acreage 2008*	Percentage of total USDA acreage 2008
		%		%
Butte	68	0.2	201	0.1
Fresno	1,354	4.0	32,928	12.2
Glenn	91	0.3	447	0.2
Imperial†	0	0.0	7,133	2.6
Kern	2,424	7.1	53,484	19.9
Kings	0	0.0	< 200	0.0
Madera§	5,666	16.6	6,451	2.4
Orange	38	0.1	446	0.2
Riverside	895	2.6	18,280	6.8
San Bernardino	1,248	3.7	3,775	1.4
San Diego	1,794	5.3	10,091	3.7
San Luis Obispo	221	0.6	1,774	0.7
Santa Barbara	184	0.5	1,460	0.5
Stanislaus	0	0.0	293	0.1
Tulare	13,497	39.6	105,194	39.1
Ventura	6,631	19.4	27,314	10.1
Total	34,111	100.0	269,271	100.0

* Source: USDA 2008.
† Only 16 surveys were mailed for entire county due to several managers handling many farms.
§ One farm manager accounts for 99.7% of reported respondent acreage in county.

TABLE 2. Pests present and insecticides applied by survey respondents

Pest	Pest not present*	Pest present: No insecticide	Insecticide	Total
	%			
Citrus thrips				
All regions (389)†	45.2	24.2	30.6	54.8
Northern (15)	26.7	40.0	33.3	73.3
San Joaquin Valley (133)	14.3	16.5	69.2	85.7
Coastal-Intermediate (202)	67.3	27.2	5.4	32.6
Interior (32)	50.0	21.9	28.1	50.0
Desert (5)	0.0	80.0	20.0	100.0
California red scale				
All regions (394)	52.3	28.9	18.8	47.7
Northern (15)	40.0	33.3	26.7	60.0
San Joaquin Valley (136)	40.4	26.5	33.1	59.6
Coastal-Intermediate (204)	60.8	28.9	10.3	39.2
Interior (32)	50.0	40.6	9.4	50.0
Desert (5)	80.0	0.0	20.0	20.0
Citrus red mite				
All regions (393)	69.4	23.5	7.1	30.6
Northern (14)	85.7	14.3	0.0	14.3
San Joaquin Valley (136)	62.5	22.8	14.7	37.5
Coastal-Intermediate (207)	71.0	25.6	3.4	29.0
Interior (32)	78.1	18.8	3.1	21.9
Desert (4)	100.0	0.0	0.0	0.0
Cottony cushion scale				
All regions (391)	70.1	27.1	2.8	29.9
Northern (16)	68.8	31.3	0.0	31.3
San Joaquin Valley (135)	60.7	34.1	5.2	39.3
Coastal-Intermediate (203)	77.3	20.7	2.0	22.7
Interior	64.5	35.5	0.0	35.5
Desert (4)	75.0	25.0	0.0	25.0

* Report of "not present" does not necessarily mean that zero pests were present, only that none were detected.
† Number of respondents is shown in parenthesis.

and San Joaquin Valley regions and least common in the Desert and Coastal-Intermediate regions. Less than half of respondents who reported California red scale present chose to apply a pesticide. (This may be due to the effect of a pesticide application persisting for more than 1 year; respondents who treated the previous year would have been unlikely to report an application in the 2009-2010 season.)

As with citrus thrips, insecticidal control of California red scale was most common in the San Joaquin Valley. This is consistent with UC IPM guidelines, which state that biological control of California red scale is most effective in coastal areas (and some inland areas of Southern California) and that California red scale has been suppressed through a pesticide eradication program in the Desert region.

Photos: Jack Kelly Clark/UC Statewide IPM Program

Natural enemies of pest insects can help control crop damage. *Euseius tularensis* is a mite that feeds on, *left*, citrus thrips, and, *right,* citrus red mite, both important citrus pests.

The reported natural occurrence of *A. melinus* — the biological control agent for California red scale — was most common in the Interior and Northern regions and least common in Desert and Coastal-Intermediate regions (table 3); this may be partially due to regional differences in the presence of California red scale. Forty-seven respondents purchased and released *A. melinus* to control California red scale, about one-quarter of those who reported the pest present (table 4). These 47 growers made an average of four releases (data not shown), the majority in the Coastal-Intermediate and San Joaquin Valley regions.

Citrus red mite and cottony cushion scale. Citrus red mite and cottony cushion scale had similar prevalence, 30.6% and 29.9%, respectively (table 2). Citrus red mite was most common in the San Joaquin Valley and least common in the Desert region, while cottony cushion scale

TABLE 3. Presence of natural enemies reported by survey respondents

Natural enemy	Naturally occurring	Not naturally occurring	Unknown
		%	
Vedalia beetle			
All regions (284)*	26.8	24.6	48.6
Northern (8)	50.0	12.5	37.5
San Joaquin Valley (71)	5.6	25.4	69.0
Coastal-Intermediate (139)	16.5	30.9	52.5
Interior (23)	26.1	30.4	43.5
Desert (2)	0.0	50.0	50.0
Aphytis melinus			
All regions (310)	22.3	26.5	51.3
Northern (9)	33.3	22.2	44.4
San Joaquin Valley (113)	26.5	23.9	49.6
Coastal-Intermediate (160)	16.9	30.0	53.1
Interior (25)	36.0	20.0	44.0
Desert (1)	0.0	0.0	100.0
Euseius tularensis			
All regions (329)	21.9	21.0	57.1
Northern (10)	30.0	20.0	50.0
San Joaquin Valley (124)	29.0	16.9	54.0
Coastal-Intermediate (163)	16.6	25.2	58.3
Interior (27)	22.2	18.5	59.3
Desert (3)	0.0	0.0	100.0

* Number of respondents is shown in parenthesis.

TABLE 4. Reliance on natural enemies for pest control among survey respondents

Natural enemy/pest	Pest not present	Degree of reliance on natural enemy (pest present)			
		None	Somewhat	Mostly	Entirely
			%		
Vedalia beetle/cottony cushion scale					
All regions (379)*	70.7	11.6	5.0	5.8	6.9
Northern (14)	71.4	7.1	7.1	7.1	7.1
San Joaquin Valley (136)	61.8	10.3	8.8	9.6	9.6
Coastal-Intermediate (195)	76.9	12.8	3.1	2.6	4.6
Interior (29)	72.4	6.9	0.0	10.3	10.3
Desert (4)	75.0	25.0	0.0	0.0	0.0
***Aphytis melinus*/California red scale**					
All regions (378)	51.6	22.2	9.3	5.6	11.4
Northern (13)	61.5	7.7	7.7	7.7	15.4
San Joaquin Valley (132)	40.2	35.6	9.8	7.6	6.8
Coastal-Intermediate (197)	57.9	16.2	8.6	5.1	12.2
Interior (3)	50.0	13.3	10.0	0.0	26.7
Desert (4)	100.0	0.0	0.0	0.0	0.0
***Euseius tularensis*/citrus thrips and citrus red mite**					
All regions (369)	45.0	36.0	7.3	5.4	6.2
Northern (14)	42.9	28.6	14.3	7.1	7.1
San Joaquin Valley (130)	18.5	55.4	12.3	7.7	6.2
Coastal-Intermediate (192)	63.5	22.4	4.2	3.1	6.8
Interior (28)	50.0	32.1	3.6	10.7	3.6
Desert	0.0	100.0	0.0	0.0	0.0

* Number of respondents is shown in parenthesis.

The majority of survey respondents who reported having cottony cushion scale or California red scale also reported using biological control.

was most common in the San Joaquin Valley and least common in the Coastal-Intermediate region.

Only 7.1% and 2.8% of respondents applied a pesticide to control citrus red mite and cottony cushion scale, and these respondents were only 23% and 9% of respondents with these pests present, respectively. For citrus red mite, healthy orchards with abundant natural enemies, such as *E. tularensis*, may be able to tolerate high populations of both pests without suffering economic damage (Grafton-Cardwell et al. 2009). Vedalia beetle and *Cryptochaetum iceryae* (in coastal areas) keep cottony cushion scale under control in most orchards, when not disrupted by pesticides (Grafton-Cardwell et al. 2009). The reported natural occurrence of *E. tularensis* was highest in the Northern and San Joaquin Valley regions, and lowest in the Desert and Coastal-Intermediate regions (table 3).

Although cottony cushion scale was the least commonly reported pest (table 2), vedalia beetle was the most commonly reported natural enemy (table 3). Vedalia beetle consumes only cottony cushion scale and cannot survive without this food source. Cottony cushion scale was likely present in more orchards, with vedalia beetle keeping it below detectable thresholds.

Reliance on biological control. We asked growers about the degree to which they relied on vedalia beetle, *A. melinus* and *E. tularensis* for pest control. While 26.8% reported having vedalia beetle present (table 3), only 17.7% reported any degree of reliance on it for cottony cushion scale control (table 4). Reliance on vedalia beetle was most common in the San Joaquin Valley, where cottony cushion scale was most prevalent. For California red scale control, 26.3% relied on *A. melinus* to some extent. Only 18.9% of respondents reported relying on *E. tularensis* for citrus red mite or citrus thrips control; more than one-third reported they had citrus thrips or citrus red mite and had not relied on the predatory mite for control, which could be due to their not knowing that *E. tularensis* was present.

Determinants for using biocontrol

We performed a statistical analysis of three groups of respondents: (1) all respondents, (2) those who incorporated some biological control into their pest management programs and (3) those who released *A. melinus.* Although large standard errors for most variables prevented statistical significance of the difference in means, the survey results did show trends (table 5). Respondents who relied to at least some extent on beneficial insects for control had substantially more citrus acreage than the average respondent. The average years of farming experience was slightly higher for respondents reporting some degree of reliance on *A. melinus* than for the average respondent, and even higher for those reporting some degree of reliance on vedalia beetle and *E. tularensis*.

Smaller shares of Asian and Latino respondents indicated any reliance on pest control provided by *A. melinus*. The "other" ethnic group comprised a

TABLE 5. Characteristics of survey respondents and those who relied on or released natural enemies: Summary statistics

	All respondents	Relied on wasp	Released wasp	Relied on beetle	Relied on mite
Number of respondents	422	93	47	67	70
Farm characteristics					
Nonorange acreage (%)	39.1	38.8	37.0	34.7	35.9
Average total citrus acres	76.4	224.7	402.1	199.0	253.0
Average total acres	167.6	347.0	632.9	295.3	346.5
Average expected value per acre ($)	6,242	6,445	6,841	5,945	6,525
Growers with organic acreage (%)	14.5	10.8	6.4	9.0	8.6
Grower characteristics					
Median education level	College degree	College degree	College degree	College degree	College degree
Average experience (years)	25.7	29.9	29.4	33.5	32.8
Female (%)	18.0	14.9	15.9	12.1	10.0
Race (%)					
White	86.4	90.9	93.2	84.9	83.5
Asian	3.6	1.1	0.0	3.0	6.0
Latino	6.4	3.4	2.3	4.5	3.0
Other	3.6	4.6	4.5	7.6	7.5
Output sold through outlet (%)					
Packinghouse/shipper	65.0	78.7	88.3	80.5	75.4
Processor	6.2	2.4	3.0	2.2	0.3
Other	21.7	3.3	4.3	1.6	2.9
Primary source of pest control information (%)					
Pest control adviser	55.3	70.1	82.2	67.7	65.6
Extension agent	13.5	9.2	4.4	9.8	14.1
Other growers	8.1	2.3	0.0	3.2	4.7
Farm/chemical suppliers	7.2	0.0	0.0	1.6	1.6
Extension publications	4.3	3.4	2.2	6.5	4.7
Organic certifying agent	3.7	0.0	0.0	0.0	0.0
Trade magazines	1.1	1.1	2.2	0.0	0.0
Other*	6.6	13.8	8.9	11.3	9.4

* Includes insectaries and packinghouses, respondents' own experience, Web research and entomologists.

TABLE 6. Grower reliance on *Aphytus melinus* and augmentative releases: Marginal effects of Probit models†

Explanatory variable	Effect on probability of grower relying mostly or entirely on *A. melinus*	Effect on probability of *A. melinus* release(s)
	.... %	
Red scale degree-days	−5.22	−0.90
Natural enemy degree-days	8.36	0.88
Output to outlet (%)		
Processor	0.07	0.12
Nonprocessor, nonpackinghouse	0.03	−0.23*
Nonorange acres (%)	−22.78	−14.82
Expected value/acre ($1,000s)	0.04*	0.03*
Organic	−5.28	−4.00
Total citrus acres	5.73	5.86*
Total citrus acres squared	−0.06	−0.02
Total acres	−8.27	0.18
Total acres squared	0.13	−0.01
Education	63.41**	18.66
Education squared	−6.26**	−1.97
Experience	0.15	−0.09
Experience squared	0.00	0.01
Primary information source (comparison base: pest control adviser)		
Extension agent	−11.81	−14.38*
Extension publications	27.10	10.45
Other growers	−19.17	—
Chemical supplier	—	—
Trade magazine‡	—	46.57
Other source	16.51	11.65
Female	12.33	7.33
Ethnicity (comparison base: white)		
Asian	−23.56*	—
Latino	43.52**	13.53
Other	—	−21.46***
Region (comparison base: San Joaquin Valley)		
Northern	40.26	14.51
Coastal-Intermediate	38.52**	22.39
Interior	51.86***	31.29*
Cover crop	23.28	25.32
Hedgerow	−15.32	−21.36***
N	154.00	167.00
Pseudo-R squared	0.1898	0.2826

*, ** and *** indicate significance at the 10%, 5% and 1% levels, respectively.

† For continuous variables, percentages reported indicate how increasing the explanatory variable by one unit from its mean affects the probability that a grower relies mostly or entirely on *A. melinus* or releases *A. melinus*. For binary variables (organic, information source, female, ethnicity, region, cover crop, hedgerows), the percentage indicates how a move from the base category (e.g., white ethnicity) or absence of a characteristic (e.g., no cover crops) to that category (e.g., Asian ethnicity) or characteristic (e.g., cover crops present) affects the probability that a respondent relies mostly or entirely on *A. melinus* or releases *A. melinus*. Binary variables for which no marginal effect is given were removed from the model because for each of those variables, all growers in the category did not rely on or release *A. melinus*. A value of one for these binary variables perfectly predicts that the grower did not rely on *A. melinus* or release *A. melinus*, and the model cannot be estimated with perfect predictors.

‡ One grower reported making augmentative releases of *A. melinus* and relying on trade magazines for information but did not report degree of reliance on *A. melinus*.

disproportionately large share of the groups that relied on vedalia beetle and *E. tularensis* compared to the entire sample. In terms of sales outlets, respondents who relied to some degree on beneficial insects sold a larger share of their output to packinghouses and a smaller share to processors and other outlets than the entire sample. Over half of all respondents (55.3%) said pest control advisers were their primary source of information, but 65.6% to 82.2% of those who relied on beneficial insects listed pest control advisers as their primary information source.

A. melinus probability analysis

We performed statistical analysis regarding two aspects of California red scale control for the subset of respondents who reported it present during the 2009 growing season. Using a Probit model, we modeled the probability that a grower relied mostly or entirely on *A. melinus* for California red scale control — either by using pesticides compatible with *A. melinus*, thereby conserving the beneficial insect, or by augmenting *A. melinus* through releases of commercially produced insects. Additionally, we modeled separately the probability that a grower chose to purchase and release *A. melinus* to augment a naturally occurring population. A Probit model measures the effects of predictor or explanatory variables on the probability of an outcome occurring (e.g., augmentation of *A. melinus*); the explanatory values we tested are listed in table 6.

Economic factors. Among the economic characteristics, an increase in the expected value of production per acre increased the probability that a respondent relied on *A. melinus* and that he or she released *A. melinus*. Both coefficients were statistically significant. Also, as the share of output sold to outlets other than processors and packinghouses — such as farmers markets, grocery wholesalers and restaurants — increased, respondents were less likely to make releases. The price effects of scale damage may differ for these outlets.

Acreage. Respondents with more acres of citrus were more likely to make releases than those with fewer acres, probably because of economies of scale. Releases must coincide with particular stages in the California red scale cycle,

Since its introduction in 1888–1889, the vedalia beetle has successfully controlled cottony cushion scale, an invasive pest that had threatened the California citrus industry.

and the quantity needed depends on existing populations, which are determined by population dynamics and previous releases. Additionally, some pesticides that provide control of common citrus pests are toxic to *A. melinus*, so growers must consider their entire pest management plan when relying on *A. melinus* (Grafton-Cardwell et al. 2009). For growers with many acres of citrus, the time needed to learn about and carry out *A. melinus* treatments is more likely to yield sufficient benefits to justify the time investment than it is for growers with fewer acres.

Education. Educational attainment had a positive and statistically significant effect on the likelihood that a respondent relied mostly or entirely on *A. melinus* to control citrus red scale. The effect of educational attainment, however, leveled off at the graduate degree level.

Information sources. Primary sources of pest control information were significant predictors of both reliance on and releases of *A. melinus*. Respondents relying on Cooperative Extension agents were about 14% less likely to make releases than those relying on pest control advisers for their pest control information, and the effect was statistically significant.

Ethnicity. Grower ethnicity had statistically significant effects. Asian respondents were 24% less likely than white respondents to rely mostly or entirely on *A. melinus,* while Latino respondents were 44% more likely than white respondents to rely mostly or entirely on *A. melinus*. Respondents of "other" ethnicity were 21% less likely to make releases than white respondents.

Region. Not surprisingly, there were regional effects. Respondents in the Coastal-Intermediate and Interior regions were 39% and 52% more likely, respectively, to rely on *A. melinus* than those in the San Joaquin Valley, probably because of climatic factors favoring *A. melinus* and biological control in those regions. Respondents in the Interior region were 31% more likely to make augmentative releases than those in the San Joaquin Valley. Respondents in the Coastal-Intermediate and San Joaquin Valley regions had similar likelihoods of releasing *A. melinus,* though for different reasons: In the Coastal-Interior region, growers can likely rely on *A. melinus* without releases because of a favorable climate and the application of compatible pesticides, while growers in the San Joaquin Valley may choose not to make releases because the area's climate impedes the establishment of *A. melinus*.

Hedgerows. The use of hedgerows (trees or shrubs planted around a field of crops) decreased the likelihood that a respondent made releases, although only about 6% of respondents had hedgerows. Hedgerows may provide additional habitat or resources for beneficial insects or may buffer orchards from nearby use of pesticides toxic to *A. melinus*, decreasing the need for releases.

Opportunities for UCCE

We were able to derive a few implications about the use of biological control among citrus growers. First, many growers already incorporate biological control into their pest management plans. The majority of respondents who reported having cottony cushion scale or California red scale reported using biological control, although their degree of reliance on it varied by pest, region and respondent characteristics. Additionally, growers are willing to incorporate releases of commercially available natural enemies in their pest management plans, as evidenced by the quarter of all growers with California red scale who currently release commercially available *A. melinus*.

Besides *A. melinus*, other beneficial insects that we surveyed are not commercially available at this time. Vedalia beetle is not likely to be produced commercially. Given evidence that a variety of beneficial insects (including two generalist predators, lacewings and minute pirate bugs, which are currently commercially available) collectively provide some degree of biological control for citrus thrips, production and augmentative releases of *E. tularensis* may not be the most effective means of enhancing the biological control of citrus thrips or citrus red mite. Research suggests that pruning and leguminous cover crops help support larger populations of *E. tularensis* (Grafton-Cardwell 1997; Grafton-Cardwell and Ouyang 1995b). Increasing the use of these practices and resources to attract and support a variety of natural enemies may be the most cost-effective approach to biological control of citrus thrips.

Consistent with economic theory, respondents whose operations and personal characteristics predicted that they had the largest potential gains from investments of time spent learning and implementing biological control were the ones who chose to rely on biological control. If the social benefits of biological control (positive benefits to the individual grower as well as nearby growers) exceed the benefits to the individual grower, the adoption of biological control practices only by growers with an individual incentive to do so will result in too little biological control relative to the socially optimal level (the level at which regional profits are greatest). Comments from respondents provided anecdotal evidence of positive spillover effects from neighbors who released *A. melinus*, suggesting that the social benefits are in fact greater than the private benefits, at least in some instances.

To increase the net private benefit of using biological control, subsidies could be implemented in regions such as the Coastal-Intermediate region and parts of the San Joaquin Valley where it would be cost effective to control California red scale with *A. melinus*. Instead of direct financial subsidies, free training workshops or reminders about when key population life-cycle events are occurring in specific regions could be effective.

Currently, UCCE provides training workshops and newsletters. Our analysis suggests that expanding them could advance the use of biological control; only about 4% of respondents relied on Cooperative Extension publications as their primary source of pest control information and only 13.5% relied on a Cooperative Extension agent. The results also suggest that efforts should be made to draw more growers away from reliance on farm and chemical suppliers for pest control information, perhaps by making other sources more accessible or appealing.

Lastly, the variation across ethnic groups merits consideration. Asian respondents were less likely to rely on *A. melinus*, and summary statistics suggest that Latino growers may rely less on pest control provided by beneficial insects than white growers, although this was not confirmed in the formal statistical analysis. At the time of our survey, detailed information on *A. melinus* releases could only readily be found in English, which favors growers whose first language is English. While ethnicity should not be conflated with English-language skills, many Cooperative Extension documents in California are translated into various languages, suggesting that there are growers who benefit from information in other languages. Providing instructions on *A. melinus* releases in additional languages might make it easier for more growers to incorporate control provided by *A. melinus* into their pest management programs.

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In a probability analysis for the use of *A. melinus* to control California red scale (shown, male), survey respondents with more citrus acreage were more likely to release the biological control agent.

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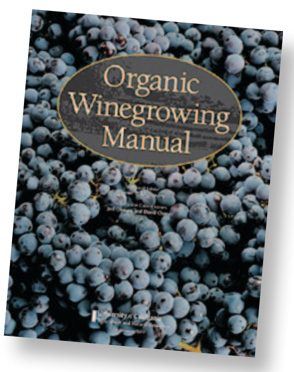

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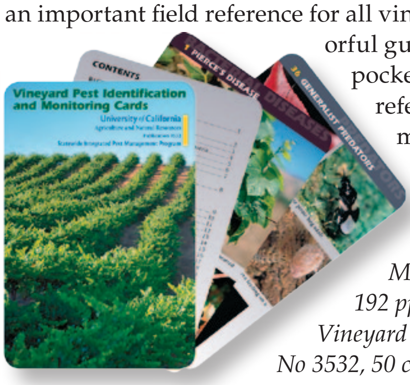

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