JULY–SEPTEMBER 2012 • VOLUME 66 NUMBER 3

California Agriculture

Long-term study:

Conservation tillage saves soil, time and money

Also: Ag burning, oak woodlands, plant microchips, erosion estimates

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

California agriculture profitable and growing

Karen Klonsky
UC Cooperative Extension Specialist, Agricultural and Resource Economics, UC Davis

Today, while many sectors of the statewide economy are struggling, California agriculture is profitable and growing. The Golden State remains the largest agricultural producer in the nation, despite the fact that since 1992, total land in California farms dropped from 29 million to 25.3 million acres.

The story behind these figures is complex. Harvested cropland decreased only slightly; the greatest losses were in pasture and grazing land. Irrigated acres actually increased from 7.6 million in 1992 to 8 million in 2010. Growers shifted toward high-value crops: orchard acreage rose from 2.2 million to 2.8 million acres and vegetable acreage from 1 million to 1.1 million.

Supported by UC research and extension, farmers across the state have adapted to changing economic conditions by changing their production mix, adopting new practices and adjusting their levels of production. The aggregate result determines the revenues, costs and net income or profitability of the farm sector. California agriculture posted a healthy $10.7 billion profit in 2010, 26% of gross income. California's agricultural products garnered $37.5 billion in revenue in 2010, while another $4 billion came from government payments and work hired by one farmer from another.

In California, three-fourths of the cash income from agriculture is attributable to cropland, and the other fourth is from livestock, poultry and related products. This ratio of crops to animal products has been nearly constant for 20 years. But the breakdown by crop type and for specific crops has changed. Increased revenue from agricultural products is the result of changes in enterprise selection, farm prices and yield per acre.

Field crops. The percentage contribution of field crops to farm income fell by $3.5 billion, from 15% in 1992 to 9% in 2010. Taking inflation into account, revenue from cotton and sugarbeets fell while rice revenue rose; these decreases reflect dramatic declines in acreage. Cotton acreage, for instance, declined due to poor prices. In marked contrast, rice revenue increased, because rice prices and acres rose.

Fruits and nuts. Fruits and nuts are increasingly important, rising from 27% of cash income in 1992 to 36% in 2010. All of the major nut crops expanded: almonds, pistachios and walnuts. Even taking inflation into account, almonds doubled in value, walnuts almost tripled and pistachios increased almost seven-fold. To meet increasing world demand, almond acreage has increased by 307,000 acres, pistachios by 79,500 acres and walnuts by 38,000 acres since 1992. Yields also grew as a result of improved irrigation and fertilization methods and the closer spacing of trees, among other cultural improvements.

Vegetables. Overall, the value of vegetable production adjusted for inflation was 10% lower in 2010 than in 1992, primarily due to lower prices and increased imports. Three of the most important vegetable crops showed increases in value: broccoli, carrots and lettuce. Perhaps the most dramatic story in yield increase is processing tomatoes with an average of 34 tons per acre in 1992 rising to a record 45.5 tons per acre in 2010. These gains, a testament to public- and private-sector research, result from improved varieties, a shift from direct-seeded to transplanted tomatoes, an increase in drip irrigation and fertigation, and a migration of tomato production from the Sacramento Valley to the San Joaquin Valley.

Livestock. Among livestock products, the relative importance of cattle and calves decreased while that of milk and cream increased. The total value of cattle and calves stayed constant while milk and cream increased in real value by 34% in 2010 compared to 1992, making California the number-one dairy state.

Organic. Organic agriculture, while still a small proportion of total revenue, rose from $75 million in 1992 to over $1 billion in 2010 and has become an important means of diversification for primarily conventional producers.

Expenses. Total farm expenses reached $31 billion in 2010. The largest increase compared to 1992 was in purchased inputs of farm origin, up by 62%, adjusted for inflation, over the time period. The dramatic increase in feed prices over the past 5 years partly reflects the jump in demand for corn in ethanol production in the Midwest. In contrast, total expenditures on pesticides only increased by 6%, adjusted for inflation, despite the fact that pesticide prices move in tandem with petroleum. This suggests more efficient and reduced use of pesticides over two decades. Farm labor, both hired and contract, represented 27% of total expenditures in 2010 and will remain a critical factor for continued profitability.

Net revenue. Overall, adjusting for inflation, total farm revenue increased 31% from 1992 to 2010, with slightly larger gains in crop than livestock production. Total costs also increased by 31% with the percentage increase in costs greater for farm-produced inputs (feed, livestock and seed) than manufactured inputs (fertilizer, pesticides, petroleum fuel and electricity). The bottom line is an increase in net farm income of 31%, to $10.7 billion in 2010. The percentage of revenue going to pay expenses is exactly the same in the 2 years, 74%. Looked at another way, for every dollar of revenue 26 cents is profit, meaning that for every dollar spent on inputs farms generate $1.35 in revenue.

Given the pressures from global economic conditions, competition from other regions and challenges that face farming in an increasingly urban state, California agriculture has shown remarkable capacity to innovate with new crops, new markets and cutting-edge technologies.

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COVER: Cotton production has traditionally relied on multiple tractor passes during the growing season, but targeted UC research — applying technological innovations — is demonstrating that conservation tillage is a viable option for California growers. In a 12-year study of cotton grown in rotation with tomato, conservation tillage lowered the number of tractor passes by about half, reducing labor and fuel usage. In the study's later years, lint yields were equivalent in the standard and conservation tillage plots. This innovative tomato transplanter (cover) tills strips of a Hollister field, rather than the entire surface. *Photo by Jeffrey P. Mitchell*

Long-term study:
Conservation tillage saves soil, time and money

News departments

Research and review articles

About *California Agriculture*

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, and the electronic journal logs about 5 million page views annually.

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

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

Indexing. The journal is indexed by AGRICOLA, Current Contents (Thomson ISI's Agriculture, Biology and Environmental Sciences and the SCIE databases), Commonwealth Agricultural Bureau (CAB), EBSCO (Academic Search Complete), Gale (Academic OneFile), 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 2010 and 2011, 23% were based at other UC campuses, or other universities and research institutions. In 2010 and 2011, 33% and 40% (respectively) of reviewers came from universities, research institutions or agencies outside ANR.

Rejection rate. The rejection rate has averaged 34% in the last 3 years. In addition, associate editors and staff may send back 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.

Editing. After peer review and acceptance, all manuscripts are extensively edited by the *California Agriculture* staff to ensure readability for an educated lay audience and multidisciplinary academics.

Submissions. *California Agriculture* manages the peer review of manuscripts online. Please read our Writing Guidelines before submitting an article; go to: http://californiaagriculture.ucanr.edu/submit.cfm.

Letters. The editorial staff welcomes your letters, comments and suggestions. Please write to us at the address below. Include your full name and address. Letters may be edited for space and clarity.

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WHAT DO YOU THINK?

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

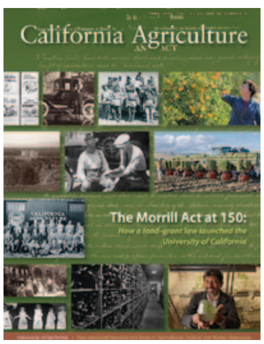
More on Morrill

I enjoyed the latest issue of *California Agriculture* with emphasis on the Morrill Act ("The Morrill Act at 150: How a land-grant law launched the University of California," April-June 2012). I have spent my entire college training and professional career at land-grant universities, but I knew only the basics of the important legislative acts affecting them. So with extra time after retirement, I began to learn more about the background of these important laws.

I'm sure that most of my colleagues don't know that there are 107 land-grant institutions in the United States, that a 1994 act added more than two dozen Native American institutions to the total, that MIT is a land-grant university, or even that Rep. Morrill almost certainly was not the author of the Morrill Act of 1862, although he did yeoman's service in getting it passed.

I have written up my findings (see http://ucanr.org/u.cfm?id=46) and shared them with various people on my campus. I am not a historian and this is not an authoritative scholarly work, but I believe it is accurate. I believe the Morrill Act of 1862 was one of the most influential events in the history of education in the world.

Arnold P. Appleby
Professor Emeritus Crop Science
Oregon State University, Corvallis



April–June 2012
California Agriculture

UC President Mark G. Yudof presented an excellent overview ("For 150 years, UC science and agriculture transform California," April-June 2012). He concluded that without the Morrill Act, UC might not have evolved into world's greatest public university system, which led California agriculture to a $37.5 billion industry. President Yudoff credited Justin Smith Morrill, who proposed the federal land-grant system, which was endorsed by President Lincoln, who signed the Morrill Land-Grant College Act of July 2, 1862.

Your readers will be enlightened to learn that Rep. Morrill left school at the age of 15! He attended commons schools in Vermont: Thetford Academy and Randolf Academy. He never went to college, since his father could not afford to send him for further education. However, his school foundation enabled him to lead the people of Vermont in the U.S. Congress for 12 years, from 1885 to 1867. Later he became a U.S. senator for over 30 years. He died in 1898 while in office. The University of Pennsylvania gave him an honorary degree for his work as a congressman.

Dilipsinh M. Gaekwar
Mendham, N.J.

Morrill Act inspires

I appreciated the article in the current publication that reviews the history of land-grant colleges, beginning with President Lincoln ("UC's land-grant mission fuels nation's growth, prosperity," by Rose Hayden-Smith, April-June 2012). I cannot imagine where the United States would be without well-funded agricultural research and technology from lab to field. UC has been a major leader, and it's interesting to know how it has influenced agriculture around the world and the topics that are crucial for food production and healthy natural resources. Thank you, *California Agriculture* and the editorial staff, for sharing.

Karen Sweet
Rancher and Steering Committee Member
California Rangeland Conservation Coalition

I am here in Pakistan on a project to help Pakistan and Afghanistan develop an extension service. I brought a number of the current issue to share with colleagues and our trainees. I thought it was excellent, especially the specific details of Lincoln and the South's secession aiding passage of the Morrill Act.

Louise Ferguson
Cooperative Extension Specialist
Department of Plant Sciences, UC Davis

UC Riverside history clarified

The UC Riverside College of Natural and Agricultural Sciences dean's office just received the magnificent April-June 2012 issue. I hasten to send congratulations to all who had a hand in it. I especially enjoyed Rose Hayden-Smith's review of the effects of the Morrill Land-Grant College Act, a piece of legislation whose importance to American higher education is matched (perhaps) only by the GI Bill.

I must draw your attention to a mistake in your timeline — a rather serious one from our point of view. On page 47 you write, "The [Citrus Experiment Station] became UC Riverside in 1959." Actually, UC Riverside was founded in 1954.

This error may have come about by a too-rapid reading of the UC Riverside website. The history presented at www.ucr.edu/about/history.html states, "In 1948, the University of California

Corrections

On page 48 of the April-June 2012 issue, the years on two images (B and C) from the Ansel Adams Fiat Lux Collection at UC Riverside/California Museum of Photography were misidentified. The photographs were taken in 1966. *California Agriculture* regrets the error.

Due to an editing error, incorrect wording appeared near the top of page 43 in the print journal. The sentence should read, "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" not ". . .and Native Americans."

Although the 1890 Morrill Act later fostered tribal colleges (through a provision that land-grant schools could not deny admission based on race), funding did not occur until passage of the Elementary and Secondary Education Reauthorization Act of 1994.

Regents approved the establishment of the College of Letters and Science. The college opened for classes in February 1954. In 1959, Riverside was declared a general campus by the Regents and courses of study began to be developed."

It would be easy to focus on that 1959 date since the earlier date is submerged, both physically and syntactically. Our timeline (www.ucr.edu/about/timeline.html) outlines the development of UC Riverside. A small liberal arts college was established in 1954 as UC Riverside, which the Regents intended as an alternative to the other comprehensive UC campuses. That model was not successful, and 5 years later the Regents reorganized UC Riverside as a general campus.

It is important that the readers of *California Agriculture* know the second most important date in UC Riverside history — the first, of course, being the foundation of the Citrus Experiment Station in 1907.

Sara Clausen
Director of Communications
College of Natural and Agricultural Sciences, UC Riverside

The photos are wonderful — an incredible collage for the different eras. I had not realized that UC Riverside had those Ansel Adams photos. The choices were diverse, such as those from the Fritz-Metcalf collection.

There was one minor typo on the very last page that caught my eye, since I am familiar with publication numbering. An ad for the *Organic Winemaking Manual is* listed as ANR Pub No. 5311, but it's actually 3511.

I know how much work went into this issue. Congratulations!

Norma Kobzina, Interim Head
Marion Koshland Bioscience and
Natural Resources Library, UC Berkeley

The UC Regents commissioned Ansel Adams to take images for a book commemorating the University's centennial; *Fiat Lux* was published in 1967. Adams photographed the UC Davis enology cellars in 1966.

The legacy of black agriculture in California

Sept. 9, 1850, Admission Day for the state of California, provided an economic infusion into the U.S. economy; fueled by the Gold Rush, this event helped to provide capital for technological change including transcontinental transportation and public education. President Abraham Lincoln was elected in 1860; in the midst of the Civil War, a slate of 1862 farm legislation passed Congress because there was no Southern block to influence U.S. farm policy.

Prior to the Emancipation Proclamation, President Lincoln wrote in September 1862, "If I could save the Union without freeing the slave, I would do it, and if I could save it by freeing all the slaves, I would do it, and if I could do it by freeing some and leaving others alone, I would also do that." Lincoln's object was to save the Union, and he chose the latter.

California must expand the equitable allocation of resources to include a renewed recognition of the contributions — past, present and future — of people of African ancestry to the landscape.

These hidden contributions must come to light. We have earned recognition as catalysts for inclusive partnerships that began with the creation of the first public school and continue with UC participation.

On April 28, we co-hosted, with Tarlesson Farms, a groundbreaking ceremony for our Black Agriculture Regional Center in historic Guinda, in the Capay Valley. On May 25, we celebrated Africa Day and passage of Senate Resolution 31 at the State Capitol in Sacramento.

The California Black Agriculture Working Group will continue raising awareness of challenges, as well as progress made, in restoring agriculture as the foundation of black culture.

Michael Harris, Chairperson
California Black Agriculture Working Group
Sacramento

Editor's note: The U.S. Department of Agriculture Office of Advocacy and Outreach offers programs to improve access to services for historically underserved communities, increase the viability and profitability of small and beginning farmers and ranchers, provide agricultural opportunities for farmworkers, and close the professional achievement gap by providing opportunities to talented and diverse young people. For more information go to www.outreach.usda.gov and www.outreach.usda.gov/USDALocalOffices.htm.

Name that fruit

Regarding the picture on page 64 of the April-June 2012 *California Agriculture* labeled "plums": it looks like prunes to me because it has a flat pit or stone.

I am confounded by the modern uses of the words "prunes" and "plums." For the last 80 years I have been told there is a difference between the two. Prunes are freestone fruits. Plums are clingstone fruits. Prunes can be dried with the pits. Plums cannot be dried with the pits. To buy these trees you must ask the nursery for either prune trees or plum trees.

Prunes or plums? An Oregon prune farmer wants to know.

I have a difficult time telling the grocery stores to list my 'Brook' prunes as prunes. The stores try to compromise and call them prune plums.

If the prunes I grow and sell are to be called plums, then other members of the *Prunis* genus might as well carry that label as well: apricots, peaches, cherries and almonds.

In Oregon, the filbert nut is now called a hazelnut for marketing purposes, so that may be the case with plums. Back in the 1800s and 1900s, the foothills of the Willamette Valley raised a lot of prunes. I have government bulletins referring to production from 1927, 1931, 1954, 1962, 1968 and 1982. I see ads from California for dried prunes and prune juice.

I would like to see the correct use of prunes and plums, whatever that is. Thank you for the good articles. Keep them accurate and scientific.

There is an old saying, "full of prunes," meaning to talk nonsense. Maybe I am full of prunes.

Glen Mills
Mills Organic Farm
Newberg, Oregon

Theodore DeJong, UC Cooperative Extension Pomologist, responds: Technically prunes are plums that are used for drying. Specific plums that will dry without fermenting when laid in the sun can also be called prunes. In the commercial trade in most countries, plums used for drying can be called prunes whether they are actually sold fresh or dry. In California, dried prunes have been marketed as dried plums to get away from the idea that they are only for old people who need a laxative. It has nothing to do with being freestone or clingstone.

Labeling biotech crops

Regarding "Research and adoption of biotechnology strategies could improve California fruit and nut crops," by Haroldsen et al. (April-June 2012): Can *California Agriculture* disprove the alleged health and environmental risks of genetically modified organisms (GMOs)? We are supporting a "label GMOs" initiative in California, to require all producers to label their products. If the GMO developers and seed manufacturers are confident and proud of their product, why are they spending millions to stop the initiative? Of course this would include transgenics. We buy only organic and are budding organic farmers.

Vazik and Janet Avedisian
Arroyo Grande

Lead author Victor Haroldsen and co-authors respond: As we cited in our article, genetically engineered (GE) crops have provided "a reduction of 86.2 million pounds (10.2%) of pesticide usage and proffer[ed] an associated 21.8% reduction in the environmental impact quotient." These are demonstrable benefits that should resonate with organic consumers and budding organic farmers. Unfortunately, there is a wide philosophical gap between organic and conventional farmers when it comes to GE crops, even though there is a shared interest in producing safe food with reduced environmental impacts. Mandatory labeling of GE foods in California will present yet another hurdle to the commercialization of improved fruit and nut crops that could be beneficial to California's economy and, in one more way, create a regulatory barrier to innovation in the state.

Okanagen Specialty Fruits is seeking regulatory approval for its nonbrowning apple (right).

Switchgrass and CDFA

Regarding "Switchgrass clarification" (Letters, April-June 2012): While switchgrass is no longer on the California Department of Food and Agriculture (CDFA) noxious weed list, it was included as a B-listed species in 2007 (see CDFA's *Noxious Times* 8(4):1–9). Interestingly, the plant has never been shown to be invasive in California, where it is not native, but it was placed on the list because of the proposed planting of large acreages as a biofuel species. By putting switchgrass on the state's noxious weed list, CDFA was then able to prevent large-scale cultivation until they were assured that it did not have high potential to become an invasive

Switchgrass, a promising biofuel, is not considered a noxious weed.

Three ACE awards for *California Agriculture*

The *California Agriculture* team has won three awards from the Association for Communication Excellence in Agriculture, Natural Resources, and Life and Human Sciences (ACE), a trade association for land-grant communicators (www.aceweb.org). The awards are:

- **Technical publications, bronze;** Janet Byron, Robin Meadows, Will Suckow, Hazel White and Janet White: "Food as Medicine: Can what we eat help cure what ails us?" (July-September 2011).
- **Writing within a specialized publication, bronze;** Robin Meadows: "Biofactors in food linked to health benefits" (July-September 2011).
- **Editing, silver;** Janet Byron: "California agritourism operations and their economic potential are growing" by Ellie Rilla (April-June 2011).

Managing Editor Janet Byron and Executive Editor Janet White accepted the awards during the 2012 ACE conference in Annapolis, Md., on June 13.

species. In fact, our lab was involved in those studies. By 2010, switchgrass had been removed from the state noxious weed list. In support of this, our research results showed that it has a very low potential to become invasive in the state.

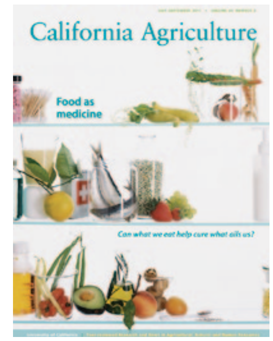
Joseph DiTomaso
Cooperative Extension Weed Specialist
Department of Plant Sciences, UC Davis

Seaweed as a source of omega-3 fatty acids

Regarding "Food as Medicine" (July-September 2011): The authors must be aware of the sources of omega-3 fatty acids. Seaweed salad from Korea solves the problem without using fish. I consume some with my nopalitos for breakfast every morning. The public should be aware of this source of omega-3 fats.

Andrew A. Benson
Scripps Institution of Oceanography
UC San Diego

Angela Zivkovic, author of "Dietary omega-3 fatty acids aid in the modulation of inflammation and metabolic health" (July-September 2011), responds: While seaweed (wakame) is a source of omega-3 fatty acids, it contains modest amounts. According to the U.S. Department of Agriculture nutrient database, there are 186 milligrams of eicosapentaenoic acid (EPA) per 100 grams of raw seaweed. This is one-third of the amount in an equivalent portion of raw pink (wild) salmon. There is even less in dried seaweed: 87 milligrams EPA per 100 grams. An entire package of dried seaweed usually contains 100 grams of seaweed, which is typically not consumed by one person in 1 day.

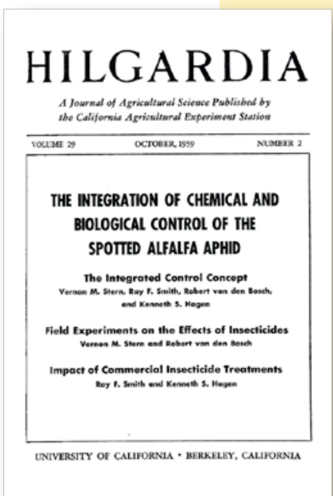


July–September 2011
California Agriculture

First phase of *Hilgardia* Project under way

The *Hilgardia* Project, launched in April 2011 to bring the classic UC publication to the Web, has received $26,550 in donations and pledges and is nearing its fundraising goal of $30,000. The project's first phase — preparing the Wine and Grape Collection for posting online — is under way.

For 70 years, until publication ceased in 1995, *Hilgardia* was the primary technical publication of UC Agriculture and Natural Resources. The archive includes classic research in agricultural, environmental and nutritional sciences, content that is still widely cited and valuable to industry and scholars.


HILGARDIA

A Journal of Agricultural Science Published by the California Agricultural Experiment Station

VOLUME 29 OCTOBER, 1959 NUMBER 2

THE INTEGRATION OF CHEMICAL AND BIOLOGICAL CONTROL OF THE SPOTTED ALFALFA APHID

The Integrated Control Concept
Vernon M. Stern, Ray F. Smith, Robert van den Bosch, and Kenneth S. Hagen

Field Experiments on the Effects of Insecticides
Vernon M. Stern and Robert van den Bosch

Impact of Commercial Insecticide Treatments
Ray F. Smith and Kenneth S. Hagen

UNIVERSITY OF CALIFORNIA • BERKELEY, CALIFORNIA

At present, *Hilgardia* has virtually no online presence, and half of published issues are out of print. The rest are paperbound, subject to wear and tear. When digitized, these works will be posted on a sister site to *California Agriculture* journal and become freely available to scholarly and lay readers.

To make a donation or for more information, write to calag@ucdavis.edu, e-mail Deborah Golino at dagolino@ucdavis.edu or go to http://californiaagriculture.ucanr.edu/hilgardia.cfm.

The *Hilgardia* Project gratefully acknowledges the following donors, whose generosity has made it possible to begin scanning and posting this vital work (31,304 pages and 966 articles):

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($5,000 or more)

Anonymous gift in memory of Harry Lawton, UC Riverside, honoring his contributions to UC
Lodi Winegrape Commission, in support of the Wine and Grape Collection
Northern California Entomological Society, in support of the Entomology Collection

GOLD DONORS
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Frank G. Zalom, UC Cooperative Extension Specialist, Integrated Pest Management

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Anonymous gift in tribute to Donald Burdick, recognizing his contributions to CSU Fresno
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G. Stuart Pettygrove, UC Cooperative Extension Soils Specialist

— Janet White

Agricultural burning monitored for air pollutants in Imperial County; exposure reduction recommendations developed

by Martha Harnly, Kinnery Naik-Patel, Stephen Wall, Penelope J. E. Quintana, Diamon Pon *and* Jeff Wagner

Air pollutants, notably particulate matter (PM) with aerodynamic diameter smaller than 2.5 micrometers ($PM_{2.5}$), are emitted during agricultural burning. We studied a winter period in Imperial County when predominantly bermudagrass stubble was burned. At four locations, $PM_{2.5}$ levels were 23% higher from 4 p.m. on burn days to 8 a.m. the following morning than on days when there were no burns. On days when a burn was within 2 miles of a monitoring site, concentrations were 7 to 8 micrograms per cubic meter higher than on days when burns were farther away; measured levels lowered air quality, which potentially approached moderate. In monitoring five specific burns, we found that the levels of particulate matter with aerodynamic diameter smaller than 10 micrometers (PM_{10}) were highly elevated and potentially hazardous directly downwind of one field. In addition, $PM_{2.5}$ was composed primarily of carbon, and levels of naphthalene, a respiratory carcinogen, were elevated compared with upwind samples. In interviews, most community leaders, residents and farmers thought health educational efforts were needed. As a result, we developed fact sheets and have made recommendations for further actions to reduce people's exposure to smoke from agricultural burning.

Martha Harnly

At a burn of bermudagrass stubble in eastern Imperial County (called the Dunham burn), a house to the right of the telephones poles was totally obscured by smoke about 10 minutes after the field's perimeter was ignited. The authors deployed ambient air monitoring equipment adjacent to and immediately downwind of the 4th, 5th, and 6th telephone poles.

Burning fields to remove crop stubble, weeds and pests occurs worldwide, and California's estimated emissions from the burning of crop residue ranks fifth nationally (McCarthy 2011). These emissions potentially contribute to particulate matter (PM) levels in the San Joaquin Valley, which often exceed standards for ambient air each season of the year (Ngo et al. 2010). Studies have documented thousands of chemicals in smoke; they can exist in gas, liquid and solid form. During burning, plant matter breaks apart and gases condense on particles or form particles. Most particulate matter in smoke is smaller than 2.5 micrometers (µm) in diameter ($PM_{2.5}$) and can be transported over long distances (Naeher et al. 2007). The California Air Resources Board (CARB) estimates annual tons of particulate matter and gases emitted from field, orchard and weed burning for California counties (CARB 2009); their estimates are derived from burns of crop residue in a laboratory (CARB 2005b).

Studies have documented emissions of 14 semivolatile polycyclic aromatic hydrocarbons (PAHs), the most abundant of which is naphthalene (US EPA 1996). A respiratory carcinogen (OEHHA 2004), naphthalene is predominantly (88% to 99%) found in the gas phase of air sampling, with the remainder measured in the particulate phase (Kakareka and Kukharchyk 2003). Few ambient air monitoring studies have been conducted in the United States during agricultural burns, either adjacent to burns or in towns and communities (Jimenez et al. 2006; Kelly et al. 2003).

Educational efforts for the general public have mostly focused on smoke from wildfires (US EPA 2003) and have included public health recommendations for those exposed to elevated particulate matter and visibility guidelines for those air levels (Lipsett et al. 2008). CARB has also distributed a lengthy educational pamphlet for farmers (CARB 1992). However, it was unknown whether health educational outreach efforts specifically targeting agricultural burning were needed.

Study area

Particulate matter emissions from field burning in Imperial County — a rural desert county in California's southeast corner — rank among the highest for any county in the state (CARB 2009). The agricultural area of Imperial County is an

Online: http://californiaagriculture.ucanr.edu/landingpage.cfm?article=ca.v066n03p85&fulltext=yes

DOI: 10.3733/ca.v066n03p85

irrigated desert valley, where a variety of crops including vegetables, hay and grain are grown (fig. 1). Fields of bermudagrass, which is grown both for hay and seed, are burned primarily in the winter, while wheat stubble is burned during the summer.

Less than 3% of homes in Imperial County use wood as a house heating fuel (US Census Bureau 2009). During the winter when night temperatures drop, inversions commonly occur; cooler ground-level air, including pollutants, are trapped near the Earth's surface by an upper layer of warmer air. For fields to be burned, the Air Pollution Control District requires that the estimated inversion layer must be at 3,000 feet or higher, and the burn must be initiated between 10 a.m. and 3 p.m. Farmers who have applied for burn permits are usually notified by the district the day before the targeted burn date that their fields may be burned. Thus, our air monitoring studies required methods that could be rapidly deployed. Our methods and results are described in greater detail in a report to the funding agency (Harnly et al. 2011).

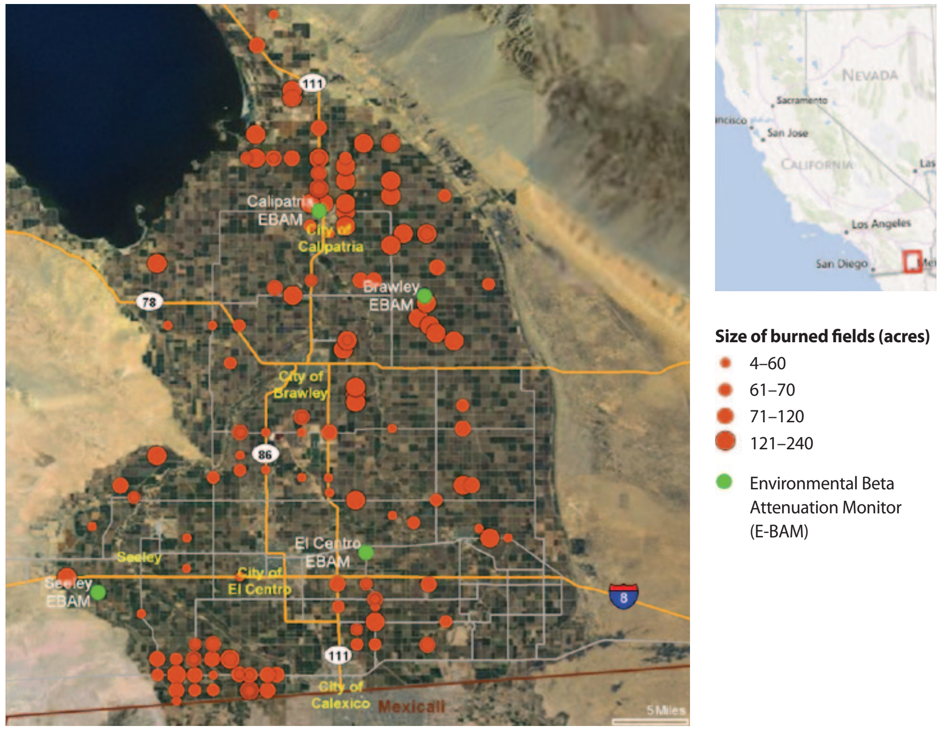


Fig. 1. Agricultural burns and E-BAM $PM_{2.5}$ monitoring locations in Imperial County from Jan. 14 to March 23, 2009. In total, 15,686 acres were burned (14,618 of bermudagrass). Circles are not the same scale as fields and are larger than actual field size.

$PM_{2.5}$ during a burn season

We selected three schools and one church (fig. 1) based on their proximity (within 2 miles) to burns in previous years and installed portable Environmental Beta Attenuation Monitors (E-BAMs) (Met One Instruments, Grants Pass, OR). We measured hourly average concentrations of $PM_{2.5}$ and meteorological variables for 69 days starting on Jan. 14, 2009. E-BAM $PM_{2.5}$ measurements are not recognized as a Federal Equivalent Method or a Federal Reference Method (FRM) (Met One Instruments 2008), one of which is required to determine if levels legally exceed air standards. However, E-BAM measurements have proven comparable to FRM measurements in field tests (CARB 2005a). A record of agricultural burn events was provided by the Air Pollution Control District. During the E-BAM monitoring period, 15,686 acres were burned (including 14,618 acres of bermudagrass) on 35 allowable burn days; the acreage burned daily ranged from 0 to 1,400 acres.

Average 24-hour $PM_{2.5}$ concentrations (taken between 12:01 a.m. and midnight) were highest — 12 micrograms (µg) per cubic meter — at the northern station (Calipatria) and lowest (6.0 µg per cubic meter) at the western station (Seeley). The lower levels in Seeley may have been because the predominant wind direction was from the west, and sources of pollution, including burned fields, were predominantly to the east of the Seeley station. All daily $PM_{2.5}$ levels were below the federal standard for unhealthy air, 35 µg per cubic meter. However, at the Calipatria station the 95th percentile of 24-hour concentrations (18.0 µg per cubic meter, $n = 69$) was above 16 µg per cubic meter, which corresponds to moderate air quality where "aggravation of heart or lung disease in people with cardiopulmonary disease and older adults" is possible (US EPA 2006).

We also compared 8-hour average $PM_{2.5}$ concentrations at the four locations. There was little difference during the day (8:01 a.m. to 4:00 p.m.), with levels slightly lower on field-burn days compared to no-field-burn days (table 1). In contrast, from the early evening (4:01 p.m.) to the morning of the next day (8:00 a.m.), average $PM_{2.5}$ concentrations on field-burn days were 23% (2 µg per cubic meter) higher than on no-field-burn days.

Additionally, on days when there was an agricultural burn within 2 miles of the Calipatria station ($n = 9$), during the evening-to-morning period the average 8-hour concentrations were 19.5 to 20.7 µg per cubic meter, 170% (6 to 8 µg per cubic

TABLE 1. Eight-hour $PM_{2.5}$ concentrations averaged among four locations in Imperial County on days with and without field burns

8-hour period	Type of burn day	Number of days	Average	Geometric mean
			µg/cubic meter	
Day	Field burn	35	4.6	3.8
(8:01 a.m. to 4:00 p.m.)	No field burn	33	5.9	4.3*
Evening	Field burn	35	10.1*	7.0
(4:01 p.m. to 12:00 a.m.)	No field burn	33	8.2	6.1
Early morning, next day	Field burn	35	11.0*	7.0
(12:01 a.m. to 8:00 a.m.)	No field burn	33	8.7	6.3

* *P* value = 0.02 to 0.03. Analysis of variance (*t*-test) between means on field-burn days compared to no-field-burn days.

meter) higher than on days when there were no burns within 2 miles (table 2). Following the burns near the Calipatria station, on the subsequent 2 days when there were no additional burns ($n = 4$ or 5), the evening-to-morning levels (13.7 to 15.0 µg per cubic meter) remained slightly above levels on days with no burns (12.6 µg per cubic meter).

Higher particulate matter levels from evening-to-morning hours associated with agricultural burning in Imperial County are consistent with air pollution dynamics. Air pollutants may rise during the day as the Earth's surfaces are heated and then be brought down to ground level by the descent of an evening inversion layer. The night and next-day accumulation of smoke is described in a CARB pamphlet for farmers (CARB 1992).

TABLE 2. Average 8-hour $PM_{2.5}$ concentrations at Calipatria† on days with and without field burns within 2 miles

8-hour period	Days with field burns within 2 miles	Number of days	Average	Geometric mean
			············ *µg/cubic meter*	············
Day	Yes	9	4.9	4.0
(8:01 a.m. to 4:00 p.m.)	No	60	4.9	3.8
Evening	Yes	9	19.5**	14.8**
(4:01 p.m. to 12:00 a.m.)	No	60	12.6	9.3
Early morning, next day	Yes	9	20.7**	13.5*
(12:01 a.m. to 8:00 a.m.)	No	60	12.6	8.7

* *P* value < 0.05 and > 0.01; ** *P* value < 0.01 and > 0.001. Analysis of variance on means on days with burns within 2 miles compared to days with no field burns.

† Other stations had few days (0 to 3) with burns within 2 miles.

PM and naphthalene during five burns

We monitored five specific burns of 65 to 150 acres of bermudagrass stubble during the E-BAM monitoring period. For four burns, ground-level winds were low at 2 to 3 miles per hour (mph), and the plume from the burn rose up to the apparent height of the inversion layer where it was observed to spread out, sometimes in the opposite direction of the ground wind direction. The ground-level plumes dispersed within about an hour, but the upper plumes remained visible, apparently limited by the inversion layer, until sunset. At one of the five burns, the Dunham burn, the wind speed was higher (5.6 mph), and the ground-level smoke plume engulfed a house on the same property as the burned field and drifted onto an adjacent field.

We deployed portable particulate matter monitors — active-flow and passive personal DataRAM (pDR 1000AN and pDR-1200, Thermo Electron Corp., Franklin, MA) nephelometers — which continuously measured $PM_{2.5}$ and PM_{10} (particulate matter less than 10 µm in diameter), respectively. This monitoring was done at three locations surrounding each of the five burns for 24 to 72 hours. Two locations were near the burns (within 0.3 to 3.0 miles) and were places of public access, homes or telephone poles; the other was at the nearest E-BAM, which was farther away (3.5 to 11 miles). At the 15 locations, field difficulties including power outages, supply delivery problems and apparent equipment or software malfunctions limited monitoring to 11 and 13 locations for the $PM_{2.5}$ and PM_{10} nephelometers, respectively.

At the 15 targeted nephelometer locations, plus an additional 14 locations near the burns, trained local personnel placed passive samplers (which did not require a field operator or electricity) to measure particulate matter (RJ Lee Group, Monroeville, PA) and naphthalene (SKC Product Code: 575-003, Eighty Four, PA) for 24 to 120 hours and then sent the samplers to our laboratory for analysis. Due to winds shifting from the predicted direction, our samplers were directly downwind only at the Dunham burn. At that burn, although passive samplers were mounted on several telephone poles immediately adjacent to the burned field, only one PM_{10} nephelometer was successfully deployed.

PM concentrations. Highly elevated PM_{10} values were observed at the Dunham downwind monitor: a maximum hourly concentration of 6,500 µg per cubic meter occurred from 1:00 to 2:00 p.m., then a dramatic decline to 4.3 µg per cubic meter by 4:00 p.m. The average 24-hour PM_{10} concentration at this Dunham location was 276 µg per cubic meter, well above the federal criteria for unhealthy air, 150 µg per cubic meter (US EPA 2006). Although we only successfully deployed one monitor, the highly elevated concentrations were consistent with PM_{10} levels reported in another study of a burned field (Kelly et al. 2003). Photo evidence was also consistent with visibility of less than 1 mile, which is expected at hazardous air levels (> 526 µg per cubic meter) (Lipsett et al. 2008). As noted, wind speed at this burn was somewhat higher (5.6 mph) than at the other burns (2 to 3 mph).

At several of the other 12 nephelometer locations, much smaller peaks were apparent in $PM_{2.5}$ and PM_{10} after the burns were initiated, up to 57 µg per cubic meter of PM_{10} within the hour. Similar to the E-BAM findings, evening-to-morning peaks in $PM_{2.5}$ and PM_{10} (up to 22.0 and 29.6 µg per cubic meter, 8-hour averages, respectively) were observed.

Although all of these peaks were relatively brief (hours), these measurements were collected at places of public access, and even short-term exposures may have health risks. An increase in $PM_{2.5}$ concentrations in air samples from city centers as low as 10 µg per cubic meter for as little as 2 hours has been associated with increased daily mortality in the surrounding population (Staniswalis et al. 2009).

Particulate matter levels from evening-to-morning hours are associated with agricultural burning in Imperial County and are consistent with air pollution dynamics.

PM analysis. At the laboratory, computer-controlled scanning electron microscopy and energy-dispersive X-ray spectroscopy were used to obtain the individual sizes and chemistry of particles collected on the samplers. Then, $PM_{2.5}$ and $PM_{10-2.5}$ (particles between 2.5 µm and 10 µm) concentrations and particle size distributions were calculated using assumed particle density and shape factors and a particle deposition velocity model (Wagner and Leith 2001).

In samples from the downwind locations at the Dunham burn, concentrations of both $PM_{2.5}$ (fine fraction) and $PM_{10–2.5}$ (coarse fraction) were elevated compared to an upwind sample. The fine fraction was primarily (94%) carbonaceous with a peak at the submicron range (< 1.0 µm), while the coarse fraction had a lower carbonaceous percentage (40%) (Wagner et al. 2012). These carbonaceous percentages were higher than those measured upwind for fine (0%) and coarse (29%) fractions, as well as those reported for fine (34%) and coarse (12%) fractions in San Joaquin Valley ambient air (Ngo et al. 2010).

The coarse fraction in the downwind sample also had higher percentages of potassium, phosphorus and chlorine (32% in the coarse fraction and 1% in the fine fraction). Potassium and chlorine are considered potential indicators of biomass smoke (Kelly et al. 2003; Ostro et al. 2009), and phosphorus is found in most plant material. We also analyzed samples of unburned and burned bermudagrass and found that among inorganic elements, they contained similar peaks of potassium, phosphorus and chlorine (Wagner et al. 2012). Their identification here may assist air pollution researchers attempting to identify sources of particulate matter in air samples.

Naphthalene. Samples were analyzed for vapor-phase naphthalene by gas chromatography/mass spectroscopy. Concentrations were calculated using an established air-sampling rate. Naphthalene was occasionally detected at the five targeted burns with levels above the reportable limit (0.42 µg per cubic meter) at seven of the 23 locations near the burns (0.3 to 3 miles) and at one of the six more-distant locations (3.5 to 11 miles). The highest level (1.4 µg per cubic meter) was detected in a sampler placed directly downwind of the Dunham burn.

That highest level was lower than a reference level for respiratory effects (9.0 µg per cubic meter) (OEHHA 2004), but only two samples were collected directly downwind and concentrations elsewhere in the plume could have been higher or lower. To compare, vapor-phase naphthalene measured in a laboratory from directly above the burning of agricultural debris was 60 µg per cubic meter (Kakareka and Kukharchyk 2003).

Community interviews

To assess health educational needs, we interviewed community leaders, community residents, farmers and school representatives from the agricultural area of Imperial County. We used a qualitative method called Key Informant Interviews (KIIs), which allows for candid and in-depth responses (Brown 2003) and the characterization of how interviewees discover and act on information. Potential participants were informed that the interview would take 30 to 60 minutes and that responses would be anonymous. If a respondent declined an interview, no information was recorded.

Community leaders. Ten community leaders were interviewed out of 15 contacted. Those interviewed held management positions within either county (government) environmental health agencies, nonprofit agencies that supported agriculture, or environmental organizations that promoted clean air.

More than half of the community leaders (n = 7) ranked burning as a medium or high concern for their organization. Respondents representing the agricultural industry considered outreach important because, as one respondent said, "The public's view of burning is fairly negative." Suggestions for educational outreach included training for staff on the health impacts of smoke and "simple recommendations, options of actions to take during a burn."

Residents. Seven interviews were conducted after we contacted 15 residents who lived either in single-family homes or apartments within 2 miles of fields. Most (n = 5) considered burning a high or medium health concern compared to other community health concerns. One person said, "You're closing doors and windows, just trying to keep the smoke out." No respondent had ever called or inquired with government agencies. One respondent explained, "We all have to live with our neighbors. . . it would be difficult to file a complaint or inquiry." None of the respondents were aware of any educational materials.

Farmers. Of 30 farmers that we contacted, three agreed to participate. All three burned bermudagrass or wheat fields, thousands of acres in some years. The farmers discussed the benefits: as one explained, "Burned fields are more profitable." All had considered disking their fields or using minimum tillage as an alternative to burning, which they had learned about by trial and error. All three discussed a certificate program used by the Air Pollution Control District to accredit and stimulate financial rewards for farmers who do not burn (Imperial County APCD 2010). All three also had voluntarily notified their neighbors about planned field burns. (Since this study was completed, Imperial County Air Pollution Control District has begun requiring notification of neighbors within one-half mile of a burn [Imperial County APCD 2010]).

Martha Harnly

At a monitored burn near Holtville, the ground-level wind direction was to the north, but the upper-level plume at the apparent inversion layer moved to the south.

School representatives. Out of 30 contacted, we interviewed five teachers or superintendents who each worked at a separate school or district near historically burned fields. School representatives were concerned about enforcement. Their suggestions included: "Have people call a number if they notice illegal burning or something suspect" and implement "stiff penalties for those who don't [follow burning rules]." They had ideas about community education, such as public service announcements on television. Two respondents, who were not enthusiastic about doing outreach, said, "There's so much that we have to do." This consideration may have also been part of the reason why the participation rate was low for key informants in this group, and possibly the farmer group.

Fact sheets

Responses from our key informants indicated that educational messages were needed. We developed two-page fact sheets for three Imperial County audiences — the general public, school representatives and farmers. These covered the reasons for burning, burn regulations, potential health impacts and behavioral recommendations to reduce exposures.

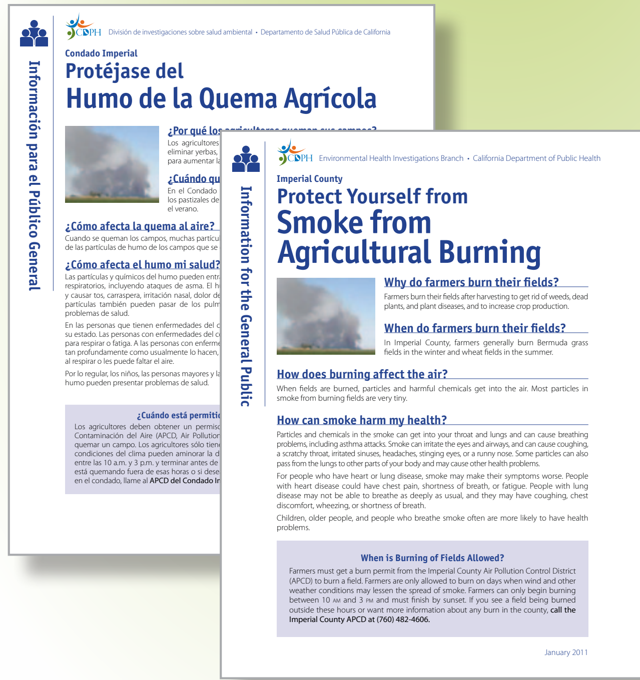
In our studies, elevated particulate matter levels and visible drift were observed as far as 500 feet from the edge of burning fields, and wind directions could quickly change. We advised that anyone who could see or smell smoke *or* was within 300 feet (the length of a soccer or football field) of a burning field should go inside.

If people had to be outside near a burning field, we recommended face-piece particulate respirators (N95, N100 or P100 respirators), which are available at most hardware stores. A worker who must be outdoors and near a burn must be in a respiratory protection program that includes medical evaluations and fit-testing of the respirator's seal on the worker's face (personal communication, B. Materna, California Occupational Safety and Health Administration, Feb. 27, 2011).

A draft of the fact sheet for the general public was tested with community members at a health clinic and shopping center. Although there were complaints about its length, the fact sheet was highly rated for usefulness: all 20 participants gave it either a four (n = 4) or a five (n = 16) on a scale of one (low) to five (high). The final fact sheets were distributed to local organizations and are available on the Internet (CDPH 2011)

Public health recommendations

In our studies, agricultural burning created potentially hazardous air levels immediately downwind; during evening-to-morning hours, $PM_{2.5}$ levels increased 2 to 8 µg per cubic meter. Many studies have associated total daily human mortality with mean daily (24-hour) particulate matter levels measured in urban centers, and some have observed a relationship at levels as low as 2 µg per cubic meter (Schwartz et al. 2002). In California, increases in children's total daily hospital admissions for respiratory problems are also associated with increases in daily (24-hour) $PM_{2.5}$ and potassium air levels, the latter an indicator of biomass smoke (Ostro et al. 2009). To protect public health and potentially reduce exposures to smoke from agricultural burns, we recommend additional health education, smoke management and air quality research.


Condado Imperial
Protéjase del
Humo de la Quema Agrícola
Información para el Público General

CDPH Environmental Health Investigations Branch • California Department of Public Health
Information for the General Public
Imperial County
Protect Yourself from
Smoke from
Agricultural Burning

Why do farmers burn their fields?
Farmers burn their fields after harvesting to get rid of weeds, dead plants, and plant diseases, and to increase crop production.

When do farmers burn their fields?
In Imperial County, farmers generally burn Bermuda grass fields in the winter and wheat fields in the summer.

How does burning affect the air?
When fields are burned, particles and harmful chemicals get into the air. Most particles in smoke from burning fields are very tiny.

How can smoke harm my health?
Particles and chemicals in the smoke can get into your throat and lungs and can cause breathing problems, including asthma attacks. Smoke can irritate the eyes and airways, and can cause coughing, a scratchy throat, irritated sinuses, headaches, stinging eyes, or a runny nose. Some particles can also pass from the lungs to other parts of your body and may cause other health problems.

For people who have heart or lung disease, smoke may make their symptoms worse. People with heart disease could have chest pain, shortness of breath, or fatigue. People with lung disease may not be able to breathe as deeply as usual, and they may have coughing, chest discomfort, wheezing, or shortness of breath.

Children, older people, and people who breathe smoke often are more likely to have health problems.

When is Burning of Fields Allowed?
Farmers must get a burn permit from the Imperial County Air Pollution Control District (APCD) to burn a field. Farmers are only allowed to burn on days when wind and other weather conditions may lessen the spread of smoke. Farmers can only begin burning between 10 AM and 3 PM and must finish by sunset. If you see a field being burned outside these hours or want more information about any burn in the county, **call the Imperial County APCD at (760) 482-4606.**

January 2011

Based on interviews with key local community leaders, residents, growers and educators, the authors developed fact sheets in English and Spanish for reducing exposure to particulate matter and other pollutants that result from agricultural burning (CDPH 2011).

Health education. Fact sheets are needed for other California counties where agricultural burning takes place, as well as educational materials for outdoor and field workers about respiratory mask protection and smoke visibility guidelines (Lipsett et al. 2008). As interviewees suggested, broader community education could include public service announcements.

Smoke management. Currently, CARB declares a permissive-burn day (when burning is allowed with a permit and notification from the Air Pollution Control District) when meteorological conditions ensure the regional dispersion of smoke, for example, a wind speed at 3,000 feet of at least 5 miles per hour (California Code of Regulations 2001). Imperial County's smoke management plan states that the Air Pollution Control District may put in place additional restrictions based on meteorological and air quality conditions, including strong ground-level or gusty winds (Imperial County APCD 2010). We observed substantial drift at a slightly greater wind speed (5.6 mph, or 2.7 meters per second) than that previously suggested for a vertical column of smoke to occur (4.5 mph, or 2.0 meters per second) (Carroll et al. 1977). Local Air Pollution Control Districts could reduce ground-level drift by specifying a ground-level wind speed above which burns should not take place. Additionally, evening-to-morning levels of particulate matter could be reduced if warranted by other restrictions, such as shortening allowable burn hours.

Interviewed residents expressed reluctance to report neighbors who might be out of compliance. Supplemental Imperial County Air Pollution Control District activities could include online instructions about how to make a complaint. In addition, posting visibility guidelines for hazardous drift (Lipsett et al. 2008) and a daily listing of the areas in the county where burns were scheduled would improve community notification.

Research. Additional air monitoring is needed to further characterize the nature and extent of ground-level plumes and how they are affected by local crop type and conditions. Although crop-specific particulate emission factors (grams particulate matter emitted/kilograms biomass burned) from burning bermudagrass stubble have not yet been developed, factors for other grasses, such as Kentucky bluegrass, are about twice those for rice and wheat (McCarthy 2011). The moisture level of burned residue can also significantly affect particulate matter emissions, with a change in moisture from 10% to 25% more than tripling particulate emissions during the burning of rice, wheat and barley straw (Carroll et al. 1977).

Ambient monitoring should also include indoor air, as outdoor $PM_{2.5}$ may substantially infiltrate buildings (Lunden et al. 2003), and we observed that outdoor particulate matter increases overnight when people are likely to be inside. Residents may be amenable to researchers installing unobtrusive passive samplers to monitor indoor air. In further studies, methods might be modified to allow the further identification of carbonaceous material, the gaseous component of other PAHs and some of the thousands of other volatile gases found in smoke (Naeher et al. 2007). Information is also needed on whether residents are following recommendations to reduce their exposure to smoke from agricultural burning.

Finally, farmers expressed a willingness to try alternative farming practices, notably tilling. We recommend further study of alternative farming techniques such as conservation tillage, which may reduce the need for burning, conserve water and soil, and reduce air quality impacts (see page 108). In addition, integrating livestock grazing with grain and hay farming as a substitute for burning or tilling may reduce pests, herbicide use and erosion and provide additional income (Hatfield et al. 2006). Further study is needed on how farmers could viably integrate alternative techniques into current practices, particularly for local crops such as bermudagrass, and the estimated human health impacts of such changes.

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References

Brown P. 2003. Qualitative methods in environmental health research. Environ Health Persp 111:1789–98.

California Code of Regulations. 2001. Title 17, Subchapter 2. Smoke Management Guidelines for Agricultural and Prescribed Burning. Sacramento, CA. www.arb.ca.gov/smp/regs/RevFinRegwTOC.pdf.

[CARB] California Air Resources Board. 1992. Agricultural Burning Self-Instruction Handbook. Sacramento, CA. http://infohouse.p2ric.org/ref/12/11252.pdf. 14 p.

CARB. 2005a. Memo. Operation Support Section E-BAM Evaluation. Sacramento, CA. www.arb.ca.gov/carpa/docs/E-BAM-eval.pdf (accessed Feb. 2012).

CARB. 2005b. Section 7.17. Agricultural Burning and Other Burning Methodology. Sacramento, CA. www.arb.ca.gov/ei/areasrc/fullpdf/full7-17.pdf. 6 p.

CARB. 2009. Almanac Emission Projection Data by EIC. Area sources. Miscellaneous processes. 670-Managed Burning and Disposal. Sacramento, CA. www.arb.ca.gov/app/emsinv/emssumcat.php (accessed Oct. 11, 2011).

Carroll J, Miller G, Thompson J, Darley E. 1977. The dependence of open field burning emissions and plume concentrations on meteorology, field conditions, and ignition technique. Atmos Environ 11:1037–50.

[CDPH] California Department of Public Health. 2011. Agricultural Burning: Air Monitoring and Exposure Reduction. Environmental Health Investigations Branch. Richmond, CA. www.ehib.org/project.jsp?project_key=AGBU01.

Harnly M, Patel K, Wall S, et al. 2011. Agricultural Burning: Air Monitoring and Exposure Reduction in Imperial County, California. Final Report to U.S./Mexico Border Environmental Cooperation Commission. Cuidad de Juárez, Mexico. www.cocef.org/eng. 76 p.

Hatfield P, Goosey H, Lenssen A, Blodgett S. 2006. Chapter 14: Incorporating targeted grazing into farming systems. In: Launchbaugh K (ed.). *Targeted Grazing: A Natural Approach to Vegetation Management and Landscape Enhancement*. American Sheep Industry. Centennial, CO. p 129–40. www.cnr.uidaho.edu/rx-grazing/Handbook.htm.

Imperial County Air Pollution Control District [APCD]. 2010. Smoke Management Program. Procedures for Operating the Air District's Agricultural Burn Program. April 27, 2010. http://imperialcounty.net/AirPollution/Default.htm (accessed Nov. 11, 2011).

Jimenez J, Wu CF, Claiborn C, et al. 2006. Agricultural burning smoke in eastern Washington — Part I: Atmospheric characterization. Atmos Environ 40:639–50.

Kakareka SV, Kukharchyk TI. 2003. PAH emissions from open burning of agricultural debris. Sci Total Environ 308:257–61.

Kelly K, Collins K, Quintero Nunez M, et al. 2003. Particulate Matter Emissions from Agricultural Burns in the Mexicali/Imperial Valley Region. Rep No A-03-02. Southwest Consortium for Environmental Research and Policy. San Diego, CA. http://scerpfiles.org/cont_mgt/doc_files/Kelly_A0302_dbb.pdf.

Lipsett M, Materna B, Stone S, et al. 2008. Wildfire Smoke: A Guide for Public Health Officials. Revised July 2008. www.arb.ca.gov/smp/progdev/pubeduc/wfgv8.pdf.

Lunden MM, Thatcher TL, Hering SV, Brown NJ. 2003. Use of time- and chemically resolved particulate data to characterize the infiltration of outdoor $PM_{2.5}$ into a residence in the San Joaquin Valley. Environ Sci Technol 37:4724–32.

McCarthy J. 2011. Remote sensing–based estimates of annual and seasonal emissions from crop residue burning in the contiguous United States. J Air Waste Manag Assoc 61:2234.

Met One Instruments. 2008. E-BAM Particulate Monitor Operation Manual: E-BAM-9800 Rev L. www.metone.com/ebamdocs/E-BAM_Manual(RevL).pdf.

Naeher LP, Brauer M, Lipsett M, et al. 2007. Woodsmoke health effects: A review. Inhal Toxicol 19:67–106.

Ngo M, Pinkerton KE, Freeland S, et al. 2010. Airborne particles in the San Joaquin Valley may affect human health. Cal Ag 64:12–6.

[OEHHA] Office of Environmental Health Hazard Assessment. 2004. Chronic Toxicity Summary. Naphthalene. Sacramento, CA. http://oehha.ca.gov/air/chronic_rels/pdf/91203.pdf.

Ostro B, Roth L, Malig B, Marty M. 2009. The effects of fine particle components on respiratory hospital admissions in children. Environ Health Persp 117:475–80.

Schwartz J, Laden F, Zanobetti A. 2002. The concentration-response relation between $PM_{2.5}$ and daily deaths. Environ Health Persp 110:1025–9.

Staniswalis JG, Yang H, Li WW, Kelly K. 2009. Using a continuous time lag to determine the associations between ambient $PM_{2.5}$ hourly levels and daily mortality. J Air Waste Manag Assoc 59:1173–85.

US Census Bureau. 2009. American Community Survey, 2005–2009 Summary Tables; B25117. Tenure by House Heating Fuel. Washington, DC. http://factfinder.census.gov.

[US EPA] US Environmental Protection Agency. 1996. Evaluation of Emissions from the Open Burning of Land-Clearing Debris. EPA-600/R-96-128. Washington, DC. www.epa.gov/ttn/atw/burn/brushburn2.pdf.

US EPA. 2003. How Smoke from Fires Can Affect Your Health. Washington, DC, www.epa.gov/airnow/smoke/Smoke2003final.pdf. 4 p.

US EPA. 2006. Guidelines for the Reporting of Daily Air Quality — The Air Quality Index (AQI). EPA-454-06-001. Research Triangle Park, NC. www.epa.gov/ttncaaa1/t1/memoranda/rg701.pdf.

Wagner J, Leith D. 2001. Passive aerosol sampler. Part I: Principle of operation. Aerosol Sci Tech 34:186–92.

Wagner J, Naik-Patel K, Wall S, Harnly M. 2012. Measurement of ambient particulate matter concentrations and particle types near agricultural burns using electron microscopy and passive samplers. Atmos Environ 54: 260–71.

RESEARCH ARTICLE

Income value of private amenities assessed in California oak woodlands

by Jose L. Oviedo, Lynn Huntsinger, Pablo Campos *and* Alejandro Caparrós

Landowners in California were surveyed using a contingent valuation technique to assess its usefulness in estimating the monetary income value of private amenities from their oak woodland properties. Private amenities — such as recreation, scenic beauty and a rural lifestyle — are considered an important influence on rangeland owners, but few studies have attempted to place a monetary income value on them. Landowners were asked to estimate the maximum amount of earnings that they were willing to forgo before selling their property to invest in more commercially profitable, nonagrarian assets, and the proportion of the land price that they thought was explained by private amenities from their land. On average, landowners were willing to pay $54 per acre annually for private amenities, and they attributed 57% of the land price to them. Regression analysis revealed that the landowners' willingness to pay per acre decreased as property size increased. This approach sheds light on how landowners value the benefits of land ownership and offers insights for outreach and policy development for privately owned oak woodlands.

More than 80% of California's oak woodlands are privately owned. The monetary value of such land's private amenities — noncommercial benefits to landowners such as beauty and open space — was assessed using a contingent valuation technique, which asks people what they would be willing to pay to maintain the asset or be compensated for its loss.

Private amenities from California oak woodlands — including benefits such as recreational opportunities, scenic beauty, living in the country, and protecting wildlife and water quality — are important influences on landowner decisions and income (Huntsinger et al. 2010). Efforts to value these amenities in California and other Western states have included analyses of the relationship between land prices and property size (Pope 1985), tree density (Diamond et al. 1987), distance to open space (Standiford and Scott 2002) and production value (Torell et al. 2005). The most common commercial land use in oak woodlands is livestock grazing (Huntsinger et al. 2010), but throughout the West, private amenities are believed to be an important factor in explaining why land prices for ranches exceed their commercial production value (Torell et al. 2005). With land-use change and fragmentation threatening the extensive habitat and watershed benefits provided by private oak woodlands, understanding landowners' decisions and values is a conservation priority.

Advocates of conserving areas that produce crops, livestock, hunting or timber, as well as other ecosystem services, call them "working landscapes," a term that fits oak woodlands well. The concept of ecosystem services is commonly defined as the benefits people obtain from ecosystems. Continued ecosystem services from oak woodlands depend largely on the commercial profitability of ranches, their amenity value to their owners and the opportunity costs of competing land uses — in other words, on the cost of maintaining oak woodland ownership measured as the foregone benefits from using the land for something else or selling it. Estimating values for private amenities can contribute to our understanding of landowners' decisions and their responsiveness to outreach and policies for oak woodlands. This is also important for assessing the economic value of the natural resource component of land.

Valuing private amenities

The *Commodity Cost and Returns Estimation Handbook* for measuring income in rangelands and other agricultural lands (AAEA 2000) does not consider private amenities as part of landowner income, despite the longstanding characterization of ranchers as lifestyle consumers. As Pope (1985) states, many land buyers are seeking an investment they can "touch, feel, experience and enjoy" and a place where they can be associated with farming or ranching. The System of National Accounts, the internationally

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agreed-upon standard set of recommendations for how to compile measures of economic activity, also fails to include the flow of private amenities as part of landowner income (United Nations 2009). In this paper, we attempt to fill this gap by applying a contingent valuation technique designed to estimate the monetary income value of such amenities to private owners of oak woodlands.

Previous studies have quantified the amenity component of rangeland market prices in the western United States using the hedonic pricing technique, in which the price paid for a good is used to estimate the component values of that good's characteristics (Pope 1985; Torell et al. 2005). This approach is useful for understanding the contribution of private amenities to land prices but does not offer a direct estimation of monetary income values. Others have also studied the role of private amenities in U.S. rangelands using alternative approaches (Huntsinger et al. 2010; Smith and Martin 1972).

Contingent valuation is a method used to estimate values for environmental resources such as reducing the impacts of contamination, preserving the beautiful view of a mountain, or conserving wildlife. These resources do not have a market price as they are not directly sold, but they do give people utility and have economic value. Values are derived by asking people what they would be willing to pay (or willing to accept) to obtain or maintain (or to be compensated for the loss of) a good or service.

We drew on a sample of oak woodland owners in California to assess the usefulness of contingent valuation in estimating the monetary income value of private amenities from oak woodland properties. For the sake of brevity, the term "amenities" is used here to include all the economic, nonmarket ecosystem goods and services that a landowner obtains from the land, including heritage and succession rights. The contingent valuation technique that we use is not designed to separate different components of the estimated amenity values.

Landowner sample

California oak woodlands extend over 5 million acres, and more than 80% are in private ownership (CDF-FRAP 2003). Landowners from two studies were used to develop a diverse sample for testing the contingent valuation approach. In the primary study in 2004, landowners were identified based on Forest Inventory Assessment plots previously used to assess hardwood volume in California (Bolsinger 1988); the methods are described by Huntsinger et al. (2010).

Response rate. The Dillman four-wave method was used (Dillman 1978), resulting in a 64% survey response rate with 98 completed questionnaires, encompassing more than 10% of California oak woodlands on an acreage basis. The response rate attained overall is considered more than adequate (Connelly et al. 2003; Huntsinger et al. 2010; Needham and Vaske 2008), but the response rate for the main contingent valuation question was lower. To augment valid responses to the contingent valuation question for modeling purposes, 17 additional oak woodland owners were interviewed as part of a study of foothill landowners (Sulak and Huntsinger 2007), making the final number of respondents 115.

Respondent demographics. The demographics of the combined sample were similar to those of the primary study. The average property size in our sample was large, with almost half of the property under the oak canopy (table 1). Livestock grazing was the most common land use, while hunting was practiced by 38%. Conservation easements were present on 6% of the sampled land. More than half the landowners lived on the property year-round, and 77% had a house on the ranch. The average landowner was middle-aged and male, 43% worked directly on the property and 14% obtained household income exclusively from the oak woodland. Half of landowner household income came from the ranch.

TABLE 1. Property and landowner characteristics of California oak woodland owner respondents, 2004–2005 (*n* = 115, varies slightly by question)

		Confidence interval (95%)	
	Mean	Lower bound	Upper bound
Property			
Size (acres)	6,461	1,430	11,491
Under oak canopy (acres)	2,862	*	6,501
Livestock grazing (%)	70	62	78
Under conservation easement contract (%)	6	*	14
Landowners			
Hunt on property (%)	38	29	47
Live on property year-round (%)	54	46	62
Have private residential house on property (%)	77	69	85
Age (years)	61	59	64
Female (%)	17	8	26
Work on property (%)	43	34	52
Household income exclusively from property (%)	14	7	21
Property contribution to household income (%)	50	41	69

* Negative bound for confidence interval.

Responses to contingent valuation

Many respondents found it difficult to answer the main contingent valuation question (described below), resulting in a 26% valid response rate (30 answers). This is at the low end of response rates now argued to be typical (Connelly et al. 2003) but is comparable to those in other contingent valuation studies of private landowners (Banerjee et al. 2007; Shaik et al. 2007). Responses were from a spectrum of property sizes and land uses appropriate for illustrating the use of the contingent valuation approach to estimate amenity income values on a case study basis (Needham and Vaske 2008). This number of responses is also comparable with other studies whose objective was closely related to ours; Diamond et al. (1987) used 30 responses in their study of oak woodland property values and oak tree density.

In their comments, landowners indicated that they found the amenity-benefits valuation question challenging, and some were simply unable to provide a monetary income value. This is common in contingent valuation studies because many people are not able or do not want to state their willingness to pay. This type of response (commonly known as a protest response) is not a zero value but rather a nonresponse.

In our sample, it was significantly more likely that owners of larger properties with residences on them, and those earning a greater proportion of household income from ranching, would not answer the contingent valuation question (Welch's *t*-test, P value < 0.10). Similarly, Kim et al. (2008) found that cattle producers were reluctant to answer contingent valuation questions.

Contingent valuation questions

Private amenity consumption implies that the land is bought or held not only as a capital investment but also for its consumptive value (Pope 1985) — a behavior termed an "investor-consumer" rationality. The contingent valuation design tested for this rationality and the values of private amenities were estimated through competitive market simulation, allowing landowners to choose among options for investment and income. Landowners stated their maximum willingness to pay for the annual enjoyment of their oak woodland amenities.

In theory, to obtain an amenity income value, the costs of land operations associated with the landowner's amenity enjoyment should be subtracted from the estimated amenity value; for example, the cost of thinning trees that obstruct a view or the cost of residential housing should be deducted. This was not possible with the survey data gathered, however, and as a result we assumed that the costs of land operations were all attributable to commercial activities. The joint production of amenities and commodities makes it reasonable to assume that most land operations would not occur without a commercial purpose, such as the sale of stumpage for trees that need thinning.

We developed the contingent valuation question based on the assumption that oak woodland owners give up, or are willing to give up, potentially higher earnings from alternative investments in order to enjoy amenities from their land. The difference in commercial earnings from the landowners' investments in their land and the best potential alternative investments they could hypothetically make — and would be willing to give up to keep their land — is the maximum price that they were willing to pay for amenities from their land. We posit that this willingness to pay represents the income value of the landowner amenities. In the questionnaire, respondents were asked:

> Imagine that you could earn more money by investing in other assets (for example, stocks or bonds) of comparable risk and time frame. How much is the maximum amount of earnings you are willing to give up, per year, before selling your property in order to invest in an alternative that brings a higher return? (Keep in mind that by selling your estate your family and friends give up the exclusive right to enjoy the natural surroundings of your land, and you can no longer pass down this property to future beneficiaries): ________________.

Although the question asked landowners about their total willingness to pay, we interpreted the results using per acre values: we divided the amount stated for the whole property by the property's total number of acres. The questionnaire also asked landowners to state what they thought the market price of their property was and to allocate this price, as a percentage of the total, among different benefits they obtained from their property; in other words, to say how much they thought each benefit contributed to the woodland's market price. The values estimated with these two questions were not market values derived from real transactions but rather values stated by the landowners based on their perceptions about the land market.

The questions were worded as follows: "How much do you estimate the current market value of your land to be without buildings or other infrastructure?" and "How important are each of the following to your personal value for your property? Express each as a percentage of the total value, so that the percentages total 100% at the bottom."

The benefits offered were timber and firewood, livestock and pasture (irrigated and nonirrigated), crops, hunting, enjoyment of the landscape, having friends and relatives visit, and "others." Although livestock management activities do not affect land price the same way as having pasture does, it was difficult for landowners to separate livestock from pasture benefits, and both were presented together.

The stated land price might include the value of other assets intertwined with the land (e.g., leases), but these assets would also be linked to private amenity consumption. Thus, the estimated amenity benefits would likewise derive from these assets. For example, Torell et al. (2001) discussed how private amenity consumption was incorporated into the grazing fee paid by ranchers. Our contingent valuation questions yielded the information necessary to obtain an estimate of the amenity benefits through the stated willingness to pay (WTP) and the market value (L_V) of the property through the stated land market price. This allowed us to calculate the stated amenity profitability rate (r_A) as the ratio of the amenity benefits divided by the total land value ($r_A = WTP/L_V$) — the percentage of nonmarket, monetary amenity return obtained by the landowner relative to their land investment (capital value).

Deer graze in oak woodlands in Mendocino County. Nearly 40% of the private landowners surveyed hunted on their land. Hunting is believed to be an important component of private amenity income, although this study was not designed to subdivide such income into components.

Oak woodland owners enjoy and value amenities that benefit society: the public enjoys natural beauty, wildlife and many other ecosystem services from well-stewarded lands.

Valuing oak woodland amenities

Investment value. Fewer than 9% of respondents believed that their annual earnings were enough to make the oak woodland a better investment than other options. About half thought that adding land appreciation to earnings was enough to make the woodland a better investment, while 44% thought that they would earn more with other investments, even considering land appreciation. Yet they had persisted in land ownership to the date of the survey, despite what was, at the time, a highly competitive real estate market. Results from a 1994 survey of oak woodland ranchers in California, in which respondents scored the factors influencing the retention of their oak woodlands, showed that the most highly ranked values were lifestyle and tradition (Liffmann et al. 2000) (table 2).

Willingness to pay. The mean willingness to pay for private amenity consumption obtained from valid responses (n = 30) was $54 per acre (table 3). The mean stated land price was almost $4,000 per acre, and the amenity component represented 57% of the land price. Of the amenity or noncommercial components, heritage was most important; among the commercial benefits, livestock and pasture made the main contribution (table 3).

Knowing how private amenity values vary depending on landowner and property characteristics is relevant to understanding how they relate to land uses and socioeconomic patterns. We used regression analysis to look at the influence of the variables (table 1) and the stated land price on willingness to pay per acre.

To select the regression models, the significance of explanatory variables was first tested individually, revealing three significant variables: acres of property size, acres of property under canopy cover and stated land price. Since the first two variables are correlated (they incorporate similar information), we kept acres of property size because it refers to the whole property. We chose a linear-quadratic (LQ) specification for a model with stated land price and a log-log (LL) specification for a model with acres of property size as explanatory variables, because they offer the highest fit (R^2) (table 4). The LQ model incorporates a quadratic term to test for nonlinear effects on the dependent variable. In the LL model, both the dependent and the explanatory variable take their natural

TABLE 2. Reasons for owning oak woodland properties in Alameda, Contra Costa and Tehama counties, 1994 (n = 243, varies slightly by question)*

Reason	Mean	Confidence interval (95%) Lower bound	Upper bound
Holding ranch is a good investment	3.00	2.84	3.17
Ranching is profitable	3.17	3.03	3.31
Ranching allows me to feel close to the earth	3.50	3.41	3.59
A ranch is a good place for family life	3.85	3.78	3.92
Ranching is what I have always done	3.59	3.43	3.75

Source: Liffmann et al. 2000.

* Scores range from 1 = not influenced at all to 5 = strongly influenced.

TABLE 3. Willingness to pay for private amenity consumption, stated land price and allocation of land price by benefit among surveyed oak woodland owners*

Question	Mean	Confidence interval (95%) Lower bound	Upper bound	n†
Mean willingness to pay ($ per acre, 2004)	54	11	98	30
Mean stated land price ($ per acre, 2004)	3,996	1,168	6,825	76
Allocation of land market price by benefit				
Private commercial benefits (%)	43	38	48	101
Timber and firewood (%)	10	7	13	101
Livestock and pasture (%)	26	22	30	101
Hunting (%)	4	2	6	101
Crops (%)	3	1	5	101
Private amenity benefits (%)	57	52	62	101
Landscape/countryside beauty (%)	13	10	16	101
Enjoying with relatives and friends (%)	10	7	13	101
Heritage (%)	24	20	28	101
Conservation values (%)	10	7	13	101

* Mean and standard deviation weighted by property size to offer a value of total sampled land.

† More valid responses were obtained for questions about land price (n = 76) and market price (n = 101).

TABLE 4. Willingness-to-pay regression analysis†

Variable	LQ model coefficients	LL model coefficients	2SH-LL model: LL model coefficients	2SH-LL model: Probit coefficients
Intercept	199.124	8.397***	8.216***	0.085
	(80.401)	(0.948)	(1.542)	(0.285)
Logarithm of property size (acres)		−0.754***	−0.761***	
		(0.157)	(0.158)	
Stated land price ($ per acre, 2004)	0.073**			
	(0.028)			
Square of stated land price ($ per acre, 2004)	−4.981E-07**			
	(1.985E-07)			
Landowner has livestock grazing on property (dummy variable = 1 if yes)				−0.505*
				(0.302)
Landowner has private residential house on property (dummy variable = 1 if yes)				−0.497*
				(0.279)
Inverse of Mill's ratio (λ)			0.189	
			(1.294)	
N	29	30	30	112
R^2	0.2015	0.4493	0.4497	0.0592‡
Chi-square test	6.53**	17.90***	21.08***	7.71**

† Linear quadratic (LQ), log-log (LL) and 2-stage Heckman for log-linear specification (2SH-LL) models. Dependent variable is willingness to pay per acre. Standard errors are shown in parenthesis; asterisks (*, **, ***) denote significance at 10%, 5% and 1% levels, respectively.

‡ Since this is a probit model, we offer an estimation of the McFadden Pseudo R^2.

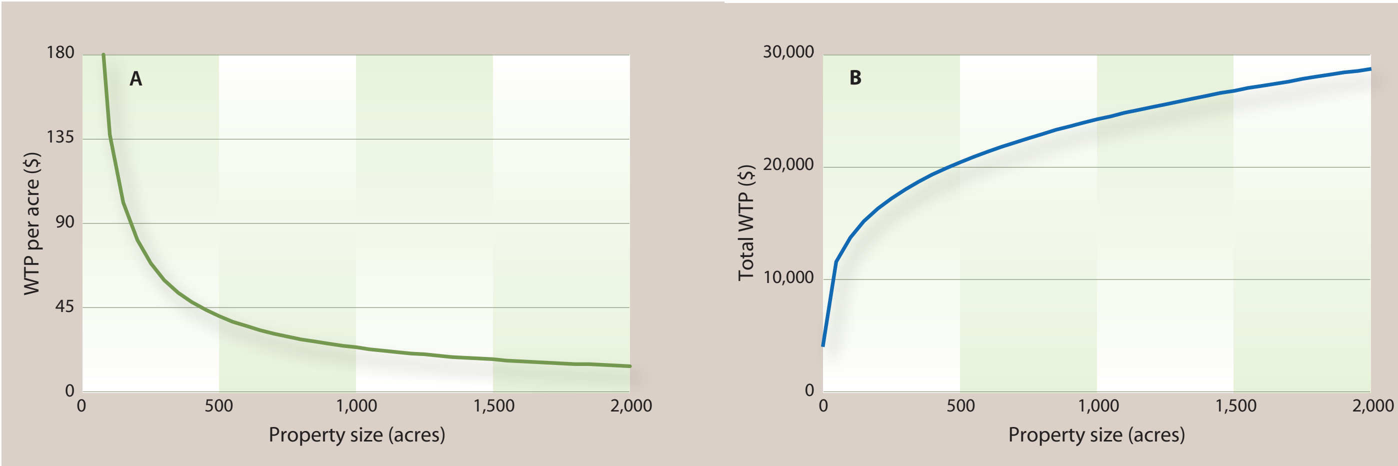

Fig. 1. Saturation effect of property size on landowners' willingness to pay (WTP). (A) A log-log (LL) function of WTP per acre shows a nonlinear decline with property size; WTP/acre = exp [8.397* (0.948) – 0.754*** (0.157) *Ln* (acres)]; *Ln* = natural logarithm; standard errors are shown in parentheses; and asterisks (***) denote significance at the 1% level. (B) Corresponding total WTP function obtained by multiplying WTP per acre predictions from LL function (A) by acres of property size of corresponding observation (WTP = [WTP/acres] × acres); total landowner amenity value becomes gradually more constant (the function becomes flatter) as property size increases.**

logarithms. This model is appropriate when the variables present a wide range of values, as in this case.

The LQ model showed a positive association between willingness to pay per acre and the land price stated by the landowners, with a negative sign for the square of this term. This implies that amenity values increased as stated land price increased, but that the contribution of amenity values to land price was relatively lower for oak woodlands with higher stated land prices (table 4). The LL model showed a saturation effect in amenity values, since willingness to pay per acre decreased with property size.

In an economic context, saturation means that above a certain level of consumption, additional units of the good do not add more value to the good. Our analysis showed that landowners with large properties did not obtain more amenity benefits with additional units of land because their amenity consumption was saturated. An LQ model type with property size as explanatory variable (data not shown) also showed this saturation effect, but the LL model was a better fit (table 4).

Property size. Graphing the willingness to pay per acre from the LL model showed that it decreased nonlinearly with property size (fig. 1A), with marginal decreases of less than $1 per acre for property sizes larger than 1,000 acres. This implies that the total willingness-to-pay function became gradually flatter as property size increased (fig. 1B). However, there was significant variability in the LL function, and the 95% confidence interval of the property size at which the marginal decrease of willingness to pay became less than $1 per acre was 200 acres for the lower bound and 10,000 acres for the upper bound. (These are estimated using the lower and upper bounds of the 95% conficence interval of the regression coefficients of the LL function.)

Given that landowners with larger properties had a lower willingness to pay per acre and were more likely not to answer the contingent valuation question, our willingness-to-pay estimations may be overvalued. However, Spash and Hanley (1995) suggest that nonrespondents in contingent valuation studies may find it difficult to answer these questions because of the high value they attach to these goods, and the potential net effect in our estimations of incorporating responses from these nonrespondents was hard to discern.

We also present a two-stage Heckman sample selection bias model for the log-log specification (2SH-LL), the one with the highest fit (table 4). This model implies first a probit regression that estimates the probability of giving a valid answer to the willingness-to-pay question from all available observations. We found that landowners with livestock and a residential house on the property were more likely to not answer the willingness-to-pay question. Property size had the same effect, but it was correlated with the other variables; we decided to leave it out of the final model. The estimated parameters from the probit regression were then used to calculate the inverse Mills ratio (a measure of the sample selection bias from valid willingness-to-pay answers), which was then included as an additional explanatory variable in the LL specification model. However, the inverse Mills ratio coefficient was not significant, and the model fit was not improved compared with the LL model (table 4).

Landowner benefits from woodlands

The results showed that the amenity profitability rate (r_A) was 1.35% ($54 per acre divided by $3,996 per acre, times 100) for the average landowner in the sample. This is a nominal rate, since landowners were not asked to consider inflation when answering the question. This value was low compared with other estimations of amenity profitability rates in oak woodlands in other Mediterranean climates (Campos et al. 2009), probably because properties in California are larger and likely closer to the saturation point for amenity values.

This saturation effect finding is important for woodland conservation policy. If landowners can obtain nearly the same amenity value from small properties as from large properties, they do not need large acreages if amenities are the only motive for owning the land. In contrast, income from grazing increases steadily with area of woodland range. This finding supports the concept of working landscapes, where private land conservation is achieved by combining multiple ecosystem services, including landowner amenities or other personal benefits (Huntsinger et al. 2010).

Lynn Huntsinger

Owners appreciated amenities such as their land's beauty and rural location, but a significant number were unable to place a monetary value on them. *Above,* a ranch house in the Gold Rush country of Calaveras County.

create effective conservation strategies for private lands.

In future studies, the costs associated with amenity income should be identified and assessed separately. Further testing of ways to ask contingent valuation questions might result in a higher response rate; however, when respondents were asked why they had not answered, a typical comment was that the value of the land to them was beyond measure in dollars. Ironically, those missing values are an important part of what we seek to understand.

When developing outreach or policy, it is important to consider landowner goals, motives and needs. The amenity values California ranchers have reported as important include having the freedom to make land management decisions and relative autonomy on their lands, as well as enjoying natural beauty, feeling close to the earth and passing property on to heirs (Huntsinger et al. 2010; Liffmann et al. 2000). At the same time, having adequate forage to maintain a commercial herd and the availability of infrastructure for marketing livestock products were also crucial to those owning most of the larger properties (Sulak and Huntsinger 2007).

Since most oak woodland owners are motivated by environmental as well as lifestyle amenities, many want to maintain and steward the land, and they have responded to incentives that help them improve wildlife habitat and environmental quality while bolstering production conditions (Symonds 2008). Fortunately, oak woodland owners enjoy and value amenities that benefit society: the public enjoys natural beauty, wildlife and many other ecosystem services from well-stewarded lands. Too often, it is assumed that production and conservation are inversely related, but as we illustrate here, there are also synergies that can be built upon to

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References

[AAEA] American Agricultural Economics Association. 2000. *Commodity Costs and Returns Estimation Handbook.* A Report of the AAEA Task Force on Commodity Costs and Returns. US Department of Agriculture, Ames, IA. p 566.

Banerjee S, Hudson D, Martin SW. 2007. Effects of seed and farm characteristics on cottonseed choice: A choice-based conjoint experiment in the Mississippi Delta. J Ag Appl Econ 39(3):657–69.

Bolsinger C. 1988. The Hardwoods of California's Timberlands, Woodlands, and Savannas. US Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, OR. Res Bull PNW-RB-148. 148 p.

Campos P, Oviedo JL, Caparrós A, et al. 2009. Contingent valuation of woodland-owners' private amenities in Spain, Portugal and California. Rangeland Ecol Manag 62(3):240–52.

[CDF-FRAP] California Department of Forestry and Fire Protection — Fire and Resource Assessment Program. 2003. Changing California: Forest and Range 2003 Assessment. Sacramento, CA. 126 p.

Connelly NA, Brown TL, Decker DJ. 2003. Factors affecting response rates to 7 natural resource–focused mail surveys: Evidence of declining rates over time. Soc Natur Resour 16:541–9.

Diamond NK, Standiford RB, Passof PC, LeBlanc J. 1987. Oak trees have varied effects on land values. Cal Ag 41(9-10):4–6.

Dillman DA. 1978. *Mail and Telephone Surveys: The Total Design Method*. New York, NY: Wiley-Interscience. p 344.

Huntsinger L, Johnson M, Stafford M, Fried J. 2010. Hardwood rangeland landowners in California from 1985 to 2004: Production, ecosystem services, and permanence. Rangeland Ecol Manag 63(3):324–34.

Kim S, Gillespie JM, Paudel KP. 2008. Rotational grazing adoption in cattle production under a cost-share agreement: Does uncertainty have a role in conservation technology adoption? Aust J Ag Resour Econ 52(3):235–52.

Liffmann R, Huntsinger L, Forero L. 2000. To ranch or not to ranch: Home on the urban range? J Range Manage 53(4):362–70.

Needham M, Vaske J. 2008. Survey implementation, sampling, and weighting data. In: Vaske J (ed.). *Survey Research and Analysis: Applications in Parks, Recreation, and Human Dimensions*. State College, PA: Venture Pub. p 173–222.

Pope III CA. 1985. Agricultural productive and consumptive use components of rural land values in Texas. Am J Agr Econ 67(1):81–6.

Shaik SL, Sun L, Van Kooten GC. 2007. Are agricultural values a reliable guide in determining landowners' decisions to create forest carbon sinks? Can J Agr Econ 55:97–114.

Smith AH, Martin WE. 1972. Socioeconomic behavior of cattle ranchers, with implications for rural community development in the West. Am J Agr Econ 54(2):217–25.

Spash CL, Hanley N. 1995. Preferences, information and biodiversity preservation. Ecolog Econ 12:191–208.

Standiford RB, Scott T. 2002. Value of oak woodlands and open space on private property values in southern California. In: Standiford RB, McCreary D, Purcell K (eds.). Proc Fifth Symposium on Oak Woodlands: Oaks in California's Challenging Landscape. US Forest Service, Pacific Southwest Research Station, San Diego, CA. Gen Tech Rep PSW-GTR-184. p 835–6.

Sulak A, Huntsinger L. 2007. Public lands grazing in California: Untapped conservation potential for private lands? Rangelands 23(3):9–13.

Symonds K. 2008. Ranchers restore amphibian-friendly ponds. US FWS End Spec Bull 33(1):30–1.

Torell LA, Rimbey NR, Ramírez OA, McCollum DW. 2005. Income earning potential versus consumptive amenities in determining ranchland values. J Agr Resour Econ 30(3):537–60.

Torell LA, Rimbey NR, Tanaka JA, Bailey S. 2001. The lack of profit motive for ranching: Implications for policy analysis. In: Torell LA, Bartlett ET, Larrañaga R (eds.). Ann Meeting of Society for Range Management, Feb. 17–23. Kailua-Kona, HI. p 47–58.

United Nations. 2009. System of National Accounts 2008. European Commission, International Monetary Fund, Organisation for Economic Co-operation and Development, United Nations, World Bank. New York, NY. p 662.

Radio-frequency identification could help reduce the spread of plant pathogens

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Radio-frequency identification (RFID) has potential uses in the production and distribution of woody plants. A microchip was implanted in a rose by drilling directly into the pith prior to grafting.

A traceable declaration of health is now necessary for many plants, especially those being monitored for disease such as certified nursery stock. Radio-frequency identification (RFID) microchips placed in woody plants can be used to store and retrieve information on their health status through all phases of propagation and in the field. The microchip is linked to a database in which many other kinds of information, such as pesticide applications, can be collected and linked. Using a Web-based platform, information can be shared globally and accessed quickly. RFID technology can also be integrated with cell phones and netbooks for the easy recording of images and audio, which can be linked back to the chip and shared — or, with global positioning systems (GPS), used to create a virtual orchard or vineyard. There are myriad uses for this new technology, which is expanding rapidly and has been implemented successfully in the European livestock industry. Trials have shown its particular relevance to plant pathology, where it could be an important risk management tool.

Product identification has become important in many aspects of agriculture. For health, sanitation and environmental safety (for example, to limit the spread of plant pathogens), government agencies now require many foods and agricultural products to have identifying labels or documents (FDA 2009). Identification also builds consumer trust; when labels and documents are lost or removed, as in the label fraud of wines, customer fidelity is at risk. Identification provides valuable information for implementing environmental protections and evaluating economic losses. It also helps control the spread of pests in propagated plant materials, which is central to international plant disease control strategies.

The declaration of a plant's health, or a product's high quality, should be traceable during all stages of its life. The International Organization for Standardization (ISO) defined traceability, as it applies to agricultural products, as the ability to trace and follow a food, feed, food-producing animal or ingredients through all stages of production and distribution (ISO 1994). Similar definitions have been issued by the United Nations General Assembly (United Nations 1986), U.S. Department of Agriculture (USDA 2002) and European Union (European Commission 2002).

A voluntary approach to traceability could be standardized, following international standards (ISO 2005). The identification of suppliers, participants in the production line, historic data and client feedback could all be linked to the plant or product.

Disease-free plants

In the 1960s, the European Economic Community drafted regulations regarding the health status of grapevines, ornamental plants and fruit trees, establishing protocols for producing certified pest-free plants. The North American Plant Protection Organization (NAPPO) undertook a similar approach (Hadidi et al. 1998). Among propagated woody plant crops, wine grapes are one of California's signature products in the global market (Ross and Golino 2008), and the state leads in U.S. production of peaches, nectarines (Boriss and Brunke 2006) and citrus (USDA 2007). Using plants certified as pest-free is a key strategy in preventing the spread of crop diseases in California.

With major crops at risk, certified propagation of disease-free stock may be an appropriate area for applying new tools in plant identification.

The spread of leafroll disease in Napa Valley vineyards (Golino et al. 2008) and an epidemic of bacterial canker of kiwifruit in Italy (Ferrante and Scortichini 2010) are recent reminders of the need to limit the spread of regulated and not-yet-regulated pests and viruses (Luvisi, Panattoni, Colosimo et al. 2010). With major crops at risk, the certified propagation of disease-free stock may be an appropriate area for applying new tools in plant identification.

In plant propagating, an information technology (IT) archiving and

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management platform could be used by producers to track and trace material. A plant's identity — its genetic, phenotypic and health characteristics — is not only a matter of interest for plant breeders and growers, but also the public. Although awareness among plant producers regarding the risk of pathogen dispersal in plant material has increased in recent years, much still needs to be done (Janse and Wenneker 2002).

TABLE 1. Plants internally tagged with RFID microchips

Plant	Method of insertion	Purpose
Cactus	Transverse drilling of trunk (Associated Press 2008)	Avoid theft
Citrus tree	T-cut above graft union and positioning tag under bark (Bowman 2005)	Disease monitoring; breeding
Cypress	Transverse drilling of trunk (Miragliotta et al. 2006)	Disease monitoring
Plane tree	Transverse drilling of trunk (INRA 2008)	Protect property rights
Grapevine, *Prunus* spp.	U-cut below graft union and positioning tag within pith; direct drilling of pith before grafting and positioning tag within pith (Bandinelli et al. 2009)	Traceability of certified plant; clonal selection
Rose	Direct drilling of pith after cane pruning and tag positioning within pith below higher bud (Luvisi, Panattoni, Bandinelli et al. 2010)	Digital urban garden management; tourism application

Radio-frequency identification

Radio-frequency identification (RFID) systems are composed of an electronic label, called a tag (frequently a microchip), a reader and a management system. The tag incorporates a unique identifying code received by the reader. RFID has applications for identifying humans, animals, plants and products. In humans, RFID has been studied for enhancing hospital responses to mass casualty events, to improve the traceability of medical information. The USDA established the National Animal Identification System to identify animals that have had contact with foreign or domestic animal diseases. RFID tags are put on the packaging of individual products, enabling consumers to read the tag with a reader embedded in a cell phone and download data from a website.

RFID technology has been successfully tested in agriculture for environmental monitoring, irrigation, specialty crops and farm machinery (Ruiz-Garcia and Lunadei 2011); in fruit harvest to overcome the limitations of existing yield mapping systems for manual fresh-fruit harvesting (Ampatzidis et al. 2009); in packaging to reduce fruit mixing and improve traceability (Bollen et al. 2007); and in winery fermenting vats to track sugar content and temperatures (Swedberg 2010). Companies and government agencies have been the driving forces behind this rapid development, stimulating global interest in RFID and its capabilities. In 2011, the value of the RFID market reached $5.84 billion, up from $5.63 billion in 2010 (IDTechEx 2011). The number of microchips sold grew from 1.97 billion in 2008 to 2.88 billion in 2011. The number of microchips used globally for livestock in 2011 was about 243 million. Growing markets are reflected in the falling price of microchips used for tagging: 65 cents in 2004 (CNIPA 2007) and 15 cents in 2012 (RFID Journal 2012).

In the last 10 years, some interesting solutions have been proposed to implement this technology in plant pathology.

Tagging plants

From 2005 to 2010, experimental trials focusing on inserting microchip tags have been carried out on woody plants in the United States, Italy and France (table 1). The most common tags are low-frequency (30 to 300 kilohertz) microchips. Tissue structure and trunk size have influenced implantation techniques and tag locations (fig. 1). The standardization of plant tagging does not seem likely. Different solutions have been suggested with respect to growth stage and aesthetics, while the purposes of tagging can also dictate the technology used and consequentially the method of tag insertion. For example, large tree trunks can be drilled transversally, and the pith of small trees can be drilled before grafting.

Grapevines and fruit trees. The optimal time for a certified plant to be tagged is as early as possible. To achieve this target for certified grapevines and fruit trees, the preferred place for the microchip is in the pith of the rootstock, installed using one of two procedures (Bandinelli et al. 2009). The first procedure involves direct-drilling the pith from the distal cut of the rootstock just before grafting, then installing the microchip below the grafting point (fig. 1A). The alternative procedure consists of a U-cut performed laterally on the rootstock below the grafting point, from the bark through to the pith (fig. 1B); in this procedure, the microchip is installed inside the pith and cut tissues are manually reassembled.

Large trees. For large-caliper trees such as the mature *Cypress* species, the depth and position of drilling to insert tags had no influence on damage to the trees (Miragliotta et al. 2006) (fig. 1C). To monitor the health status of each tree, the tag included a tree identification number. This data was stored in a digital database and linked to tree positioning and health observations, similar to systems used for livestock identification.

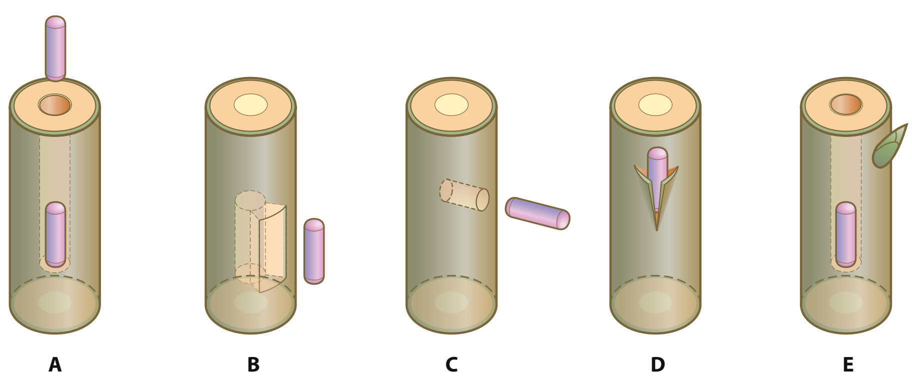


Fig. 1. Common microchip implantation techniques: (A) direct drilling of pith before grafting and positioning microchip within pith; (B) U-cut below graft union and positioning microchip within pith; (C) transversal drilling of trunk; (D) T-cut above graft union and positioning microchip under bark; and (E) direct drilling of pith after cane pruning and positioning chip within pith below a bud.

Small trees. Different methods are required to tag smaller trees, such as those typically found in nurseries producing certified disease-free stock. A report on microchip implantation in citrus at the nursery stage described a tagging procedure that was reliable, durable and secure (Bowman 2005). An upright T-cut was made above the graft union during active tree growth, followed by an insertion procedure similar to budding (fig. 1D). The signal penetration varied significantly depending on the scanning device (for example, AVID Power Tracker II doubled the reading distance of AVID Breeder Reader) and, in a more limited way, on the wood type (signals penetrated better in pine than oak wood). Microchips can be read in most woody plant species for 10 years or more when appropriate RFID scanners are selected, as confirmed by later tests (Bowman 2010).

Ornamentals. Ornamental shrubs such as roses can also be tagged (fig. 1E). Rose canes with a diameter of one-third inch are most suitable; in smaller diameter canes, wilt of the lateral shoot and growth detriments were observed (Luvisi, Panattoni, Bandinelli et al. 2010).

External tagging. Implanting microchips is the best way to tag certified plants, but RFID tags can be placed outside plants using a relatively inexpensive electronic barcode system. Rectangular plastic tags (1.2 by 1.2 inches) were attached to trees using a monofilament line, or a microchip was attached externally using a plastic wristband. This approach is useful for recording and retrieving data from plant samples. External tags are simple, inexpensive and can be attached at any stage of plant growth, but they can also be removed or damaged more easily.

Kumagai and Miller (2006) studied the use of barcodes in a tropical environment. The barcodes maintained their readability under a variety of environmental conditions, including temperatures ranging from –112°F to 212°F and immersion in liquid nitrogen and other liquids. The tags could also be autoclaved (sterilized).

Database links

Microchips without large memory capacity must be interfaced to a database (fig. 2); the code in each tag is useless for traceability unless it is linked to other information. For a certified disease-free plant, the tag can be linked to health observations, plant specifics (genetic and phenotypic characteristics, positioning) and certification and treatment specifics (agrochemicals and dates of treatment), which are then recorded in datasheets and stored in the online database. The tag code of the plant is required to access the database. Codes can be read from a tagged plant using a mobile device, granting (directly or via a desktop device) access to the online database. Different users such as workers in foundation blocks and nurseries and other stakeholders can be identified and a privilege-access system developed to grant access for various uses. For example, a nursery workers can create or edit the datasheets that refer to products, while agricultural agencies or researchers can view fields regarding health status and treatments.

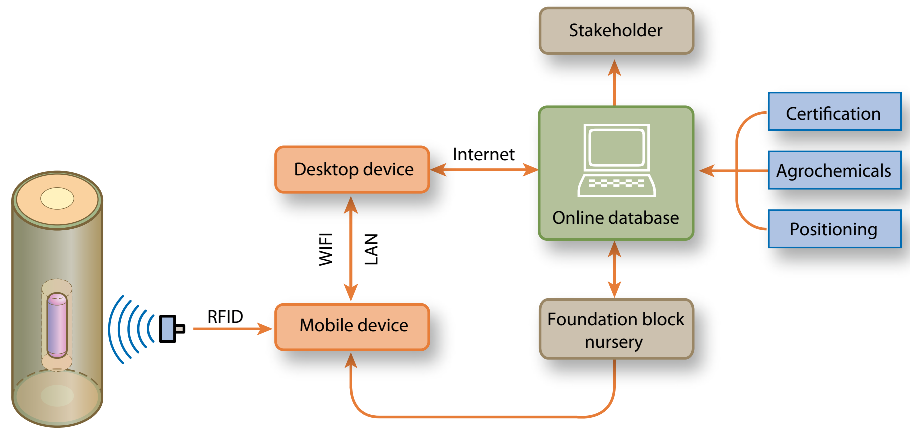
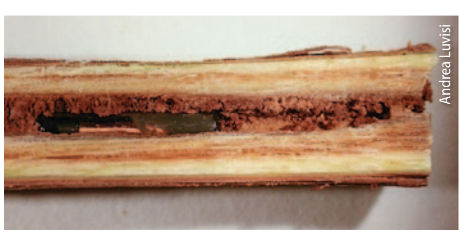


Fig. 2. Sharing information from an RFID-tagged plant.

In other applications, the database can be used to support product performance claims, track pesticide and fertilizer use, detail production costs and establish field histories. If pesticide complaints are made against a producer, good records such as those possible with this kind of database are almost always beneficial (PEI 2003). Peets et al. (2009) reported on the tracking and application of agrochemicals and suggested using RFID microchips in an automatic recording system for traceability. RFID tags were attached to physical containers of products, and essential information tracked included the country of registration, chemical type, unique registration number of agrochemicals, container size, specific gravity, unit of measure and a digital signature.



An RFID microchip was placed longitudinally in a grapevine. Plant-specific data can be used for certifying stock, monitoring pests and mapping vineyards.

With a database designed for tracking RFID-tagged grapevines from the nursery stage, RFID codes can be digitally entered into the search field and the user can view datasheets on the tagged plants detailing all customers along the production line (Luvisi, Triolo et al. 2010). Datasheets can be considered a sort of electronic identity card (eID) for individual plants. A similar system has been tested for certified citrus plants (Porto et al. 2011).

Many kinds of data can be linked to the eID. In an urban forest context, geospatial tools such as global positioning systems (GPS) and geographic information systems (GIS) can provide timely and extensive spatial data from which attributes such as land cover, forest structure, species composition and condition, heat island effects and carbon storage can be derived (Ward and Johnson 2007). GIS can locate tagged plants on an electronic map, recreating a virtual vineyard or orchard (Luvisi et al. 2011). This feature can be used for management, monitoring or teaching. For marketing, a vineyard or orchard could be remotely shown to stakeholders or consumers on a website and the link placed on product labels.

Web links

Researchers have studied the transfer of information via the Web for agriculture and plant health monitoring since the 1990s. Using Web applications to collect information on the sanitary status of plants allows for rapid communication to prevent the spread of pathogens. The U.N. Food and Agriculture Organization (FAO) has introduced global information sharing and collaboration between users via the Web, and the FAO Agricultural Information Management Standards (AIMS) system provides a platform to disseminate standards and good practices in information management in support of the right to food, sustainable agriculture and rural development. The European Forest Information System (EFIS) includes elements that allow the searching of metadata catalogues and the importing of identified data for exploratory analysis (Schuck et al. 2005). A database with Web interface was specifically designed for plant-associated and plant-pathogenic microorganisms. The Plant-Associated Microbes Database (PAMDB) comprises data from multilocus sequence typing and analysis studies (Almeida et al. 2010).

RFID-based technologies can be implemented in platforms to share and manage information in agriculture, providing a safe and durable link between plants and information (Sørensen et al. 2010). A conceptual model was developed based on soft systems methodology and information derived from four pilot farms, representing diverse conditions across the European Union. This research showed the benefits of dedicated system analysis methodologies as a preliminary step toward the actual design of a novel farm management information system, compared with other more rigid and activity-oriented system analysis methods.

RFID systems can be compared to Web 2.0, which allows data to be controlled by users. A collaborative Web 2.0–based workspace was used to support research data management and interaction, allowing useful data interchange and communications between plant pathology researchers conducting long-term trials on the sanitary selection of grapevines (Luvisi et al. 2012). Laboratories might use RFID to share information about plant or sample types and the results of assays involved in trials, although at present these applications are limited. RFID could represent a useful starting point for a more in-depth computerization of plant research and health monitoring practices.

Integration with a Web-based system was recently reported in agriculture with the FARMA platform (Voulodimos et al. 2010). The platform introduces the use of rewritable tags for storing information, which can identify lost animals or even recognize the animal's basic information without contacting the related database.

Mobile links

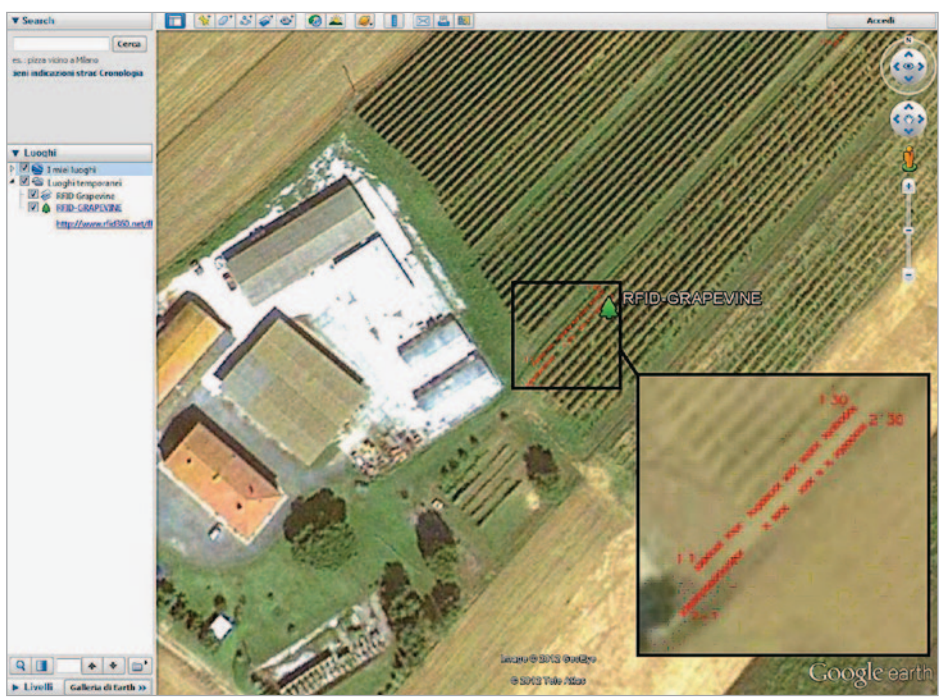
Kumagai and Miller (2006) reported using barcode tags and mobile devices to manage plant pathology samples. A novel electronic barcode system that uses RFID tags, cell phones and portable computers to link phenotypic, environmental and genomic data was developed. RFID tags were used in outdoor field trials in Hawaii, attaching the tags to mango trees with monofilament line or wristbands.

An RFID barcode tag containing sanitary, phenotypic, environmental and genomic data was linked to a Multimedia Messaging Service (MMS) system, allowing the data to be recorded and retrieved using a cell phone. Researchers were able to take photographs of plant samples and record and link audio information about their work to the image. The name of the image and audio file was then changed to an RFID code and entered into the cell phone's contact database. Then files were sent to a personal email account via cell phone MMS with the RFID code as the subject line. The cell phone had also been set to record a GPS reading and date. The RFID reader was switched to writing mode, and the information was recorded to the RFID barcode. A system to transfer the RFID data to an external database was also developed.

Mobile devices such as netbooks, tablet PCs and smart phones are optimal instruments for consulting and updating a virtual orchard or vineyard from the field; by pointing a mobile device to a tag, the viticulturalist may download climatic data or upload information such as disease and pest incidence, without having to provide coordinates or any other references and without having to return to a central office (Cunha et al. 2010). Unfortunately, widespread implementation of this technology has not been reported, suggesting difficulty in updating IT systems in agriculture.

Implementation challenges

The IT revolution has made traceability, logistics and monitoring economically feasible for food products in the agricultural product supply chain. Electronic identification has been implemented in livestock farming (Stumbos 2005), but



With RFID, geographic information systems (GIS) can be used to locate plants on an electronic map, creating a virtual vineyard or orchard. Google Earth was utilized to show the locations of grapevines marked by an RFID system. ***Courtesy of Associazione Toscana Costitutori Viticoli.***

applying the technology to plants has not taken off. The cost of microchips may be the main limitation, although they may be affordable now for high-value certified plants such as grapevines. Unfortunately, there is no data on the cost of training operators to properly place RFID in plants or the loss rate of microchips and plants during implanting. Other limitations include the low level of computerization on farms and the lack of urgent reasons to make the change.

For the livestock industry, RFID has proven useful for avoiding and managing outbreaks of animal diseases and foodborne illness. In 2008, the California Department of Food and Agriculture used individual animal RFID tags to control bovine tuberculosis. The USDA's National Animal Identification System (NAIS) is a voluntary program intended to allow the tracking of specific animals by assigning each a unique identification number. The tags used by NAIS participants need not include RFID technology, but many are employing RFID-enabled tags to track the cattle as they move through the supply chain. In 2007, the European Council mandated that each member state must establish a system for the identification and registration of ovine and caprine animals.

Woody plants such as grapevines and orchard stock cause less concern about human health than animals, and a cost-benefit analysis (including the cost of tags and industry restructuring) has not been done for woody plants. Yet RFID might be a useful tool for managing risks related to the environmental impacts of production systems, chemical residuals and the worldwide spread of plant pathogens (in particular, viruses). In certified plant propagation and breeding programs, risk management may be sufficient reason to change to an RFID system. The loss, removal or damage of traditional plant labels at any stage of production can result in a mother plant that has no known history, which is especially problematic because of the many viruses, viroids, phytoplasmas and other systemic pathogens that can infect propagative material.

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References

Almeida NF, Yan S, Cai R, et al. 2010. PAMDB, a multilocus sequence typing and analysis database and website for plant-associated microbes. Phytopathology 100:208–15.

Ampatzidis YG, Vougioukas SG, Bochtis DD. 2009. A yield mapping system for hand-harvested fruits based on RFID and GPS location technologies: Field testing. Precis Agric 10:63–72.

Associated Press. 2008. Theft deterrence for an Arizona icon. New York Times, Oct. 12. p 39.

Bandinelli R, Triolo E, Luvisi A. 2009. Employment of radiofrequency technology (RFId) in grapevine nursery traceability. Adv Hort Sci 23(2):75–80.

Bollen AF, Riden CP, Cox NR. 2007. Agricultural supply system traceability, Part I: Role of packing procedures and effects of fruit mixing. Biosyst Eng 98(4):391–400.

Boriss H, Brunke H. 2006. Commodity Profile: Peaches and Nectarines. Agricultural Issues Center, UC Davis. http://aic.ucdavis.edu/profiles/Peach-2006B.pdf (accessed Nov. 1, 2011).

Bowman KD. 2005. Identification of woody plants with implanted microchips. HortTechnology 15(2):352–4.

Bowman KD. 2010. Longevity of radiofrequency identification device microchips in citrus trees. HortScience 45(3):451–2.

[CNIPA] Centro Nazionale per l'Informatica nella Pubblica Amministrazione. 2007. Linee guida per l'impiego dei sistemi RFId nella Pubblica Amministrazione. I Quaderni 2:45–7.

Cunha CR, Peres E, Morais R, et al. 2010. The use of mobile devices with multi-tag technologies for an overall contextualized vineyard management. Comput Electron Agr 73(2):154–64.

European Commission. 2002. Directive 2002/178/EC. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2002:031:0001:0024:EN:PDF (accessed Mar. 2, 2012).

[FDA] Food and Drug Administration. 2009. Title 21 of CFR. www.fda.gov/medicaldevices/deviceregulationandguidance/databases/ucm135680.htm (accessed Mar. 2, 2012).

Ferrante P, Scortichini M. 2010. Molecular and phenotypic features of *Pseudomonas syringae* pv. *actinidiae* isolated during recent epidemics of bacterial canker on yellow kiwifruit (*Actinidia chinensis*) in central Italy. Plant Pathol 59:954–62.

Golino DA, Weber E, Sim ST, Rowhani A. 2008. Leafroll disease is spreading rapidly in a Napa Valley vineyard. Cal Ag 62(4):156–60.

Hadidi A, Khetarpal RK, Koganezawa H. 1998. *Plant Virus Disease Control.* St. Paul, MN: APS Pr. p 684.

IDTechEx. 2011. RFID Forecasts, Players and Opportunities 2011–2021. www.idtechex.com/research/reports/rfid_forecasts_players_and_opportunities_2011_2021_000250.asp (accessed Mar. 5, 2012).

[INRA] French National Institute for Agricultural Research. 2008. *Platanor Vallis clausa*, a Plane Tree Variety Resistant to Canker Stain. www.international.inra.fr/press/platanor_r_vallis_clausa (accessed Mar. 2, 2012).

[ISO] International Organization for Standardization. 1994. ISO 8402:94. Quality Management and Quality Assurance. www.iso.org/iso/iso_catalogue/catalogue_ics/catalogue_detail_ics.htm?csnumber=20115 (accessed Mar. 2, 2012).

ISO. 2005. ISO 22000:2005. Food Safety Management Systems — Requirements for any Organization in the Food Chain. www.iso.org/iso/catalogue_detail?csnumber=35466 (accessed Mar. 2, 2012).

Janse JD, Wenneker M. 2002. Possibilities of avoidance and control of bacterial plant diseases when using pathogen-tested (certified) or -treated planting material. Plant Pathol 51(5):523–36.

Kumagai MH, Miller P. 2006. Development of electronic barcodes for use in plant pathology and functional genomica. Plant Mol Biol 61:515–23.

Luvisi A, Pagano M, Bandinelli R, et al. 2011. Virtual vineyard for grapevine management purposes: A RFID/GPS application. Comput Electron Agr 75:368–71.

Luvisi A, Panattoni A, Bandinelli R, et al. 2010. Radiofrequency identification tagging in ornamental shrubs: An application in rose. HortTechnology 20(6):1037–42.

Luvisi A, Panattoni A, Colosimo A, et al. 2010. Sanitary selection of grapevine supported by RFID system. J Plant Pathol 92(4):88.

Luvisi A, Panattoni A, Triolo E. 2012. Electronic identification-based Web 2.0 application for plant pathology purposes. Comput Electron Agr 84:7–15.

Luvisi A, Triolo E, Rinaldelli E, et al. 2010. Radiofrequency applications in grapevine: From vineyard to web. Comput Electron Agr 70:256–9.

Miragliotta G, Perego A, Battezzati L. 2006. RFID alla prova dei fatti. Wireless 12:56–62.

Peets S, Gasparin CP, Blackburn DWK, et al. 2009. RFID tags for identifying and verifying agrochemicals in food traceability systems. Precis Agric 10:382–94.

[PEI] Prince Edward Island. 2003. Field records: Pesticide applications. Department of Agriculture and Forestry. Charlottetown, Can. www.gov.pe.ca/photos/original/AF_Fieldrecoful.pdf. (accessed Oct. 1, 2011).

Porto SMC, Arcidiacono C, Cascone G. 2011. Developing integrated computer-based information systems for certified plant traceability: Case study of Italian citrus-plant nursery chain. Biosyst Eng 109(2):120–9.

RFID Journal. 2012. How much does an RFID tag cost today? www.rfidjournal.com/faq/20/85 (accessed Mar. 2, 2012).

Ross K, Golino DA. 2008. Wine grapes go green: The sustainable viticulture story. Cal Ag 62(4):125–6.

Ruiz-Garcia L, Lunadei L. 2011. The role of RFID in agriculture: Applications, limitations and challenges. Comput Electron Agr 79:42–50.

Schuck A, Andrienko G, Andrienko N, et al. 2005. The European Forest Information System — an Internet-based interface between information providers and the user community. Comput Electron Agr 47:185–206.

Sørensen CG, Fountasb S, Nashf E, et al. 2010. Conceptual model of a future farm management information system. Comput Electron Agr 72:37–47.

Stumbos J. 2005. Beef quality program meets evolving consumer and producer concerns. Cal Ag 59(3):151–2.

Swedberg C. 2010. UC Davis winery tracks fermentation via RFID sensors. RFID Journal. www.rfidjournal.com/article/view/8033/1 (accessed Nov. 1, 2011).

United Nations. 1986. UN Guidelines for Consumer Protection. www.unctad.org/en/docs/poditcclpm21.en.pdf (accessed Mar. 2, 2012).

[USDA] U.S. Department of Agriculture. 2002. Traceability for Food Marketing & Food Safety: What's the Next Step? Agricultural Outlook 1:21–5.

USDA. 2007. Background Information and Statistics: California's Citrus Industry. www.ers.usda.gov/news/CAcitrus.htm (accessed Nov. 1, 2011).

Voulodimos AS, Patrikakis CZ, Sideridis AB, et al. 2010. A complete farm management system based on animal identification using RFID technology. Comput Electron Agr 70:380–8.

Ward KT, Johnson GR. 2007. Geospatial methods provide timely and comprehensive urban forest information. Urban For Urban Gree 6:15–22.

REVIEW ARTICLE

Standards vary in studies using rainfall simulators to evaluate erosion

by Mark Grismer

Rainfall simulators are often employed to measure erosion rates, in order to estimate stream loading of sediment and nutrients in California foothill watersheds. The rainfall simulator enables the precise application of artificial rain with controlled drop sizes, intensity and duration. In addition to rain factors such as drop energy and intensity, several soil- and cover-related factors affect erosion rates. While computational models have evolved to quantify erosion based on field measurements taken by rainfall simulators, there has not been a consensus on the methodology to be deployed, especially in forested and remote landscapes. In addition, it is challenging to apply study results from small plots to entire watersheds. To guide future fieldwork on sediment loading to water bodies, we review key concerns related to rainfall simulator studies.

Kevin Drake

Rainfall simulators are used by researchers to measure erosion and the loading of sediments into streams. UC Davis hydrology professor Mark Grismer (right) and GIS specialist Lee Perlow collect data using a simulator installed on a bare soil slope above Kings Beach, Lake Tahoe.

The ability to estimate how land-use practices affect soil erosion has become critically important. The U.S. Environmental Protection Agency, under section 303(d) of the Clean Water Act, has listed dozens of streams in California and the Western states as impaired or threatened due to excessive sediment concentrations, which adversely affect fish habitat. If erosion rates specific to site and land-use practices can be measured adequately, estimates of stream sediment loading can be developed.

The unpredictable and infrequent nature of rain makes it difficult to study its eroding effects on soils while it is raining. To overcome these difficulties, rainfall simulators can be used to apply precisely defined "storms" over frames designed to capture and enable the measurement of runoff and erosion rates. A variety of rainfall simulators have been developed over the past two decades and deployed in the field. Rainfall simulators typically use needle tanks or nozzle sprayers to apply water at desired rates and durations. Since 2000, extensive studies across the Lake Tahoe Basin have used drop-former type rainfall simulators (Battany and Grismer 2000) to help determine the impacts of road and forest management on sediment loading to the lake (Grismer and Hogan 2004, 2005a, 2005b), and researchers overseas have used rainfall simulators in similar studies.

A major handicap in this area of critical research, however, is that there is no standardized methodology for measuring erosion rates. This article reviews the literature on rainfall simulator techniques and their applicability to forest, rangeland and ski-run areas in the Sierra Nevada of California (the complete report is available at http://ucanr.org/u.cfm?id=48).

Rainfall simulator approaches

In general, rainfall runoff and erosion are initiated by the impact of rain drops on bare or nearly bare soils, which detaches and splashes soil particles and subsequently transports them downslope as part of overland flow. Net erosion rates (sediment mass/unit area) are a function of both rain splash and overland flow transport. Runoff, as overland flow, carries with it the most erodible silt and very fine sand particles from the soil surface as the water flows downhill. When rills (small streams or rivulets) form they initiate small channels, eventually forming gullies, which can result in massive soil losses. Rainfall simulators are typically used to determine inter-rill erosion rates and their dependence on rainfall and soil parameters.

European researchers have tried to develop standards for the use of rainfall simulators. Parsons and Lascelles (2006) detailed efforts to catalog the rainfall simulators in use and their specifications and performance characteristics, and to develop a standard evaluation and test methodology so that data from various studies could be compared. Facing erosion and stream sedimentation problems from vineyards and rangelands similar to those in California, researchers in Spain, including Cerdà (1997), have been interested in California rainfall simulator research. Agassi and Bradford (1999)

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reviewed inter-rill erosion measurement studies using rainfall simulators and found inadequate characterization of (1) the type of rainfall simulator and deployed rainfall intensities, mean drop size, drop size distribution and water quality, (2) the soil plot's physical and chemical properties and (3) the type of results obtained and how they were presented. Later, Kinnell (2005, 2006) reviewed several raindrop-affected erosion processes in the laboratory and noted that conceptual models and measurements failed to adequately characterize observed erosion processes from bare soils. Due to difficulties in comparing rainfall simulator studies across rangelands and forested areas of the Tahoe Basin (Foltz et al. 2012; Grismer and Hogan 2004), members of the Tahoe Science Consortium have recently raised concerns about the variety of rainfall simulator methods and the lack of standardization in measuring infiltration and erosion rates.

The erosion process

Raindrop energy. A raindrop's kinetic energy (KE) is one-half of the product of its size (mass) and velocity squared. Lal (1988) maintained that kinetic energy is a major factor in the soil detachment process, and therefore that the total energy of a storm is proportional to its "erosivity." It has been shown in statistical analyses that kinetic energy is insufficient to describe erosivity; the terms "erosivity," or "erodibility," in fact stem from qualitative descriptions and lack quantitative definitions based on physical processes.

Infiltration and erosion. The impact of raindrops on bare soil compacts the surface and may detach soil particles; the soil surface may become sealed, reducing the infiltration rate. For mild bare slopes, detachment and rain splash are the dominant factors causing erosion. As the slope angle increases, runoff becomes the dominant factor. When the rainfall intensity exceeds the infiltration rate, surface water accumulates on the soil, and when surface depressions are filled, runoff can occur. Increased surface roughness due to soil textural variations, tillage, residues on the surface or the presence of living plant stems reduces the velocity of overland flow. Soil surface cover, in the form of living vegetation or residues, reduces the impact (kinetic energy) of the raindrops and prevents them from striking bare soil.

Soil cover. The effect of plant canopy cover on reducing runoff and erosion in rangeland is attributed primarily to increased litter cover, soil macro-porosity and soil structure, rather than the direct interception of rainfall. Similarly, rock cover tends to reduce erosion rates proportionally to the area of coverage. Overland flow on a specific site is difficult to measure, and little is known about the mechanics of soil loss by this process.

Slope changes. All other factors being equal, it has been established that erosion rates increase as slope angles increase; presumably as overland flow velocities increase, so does the erosive power and transport capacity of runoff to carry suspended sediments. Slope angle is also important to how raindrop splashes affect erosion; as steepness increases, more soil is splashed downhill. However, the runoff rate is most sensitive to slope change; beyond a soil- and cover-dependent threshold, it is the dominant erosive process.

Interrelated processes. Erosion from soil surfaces involves interrelated processes that combine in complex spatial and temporal variations. These processes include particle (aggregate) breakdown and detachment; rain splash effects followed by particle suspension and transport as part of overland flow or wind transport; particle filtration by covers or mulch layers; and particle movement into the soil profile. These processes are affected by basic hydrologic phenomena such as precipitation form and rates, soil infiltration rates and capacity, and soil surface conditions.

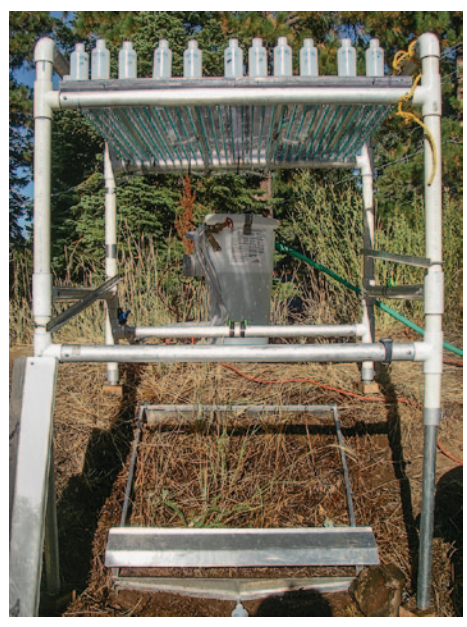
In contrast, most water erosion research assumes the simplest conditions: bare soils (no cover or mulch) of known texture and bulk density, on mild slopes (< 10%) with no infiltration-limiting layer. With the exception of areas that have roads or are disturbed, such conditions are rarely found in rangelands or forests of the California foothills.

Erosion loss models

Following the Dust Bowl era and the consequent dramatic losses of soils due to cultivation and grazing, research efforts were directed at determining the primary factors contributing to soil losses from agriculture. These efforts included the development of simple-to-use equations and models for estimating erosion rates under various agricultural practices. The value of erosion models lies primarily in conservation planning, as tools to predict soil loss. Increasingly, though, they are used to develop regulatory guidelines and evaluate compliance when monitoring information is lacking.

Physically or process-based models employ mathematical representations of flows of mass, momentum and various forms of energy to describe soil-water processes. They consist of a number of linked equations with parameters that have direct physical significance and can each be evaluated by independent field measurements. In principle, physically based processes only require representative physical characteristics of the soil-water system in the model for the results to be realistic.

Universal Soil Loss Equation. The Universal Soil Loss Equation (USLE) was codified in 1965 in the U.S. Department of Agriculture (USDA) Agriculture Handbook No. 282 and revised by Wischmeier and Smith (1978) in Agriculture Handbook No. 537. The USLE was derived from statistical analyses of natural runoff and erosion data and equivalent rainfall simulator–derived plot data largely gathered in the central United States. The authors emphasized that the USLE was an erosion model designed to predict the long-term average annual soil losses from rill and inter-rill erosion that might be expected from specific field



Rachel McCullough

This simulator uses a frame with nozzles (top) to apply water at various rates and a frame on the ground to catch sediments.

areas under various cropping and management systems. The USLE identified six major erosion factors, the product of which represents average annual soil loss:

(1) $A = R \times K \times L \times S \times C \times P$

where: A = estimated soil loss (tons per acre per year), R = rainfall runoff, K = soil erodibility, L = slope length, S = slope steepness, C = cover and management and P = supporting practice.

Rainfall runoff (R) is a key factor of the USLE model and is determined by local climate conditions. The erodibility factor (K) is determined from the soil type, and the management and practices factors (C and P) are estimated from tables of values associated with management and practice descriptions. The USLE equation was derived from soil loss data measured from erosion plots after about 1 year of runoff, and as such the equation predicts annual accumulated soil losses rather than individual rain event losses.

WEPP model. Later, the Water Erosion and Prediction Project (WEPP) model was developed (Nearing et al. 1990) with the concept of developing a physically based mathematical description of erosion processes, but it also uses the equivalent of the K, C and P factors of the USLE equation. Both the USLE equation and WEPP model need estimates of inter-rill erodibility (K), which can be obtained using rainfall simulators.

Post-WEPP developments

While the WEPP model and its related equations represent accumulated research of the past several decades, they originated from Ellison's (1947) paradigm that "erosion is a process of detachment and transport of soil materials by erosive agents." Such a view has come under criticism, because erosion processes are sufficiently complex that many questions remain unresolved, including laminar versus turbulent flows in the field; the fundamental applicability of the turbulent flow–based shear stress equations to slopes greater than 10%; the discrepancy between measured and modeled soil shear strength; and raindrop effects on steeper, relatively undisturbed forest soils. As a result, the precise definition of erodibility remains elusive (Agassi and Bradford 1999).

Owoputi and Stolte (1995) suggested that the semi-empiricism implicit in

Kevin Drake

The models for analyzing rainfall simulator data are based on rainfall and soil loss rates, slope length and steepness, percentage of vegetative cover and other factors. Monitoring specialist Mike Ukraine filters samples at the Integrated Environmental Restoration Services lab in Tahoe City.

the WEPP model and related equations should be replaced by more careful definitions of the forces acting on hypothetical soil particles or aggregates. Presumably from there the forces or energy needed for aggregate breakdown could be applied to determine the extent of finer particle liberation and subsequent transport (Fristensky and Grismer 2009). Owoputi and Stolte (1995) underscored the need to account for the moisture dependence of soil strength and seepage, though in a rainfall- or runoff-induced erosion event it is likely that the surface soil layers are at or near saturation, their weakest state.

Similarly, in a thorough review of erosion induced by raindrops on mildly sloping bare soils, Kinnell (2005) claimed that current models "do not represent all of the erosion processes well." None of the models deal with temporal changes in surface properties, and all simplify the process descriptions to a planar surface lacking the variations in microtopography or surface roughness found in even relatively smooth field soils. Grismer (2007) noted that the research briefly summarized here, and similar studies, by necessity were conducted on bare soils and as a result may not apply to duff-covered or litter- and mulch-matted range and forest soils in which the dominant sediment detachment and transport processes are perhaps better characterized as filtration.

According to Zhang et al. (2003), soil erodibility would ideally be quantitatively defined as a detachment or transport coefficient relating soil detachment rates to an appropriate form of stream power (the product of runoff velocity and land slope). A rise in stream power likely increases possible aggregate disintegration, and there may be a practical threshold of stream power effects to consider in detachment modeling (Fristensky and Grismer 2009). Thus, either the physical process description given by equations such as those in the WEPP model is inadequate, or erodibility needs greater clarification and evaluation.

Natural and simulated rainfall

The role of raindrop velocity, or energy, in the splash detachment of soil particles has been a concern for decades (Bisal 1960; Ellison 1947). Debate centers on whether raindrop size, velocity, momentum, kinetic energy or some combination of these is the key parameter in the design of rainfall simulators used for erosion studies. In addition, a threshold concept must account for the limited erosion rates encountered during low-intensity storms (for which the use of kinetic energy alone tends to overestimate erosion rates). Nonetheless, in contrast to earlier studies, recent work includes determinations of rainfall kinetic energy as a measure of total energy available for aggregate disintegration, detachment and transport. These estimated kinetic energies depend in part on drop sizes and their distribution.

The median drop size of natural rainfall varies with intensity. Several studies suggest that drop sizes of around 2.5 millimeters may be appropriate for simulated rainfall at the intensities often employed in the field. When drop size distributions are expressed as a fraction of the rain event's volume and intensity, relatively low-intensity events are dominated by drop sizes of less than 1 millimeter, while rainfall intensities between 40 and 120 millimeters (1.6 to 4 .8 inches) per hour are associated with a median drop size of around 2 millimeters. Few direct measurements of kinetic energy for simulated and natural rainfall exist; rather, kinetic energies are estimated from drop sizes, assumed distributions and fall heights or terminal and nozzle velocities.

Van Dijk et al. (2002) reviewed studies of the relationship between rainfall drop sizes, intensity and kinetic energies from around the world and found that in good quality data, kinetic energy ranged from 11 to 36 joules per square meter per millimeter depth (J/m^2-mm) with maximum values averaging around 29 J/m^2-mm and minimum values of about 12 J/m^2-mm. Particular kinetic energy values depended on location, type of storm and storm pattern. They found that high-intensity storms typical of rainfall simulator studies (> 40 millimeters per hour) result in average kinetic energies of 23 to 24 J/m^2-mm.

Overlooked by van Dijk et al. (2002) were earlier studies (Madden et al. 1998) that used piezoelectric crystals to directly measure natural and simulated raindrop power (kinetic energy per unit of time). Simulated rains at intensities of 23 to 48 millimeters per hour developed powers of 200 to 1,320 joules per square meter per hour (J/m^2-hr), while natural rainfall powers for 85 events ranged from around 200 to 3,000 J/m^2-hr at intensities of 1 and 42 millimeters per hour, but reached as much as 6,000 J/m^2-hr for short, high-intensity storm events.

What this range of kinetic energies at given intensities means with respect to the evaluation of erodibilities remains unclear. Van Dijk et al. (2002) commented, "In terms of process-based research, it appears that our knowledge of the distribution of drop size and terminal velocity in natural rainfall is well ahead of our understanding of the way in which these interact to detach and transport soil particles by splash."

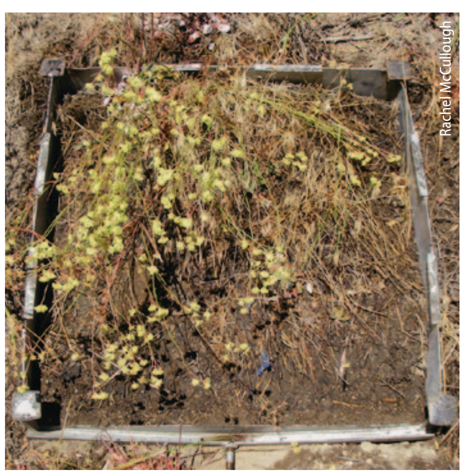
In another review, Dunkerley (2008) lamented that most rainfall simulator–based studies employ extreme rainfall intensities for the application region or duration, with an overemphasis on drop sizes, their distributions and kinetic energies. It is not clear if the variability of natural rainfall duration, intensity and drop size is critical in terms of soil detachment and erosion, if the mean or maximum kinetic energies are known or estimated.

Rainfall simulator designs

Rainfall simulators must be designed to meet competing demands: replication of natural rainfall, ease of portability across remote and steep terrain, reasonable costs of construction, and uniformity across the test plots in terms of rainfall intensity, drop size and kinetic energy. Duplicating the range of drop sizes and kinetic energies of natural rainfall has proven difficult.

Two types of rainfall simulators have emerged in field research, broadly categorized as the spray/sprinkler nozzle and the drop-former, which simulate rain intensities of 10 to 200 millimeters per hour and drop sizes of 0.1 to 6 millimeters. In terms of size, rainfall simulators range from a simple, small, portable infiltrometer with a 6-inch-diameter rainfall area (Bhardwaj and Singh 1992) to the complex Kentucky rainfall simulator, which covers a plot 14.75 feet by 72 feet (4.5 meters by 22 meters) (Moore et al. 1983).

Many original laboratory rainfall simulators were of the nozzle type, presumably due to ease of construction. Laboratory drop-former simulators emerged later in response to uncertainties associated with nozzle-generated drop sizes, distributions and intensities. In the past decade, about 40 different rainfall simulators have been used in erosion-related research, as reported in more than a dozen journals, of which around 80% were the nozzle type and the remainder variations on the drop-former type. (See full report at http://ucanr.org/u.cfm?id=48 for a summary of rainfall simulator characteristics.) Two rainfall simulators used in a variety of field environments across a range of slopes for roughly 1-square-meter plots have emerged as de facto standards: the oscillating veejet nozzle system (Paige et al. 2003) and the needle drop-former (Battany and Grismer 2000). Assuming cost and portability of the two are relatively equivalent, the differences are related to their simulated rainfall characteristics. Simple drop-former designs are commonly used where access is more difficult or water availability is limited.



Rachel McCullough

Standardization of erosion studies using rainfall simulators would allow more effective comparisons and data analysis. *Above*, a collection frame after a simulation near Lake Tahoe.

Method evaluations. Rainfall simulators have been widely used to assess erosion control or treatment technologies. Sutherland (1998a, 1998b) noted that the "formative years" prior to around 1990 produced a mass of information that lacked scientifically credible, standardized methods or data from actual applications. His arguments for standardized evaluation methods that have field applicability, with greater emphasis on the study of surface or near-surface processes controlling erosion, remain valid more than a decade later.

Relatively portable rainfall simulators have been more commonly deployed in the past two or three decades with corresponding plots of 1 or 2 square yards that are well suited to a wide range of field studies, particularly where access is difficult or when multiple replications are needed across a large area. They have been used to study runoff and erosion mechanisms in a wide range of environments; however, in practice these rainfall simulators necessarily fail to accurately replicate natural rainfall characteristics, due to their portability, cost design or management limitations. While runoff and erosion rates from rangeland and forest soils are generally much lower than that from bare and disturbed soils, these latter soils often comprise substantially larger areas within watersheds and as a result may contribute significant loading to streams.

However, there have been few direct field measurements of runoff and erosion rates, or modeling approaches capable of predicting these rates, from less-disturbed forest and rangeland soils (Grismer 2012). Meyer (1988) contended that simulated rainfall results only give relative, rather than absolute, erosion data, and that to correlate the simulation results to that of natural events, data from similar plots subject to long-term natural rainfall events must be available for comparison (Hamed et al. 2002). Nonetheless, rainfall simulators in the field continue to be developed and used as few replacements are available for generating physical process–based erosion information.

Field methodologies. The area of simulated rainfall coverage is inherently limited by the rainfall simulator, slope, available water and the possibility of replication, so small field-plot erosion studies are necessarily compromised by sampling issues relative to the larger landscape. Methodological variations and sources of uncertainty regarding the comparison of results include water supply (water chemistry and soil interaction); simulated rainfall characteristics (e.g., drop size, intensity and kinetic energy); plot runoff frame size and installation; runoff sampling size, frequency and duration; the identification of plot cover, slope and surface soil conditions; the measurement of inter-rill erosion, rill erosion or combinations; plot replication or the degree to which plots represent hill slope conditions; and the interpretation of runoff sediment sampling relative to local soil, cover and climate conditions. At a minimum, each of these should be addressed in research deploying rainfall simulators to facilitate comparisons between studies.

TABLE 1. Issues to address in the standardization of field rainfall simulator erosion studies

Issue/question	Comments
How do the local natural rain characteristics compare to those of the rainfall simulator?	Include drop size, drop distribution and kinetic energies.
Which rainfall characteristics are expected to be important for determining local erosion rates or erodibility?	Depends on cover conditions.
Are there soil-related thresholds that are critical to determining erodibility? If so, how can they be determined or measured?	Aggregate strength is a dynamic soil property that is largely unknown.
How do we quantify the soil hydrophobicity effects common in range and forest soils of the California foothills?	Hydrophobicity is a dynamic property that increases runoff rates in late summer or after fire (Rice and Grismer 2010).
What is erodibility in the context of forested landscapes or deeply mulch- or duff-covered soils? How can it best be defined or measured in this situation?	The definition of erodibility depends on the conceptual equation applied. Information is required about infiltration rates, soil compaction, antecedent moisture and depth to the less-permeable layer.
How many replications in studies of runoff or erosion rates are sufficient to characterize the sample area of interest?	Plot variability effects increase with decreasing measured sediment yields; the assumption of evenly distributed erosion rates may not be valid. With the considerable plot-to-plot variability in measured erosion rates from seemingly homogeneous areas, standard replication and statistical analyses should be promoted.
While erosion rates conceptually increase with increasing slope and the associated increased runoff rate for given rainfall intensities, are there thresholds below which slope effects are negligible and above which they are significant?	Plot variability may have a greater effect on measured erosion rates than increased slope at less than about 20% for bare soils and 50% for forest soils.
In addition to rainfall and runoff rates, are there slope-related thresholds, especially on steep slopes, that are critical to determining their erodibility?	Maybe; see above.
At what combinations of bare-soil slope length, surface runoff rate, slope angle and surface condition does rill erosion become dominant compared to inter-rill erosion?	Open question; appears to depend on soil type.
What are the effects of frame installation methods, and do frames capture surface erosion appropriately?	No studies quantify the effects of frame installation on measured erosion rates.
What are the most appropriate methods for quantitatively characterizing the plant, mulch and/or duff covers?	There may be a threshold-based effect that needs further clarification or definition (Grismer et al. 2009).

Scalability issues

In most forested catchments, the main sources of stream sediment are erosion associated with disturbances such as dirt access roads (for logging and fire control), and log skid trails and channel incisions linked to increased overland flows following disturbances. Nonetheless, rainfall simulator erosion evaluations are conducted in the field to guide general assessments of hill slope and catchment runoff and the erosion rates associated with different soils and land uses. Scaling up to the hill slope or catchment involves at least three issues beyond the scope of small-plot rainfall simulator studies: (1) the natural heterogeneity of soil conditions (e.g., infiltration and erosion rates) across the hill slope, or plot-to-plot variability; (2) the interconnectivity between measured and nonmeasured areas, or between eroding and depositional areas; and (3) soil plot disturbance effects as a result of the rainfall simulator measurements themselves.

Le Bissonnais et al. (1998) noted the need to consider the spatial structure of the catchment, while García-Ruiz et al. (2010) and others have highlighted that connectivity with fluvial channels is the most important factor linking plot to catchment studies. Both studies underscored the importance of considering various spatial and temporal scales, since it is well known that geomorphic and hydrological processes are scale dependent.

Some of the issues associated with field variability, including that introduced by experimental design of the erosion plot (Zöbisch et al. 1996), were recognized more than a decade ago (Bagarello and Ferro 1998). Unexplained variability between erosion test-plot results, even in apparently homogeneous, cultivated fields (Rüttimann et al. 1995), remains perplexing and limits the development of more generalized conclusions about runoff and erosion rates (Gómez et al. 2001). Variability of 30% to 75% between plots located on a seemingly homogeneous landscape is common (Foltz et al. 2012; Grismer and Hogan 2004; Nearing et al. 1999). At the same time, knowledge is needed about soil erosion processes occurring in field plots across a range of sizes, the threshold limits at which different processes are significant and the factors that determine natural variability (Bagarello and Ferro 2004).

Boix-Fayos et al. (2006) sought to review these issues within the following framework: "(i) temporal and spatial scales, (ii) representation of natural conditions, (iii) the disturbance of natural conditions and (iv) accounting for the complexity of ecosystem interactions." Ultimately, the uncertainties associated with these issues are set aside so that erosion predictions can be made as part of watershed process modeling, to evaluate the effects of changing landscape conditions on watershed health and the quality of discharge water.

The research related to scaling erosion estimates from plot-based measurements to the entire hill slope or catchment is conflicting. Grismer (2012) used 1-square-meter rainfall simulator erosion test plots to relate sediment yields to soil type, condition and slope, in order to model daily sediment loads from paired 630- and 1,300-acre watersheds on the Tahoe Basin west shore. Unfortunately, actual field data on infiltration and erosion rates at different spatial scales from one to tens of meters are difficult to obtain, and little can be found in the literature (Bagarello and Ferro 2004, 2010), since most field measurements have concentrated on water erosion at the runoff plot scale (Poesen and Hooke 1997).

Key questions

The lack of quantitative, physical-process-based information about infiltration, runoff and erosion rates from forest and range conditions suggests that rainfall simulators will continue to be used for decades to come. A standardized methodology for rainfall simulator design, runoff frame installation and the analysis of results needs to be developed and applied to all studies as they attempt to address key issues (table 1).

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References

Agassi M, Bradford JM. 1999. Methodologies for inter-rill soil erosion studies. Soil Till Res 49:277–87.

Bagarello V, Ferro V. 1998. Calibrating storage tanks for soil erosion measurement from plots. Earth Surf Proc Land 23:1151–70.

Bagarello V, Ferro V. 2004. Plot-scale measurement of soil erosion at the experimental area of Sparacia (southern Italy). Hydrol Process 18:141–57.

Bagarello V, Ferro V. 2010. Analysis of soil loss data from plots of differing length for the Sparacia experimental area, Sicily, Italy. Biosyst Eng 105:411–22.

Battany MC, Grismer ME. 2000. Development of a portable field rainfall simulator for use in hillside vineyard runoff and erosion studies. Hydrol Process 14(6):1119–29.

Bhardwaj A, Singh R. 1992. Development of a portable rainfall simulator infiltrometer for infiltration runoff and erosion studies. Ag Water Manage 22(3):235–48.

Bisal F. 1960. The effect of raindrop size and impact velocity on sand splash. Can J Soil Sci 40:242–5.

Boix-Fayos C, Martinez-Mena M, Calvo-Cases A, et al. 2006. Measuring soil erosion by field plots: Understanding the sources of variation. Earth-Science Rev 78:267–85.

Cerdà A. 1997. The response of abandoned terraces to simulated rain. In: Rickson RJ (ed.). *Conserving Soil Resources: European Perspectives*. Oxford, UK: CAB Int. p 44–55.

Dunkerley D. 2008. Rain event properties in nature and in rainfall simulation experiments: A comparative review with recommendations for increasingly systematic study and reporting. Hydrol Process 22:4415–35.

Ellison WD. 1947. Soil erosion studies, Part I. Agr Eng 28:145–6.

Foltz RB, Elliot WJ, Wagenbrenner NS. 2012. Soil erosion model predictions using parent material/soil texture-based parameters compared to using site-specific parameters. T ASABE 54(4):1347–56.

Fristensky A, Grismer ME. 2009. Evaluation of ultrasonic aggregate stability and rainfall erosion resistance of disturbed and amended soils in the Lake Tahoe Basin, USA. Catena 79:93–102.

García-Ruiz JM, Lana-Renault N, Beguería S, et al. 2010. From plot to regional scales: Interactions of slope and catchment hydrological and geomorphic processes in the Spanish Pyrenees. Geomorphology 120:248–57.

Gómez JA, Nearing MA, Giráldez JV, Alberts EE. 2001. Analysis of sources of variability of runoff volume in a 40-plot experiment using a numerical model. J Hydrol 248:183–97.

Grismer ME. 2007. Soil restoration and erosion control: Quantitative assessment in rangeland and forested areas. T ASABE 50(5):1619–26.

Grismer ME. 2012. Erosion modeling for land management in the Tahoe Basin, USA: Scaling from plots to small forest catchments. Hydrol Sci J 57(5):1–20.

Grismer ME, Hogan MP. 2004. Simulated rainfall evaluation of revegetation/mulch erosion control in the Lake Tahoe Basin: 1. Method assessment. Land Degrad Dev 15(6):573–88.

Grismer ME, Hogan MP. 2005a. Simulated rainfall evaluation of revegetation/mulch erosion control in the Lake Tahoe Basin: 2. Bare soil assessment. Land Degrad Dev 16(4):397–404.

Grismer ME, Hogan MP. 2005b. Simulated rainfall evaluation of revegetation/mulch erosion control in the Lake Tahoe Basin: 3. Soil treatment effects. Land Degrad Dev 16(5):489–501.

Grismer ME, Shnurrenberger C, Arst R, Hogan MP. 2009. Integrated monitoring and assessment of soil restoration treatments in the Lake Tahoe Basin. Env Monit Assess 150:365–83.

Hamed Y, Albergel J, Pépin YJ. 2002. Comparison between rainfall simulator erosion and observed reservoir sedimentation in an erosion-sensitive semi-arid catchment. Catena 50:1–16.

Kinnell PIA. 2005. Raindrop-impact-induced erosion process and prediction: A review. Hydrol Process 19:2815–44.

Kinnell PIA. 2006. Simulations demonstrating interaction between coarse and fine sediment loads in rain-impacted flow. Earth Surf Proc Land 31:355–67.

Lal R. 1988. Erodibility and erosivity. In: Lal R (ed.). *Soil Erosion Research Methods*. Soil and Water Conservation Society, Ankeny, IA. p 141–60.

Le Bissonnais Y, Benkhadra H, Chaplot V, et al. 1998. Crusting, runoff and sheet erosion on silty loamy soils at various scales and upscaling from m^2 to small catchments. Soil Till Res 46:69–80.

Madden LV, Wilson L, Ntahimpera N. 1998. Calibration and evaluation of an electronic sensor for rainfall kinetic energy. Phytopathology 88(9):950–9.

Meyer LD. 1988. Rainfall simulators for soil conservation research. In: Lal R (ed.). *Soil Erosion Research Methods*. Soil and Water Conservation Society, Ankeny, IA. p 75–96.

Moore ID, Hirschi MC, Barfield BJ. 1983. Kentucky rainfall simulator. Trans ASAE 26:1085–9.

Nearing MA, Deer-Ascough L, Laflen JM. 1990. Sensitivity analysis of the WEPP hill-slope profile erosion model. T ASAE 33(3):839–49.

Nearing MA, Govers G, Darrell Norton L. 1999. Variability in soil erosion data from replicated plots. Soil Sci Soc Am J 63:1829–35.

Owoputi LO, Stolte WJ. 1995. Soil detachment in the physically based soil erosion process: A review. T ASAE 38:1099–110.

Paige GB, Stone JJ, Smith JR, Kennedy JR. 2003. The Walnut Gulch rainfall simulator: A computer-controlled variable intensity rainfall simulator. Appl Eng Agric 20(1):25–31.

Parsons AJ, Lascelles B. 2006. Rainfall simulation in geomorphology. Earth Surf Proc Land 25:679.

Poesen JW, Hooke JM. 1997. Erosion, flooding and channel management in Mediterranean environments of southern Europe. Prog Phys Geog 21(2):157–99.

Rice EC, Grismer ME. 2010. Dry-season soil-water repellency affects Tahoe Basin infiltration rates. Cal Ag 64(3):141–8.

Rüttimann M, Schaub D, Prasuhn V, Rüegg W. 1995. Measurement of runoff and soil erosion on regularly cultivated fields in Switzerland — some critical considerations. Catena 25:127–39.

Sutherland RA. 1998a. Rolled erosion control systems for hillslope surface protection: A critical review, synthesis and analysis of available data. I. Background and formative years. Land Degrad Dev 9:465–86.

Sutherland RA. 1998b. Rolled erosion control systems for hillslope surface protection: A critical review, synthesis and analysis of available data. II. The post-1990 period. Land Degrad Dev 9:487–511.

Van Dijk AJM, Bruijnzeel LA, Rosewell CJ. 2002. Rainfall intensity — kinetic energy relationships: A critical literature appraisal. J Hydrol 261:1–23.

Wischmeier WH, Smith DD. 1978. Predicting Rainfall Erosion Losses: A Guide to Conservation Planning. Agriculture Handbook, No. 537. USDA/Science and Education Administration, Washington, DC. 58 p.

Zhang GH, Liu BY, Liu GB, et al. 2003. Detachment of undisturbed soil by shallow flow. Soil Sci Soc Am J 67:713–9.

Zöbisch MA, Klingspor P, Oduor AR. 1996. The accuracy of manual runoff and sediment sampling from erosion plots. J Soil Water Conserv 51(3):231–3.

Conservation tillage systems for cotton advance in the San Joaquin Valley

by Jeffrey P. Mitchell, Lyle Carter, Dan Munk, Karen Klonsky, Robert Hutmacher, Anil Shrestha, Rich DeMoura *and* Jon Wroble

Cotton production in the San Joaquin Valley has traditionally relied heavily on tillage for its presumed benefits to plant establishment, yields and insect management. Research in the 1960s and 1970s demonstrated the potential of precision or zone tillage, which foreshadowed the introduction of a variety of minimum tillage implements in the early 1990s. During a 3-year comparison study from 2001 to 2003, cotton yields in strip tillage plots matched or exceeded yields of standard tillage plots in all 3 years. In a 12-year study from 1999 to 2011, tillage costs were lowered an average of $70 per acre in 2011 dollars using no-tillage compared to standard tillage while achieving statistically comparable yields, provided that adequate crop stands were achieved. If bottom-line profitability can be maintained, conservation tillage may become increasingly attractive to cotton producers in the San Joaquin Valley.

Alan Wilcox

In traditional cotton tillage, fields may undergo multiple operations. New implements and strategies allow growers to significantly reduce that number. A Wilcox Agriproducts Eliminator creates a flat seedbed in one pass after cotton harvest and shredding in Firebaugh, 2006.

Cotton production systems in the San Joaquin Valley have evolved over the past 60 years to rely heavily on intensive tillage, which is costly. Numerous tillage passes require not only considerable labor and time, but also specialized implements and the tractor power to pull them. Historically, tillage costs have not been a major part of crop production budgets (Hutmacher et al. 2003), but because of rising diesel fuel and equipment costs, they are becoming an increasingly important component of a farm's business model. During the past decade researchers have evaluated a variety of conservation tillage (CT) approaches that reduce the frequency of tillage, and cotton producers are now using some of these approaches.

Traditional multipass tillage

Cotton has been an important crop in the San Joaquin Valley for more than 150 years. Tillage management systems for cotton changed relatively little here during the last half of the 20th century (Abernathy et al. 1975; Carter 1996; Carter et al. 1965), and cotton remains a tillage-intensive agronomic crop (Mitchell et al. 2007; Mitchell, Pettygrove et al. 2009). Even though there are incentives to reduce tillage, such as the Environmental Quality Incentives Program (EQIP) of the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS), most of the crop continues to be produced using traditional, multiple-pass tillage practices (CCTCSW 2011; Mitchell, Pettygrove et al. 2009).

Tillage begins at the end of the previous crop. Aboveground crop material is typically shredded, and roots are undercut and mixed with the soil in a series of diskings designed to provide a host-free period (without cotton plants) in accordance with the California Department of Food and Agriculture's pink bollworm control and eradication program (CDFA 2012), a successful biological control program for insects in operation since the 1960s. In sequence, weeds are then eliminated; herbicides are incorporated; soil clods are broken up; and uniform planting beds are shaped, prepared for furrow irrigation and dry mulched, which is shallow cultivation using rolling harrow implements to kill weeds and even out surface soil moisture. This can amount to six or more field operations before the crop is even seeded (Hutmacher et al. 2003; Mitchell, Pettygrove et al. 2009). In many soil types compaction in subsoil zones is loosened or fractured, annually or less frequently, to avoid root restriction due to consolidated, hard soil layers.

Each tillage pass performs a different function and contributes to reducing the risk of crop failure due to weed pressure, inadequate plant populations and, in some specific cases, damage from insects and pathogens. The sequence of tillage operations is by no means capricious, but in many respects tillage begets tillage: for example, stubble disking requires a carefully devised series of follow-up

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operations to break up clods created by the disking.

Evolution of minimum tillage

Minimum tillage is a form of conservation tillage, which by definition reduces the number of tillage passes by 40% or more compared to conventional practices in 2000 (see glossary) (Mitchell, Pettygrove et al. 2009). Its evolution began in the 1950s.

In 1957 (fig. 1), Al Ruozi in Bakersfield developed a patented one-pass Shredder Bedder (Interstate Equipment & Mfg., Bakersfield, CA) that could shred aboveground stalks, undercut and kill roots, and then mix cotton residues with soil and prepare new planting beds in one operation. In the 1960s and 1970s, Lyle Carter, USDA Agricultural Research Service engineer at the Cotton Research Center in Shafter, promoted the concept of precision tillage for cotton, in which the only tillage used is in the plant row and not broadcast throughout the entire field (Carter and Stockton 1963; Carter et al. 1965; Stockton et al. 1962). These early efficiency efforts eventually led to the concept of zone production, in which crop growth zones are separated from tractor traffic zones (Carter 1985, 1991; Carter et al. 1987), and in particular to the strip and vertical tillage systems, in which only the crop seed line is tilled. These systems are used to great advantage in the Southeast and increasingly in other regions of the United States, such as Colorado and western Nebraska. In recent years, strip tillage has become more common in San Joaquin Valley dairy corn silage systems, but it is currently not used in cotton.

Carter also developed the spanner, equipment with wide spaces between tractor wheels that covers broad swaths of a field (Carter 1991; Carter et al. 1987). His pioneering systems reduced tractor traffic, energy costs and the soil compaction associated with equipment traffic, which improved soil conditions and water conservation.

More recently, beginning in the mid-1990s, implements that combine tillage tools onto a single frame were developed, such as the Optimizer (New World Tillage, Modesto, CA), the Eliminator and Performer (Wilcox Agriproducts, Walnut Grove, CA), the Hahn Bed Disk (Hahn Tractor, Stockton, CA), the Rome-Pegasus (Rome Plow Equipment, Cedartown, GA) and the Sundance Wide Bed Disk (Arizona Drip Systems, Coolidge, AZ). This equipment accomplishes tillage functions with fewer passes (Mitchell, Pettygrove et al. 2009). Each of these implements has been successfully used in crop production in some locations and situations; however, most have particular characteristics that can affect where and when they can be best used in fields,

Glossary of tillage systems

California's Conservation Agriculture Systems Innovation (CASI) initiative has outlined the following general categories of tillage systems. (For more complete definitions and additional information, see Mitchell, Pettygrove et al. 2009.)

Conservation tillage, minimum tillage: Tillage practices that have a conservation goal, such as reducing the volume of soil disturbed and preserving rather than incorporating surface residues, and result in the broad protection of resources. CASI defines conservation tillage as including no-tillage, strip tillage, ridge tillage and mulch tillage systems that preserve 30% or more of the soil surface covered by residues after planting, and minimum tillage systems that reduce tillage passes by 40% or more compared with convential practices in 2000.

No-tillage: Seed is planted directly into soil that has been left undisturbed, except for the injection of fertilizers, since harvest of the previous crop.

Ridge tillage: Crops are seeded and grown on ridges or shallow beds formed during the prior growing season, generally during cultivation using implements fitted with sweeps, hilling disks and furrowing wings. Soil is generally left undisturbed from harvest to planting except for fertilizer injection.

Standard tillage: The sequence of operations historically used to prepare a seedbed and produce a crop.

Strip tillage: The seed row is tilled before planting to allow residue removal, soil drying and warming, and in some cases subsoiling.

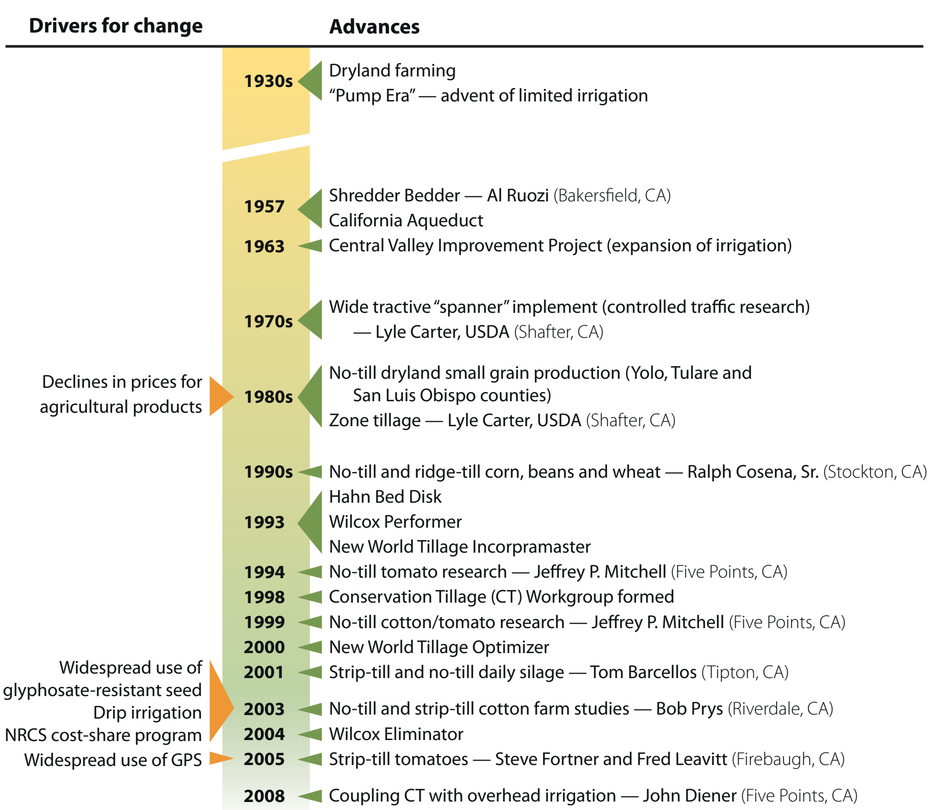

Fig. 1. Changes in tillage management in California's Central Valley.

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The field layout for the cotton-tomato rotation study shows postharvest tomato beds (left) and conservation tillage cotton beds (right), with and without a cover crop in Five Points, 2007. In later years of the study, cotton lint yields were similar for the conservation tillage and standard systems.

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Fewer passes translate into about $70 less per acre spent on fuel, labor and repairs. A Wilcox Performer incorporates tomato postharvest residue before the next crop in Five Points, 2007.

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A Case DMI Ecolo-till six-row strip-tiller prepares seedbed strips prior to cotton seeding (in Riverdale, 2003), generating less dust and particulate matter than disking the entire field.

depending on factors such as soil texture, moisture content and aggregation. These affect the extent to which the soil fractures and permits good seedbed conditions following operations.

Lowering the number of tillage operations reduces diesel fuel usage (Upadhyaya et al. 2001) and dust generated (Baker et al. 2005; Madden et al. 2008). In the Sacramento Valley, an average savings of 50% for fuel and 72% for time have been reported with one-pass tillage equipment (Incorpramaster, New World Tillage, Modesto, CA) compared with the standard tillage program of disking and land planing (Upadhyaya et al. 2001). In a Los Banos cotton field, recent investigations using advanced atmospheric light detection and ranging measurement techniques showed that combined minimum tillage operations (Optimizer) reduced the time and fuel used per acre by 40% and 50%, respectively, compared with conventional methods. Particulate matter (PM) levels were also reduced — $PM_{2.5}$ emissions by 29% and PM_{10} by 60% (personal communication, J. Hatfield, Research Leader, USDA ARS National Soil Tilth Lab, Ames, IA).

There are two general types of minimum tillage implements: those that preserve dedicated planting beds and those that do not. In zone tillage — a term originally coined in 1985 to describe the deliberate preservation of crop growth and tractor traffic zones throughout a field — permanent or semipermanent bed tillage implements such as the Sundance Wide Bed Disk, Hahn Bed Disk and Wilcox Performer are used with steering guided by global positioning systems (GPS) to maintain beds and traffic furrows (Carter 1985, 1991; Carter et al. 1987). Permanent-bed minimum tillage is widely used in subsurface-drip tomato production throughout the San Joaquin Valley's West Side (CCTCSW 2011). Variations of commercially available permanent-bed minimum tillage equipment have been introduced during the last decade. A one-pass tillage implement developed in 2001 by Jim Couto, a farmer in Kerman, uses a Bigham Brothers Terratill (Lubbock, TX) strip tillage toolbar fitted with Lilliston rolling cultivators and a roller to recreate beds prior to seeding. The second type of implement is typified by the Eliminator or Optimizer, which do not preserve beds but rather flatten fields while mixing and incorporating residues and preparing seedbed tilth in a single pass.

With these minimum tillage implements, less deep or vertical tillage is generally accomplished, while the extent of horizontal or shallow surface tillage is generally similar to conventional tillage. The number of total passes across a field is reduced by combining tillage tools and functions onto one implement. However, unless farmers use techniques that control traffic in the field — restricting tractor and implement load traffic away from crop growth zones — tillage-induced subsoil compaction must still be addressed, and the tillage treadmill may continue even with reduced-pass approaches.

3-year farm tillage study

The first firm recorded usage of no-tillage and strip tillage for cotton production in the San Joaquin Valley was in 2000. From 2000 to 2003, Bob Prys, a Riverdale (western Fresno County) farmer, in conjunction with UC researchers, compared various conservation tillage planting and stalk management systems with standard tillage practices in three successive cotton crops (Mitchell et al. 2006). In this study, three replications of seven cotton planting and postharvest stalk management systems were set out with 30-inch spacing between rows across a 12-acre field of Panoche clay loam soil. Before each cotton crop, a winter cover crop of barley (*Hordeum vulgare*) was grown across the entire experimental field to add organic matter to the soil and improve tilth. The cover crop was terminated by spraying glyphosate or by a combination of glyphosate and mowing. Sixteen trips across the field were made in the standard tillage plot, whereas seven or eight were made in the alternative system plots (table 1).

Yield and details on each of these cotton tillage systems for the first 2 years of this study have been previously reported (Mitchell et al. 2006). An important finding was that strip tillage resulted in yields that for 2 years consistently matched and in 1 year exceeded those of the control (table 2). The study also showed that conservation tillage produced higher yields over the 3-year study, and reductions in operating costs from eliminating tillage passes were about $40 per acre.

TABLE 1. Preplant and postharvest tillage operations, Riverdale, 2001–2003

Tillage operation	Standard tillage	No-tillage, cover chopped	No-tillage, no chop	Ridge tillage, cover chopped	Ridge tillage, no chop	Strip tillage, cover chopped	Strip tillage, no chop
Spray glyphosate	■	■	■	■	■	■	■
Chop cover crop	■	■		■		■	
Disk	■						
Disk	■						
Chisel	■						
Disk	■						
List beds	■						
Plant cotton	■	■	■	■	■	■	■
Ring-roll	■						
Apply glyphosate	■	■	■	■	■	■	■
Cultivate	■	■	■	■	■	■	■
Harvest cotton	■	■	■	■	■	■	■
Shred stalks	■	■	■	■	■	■	■
Disk	■						
Disk	■						
Subsoil/relist beds	■						
Root-pull stalks and/or relist beds		■	■	■	■	■	■
Times over field	16	8	7	8	7	8	7

TABLE 2. Cotton yields, fuel use and operating costs for tillage systems, Riverdale, 2001–2003

Tillage system	Times over field*	Yield 2001	Yield 2002	Yield 2003	Fuel use	Total operating costs*
		lbs. lint/acre			*gal./acre*	*$/acre*
Standard tillage	16	993c†	1,311a	1,156ns‡	19.5	237
No-tillage, cover crop chopped	8	1,183abc	1,258a	1,291ns	7.5	199
No-tillage, no chop	7	1,081bc	1,215a	1,258ns	7.5	195
Ridge tillage, cover crop chopped	8	1,292abc	709b	1,303ns	7.5	199
Ridge tillage, no chop	7	1,229abc	809b	1,156ns	7.5	195
Strip tillage, cover crop chopped	8	1,352a	1,278a	1,365ns	10.2	204
Strip tillage, no chop	7	1,262ab	1,223a	1,340ns	9.2	200

* Average of 3 years.
† Within the same column, different letters mark values significantly different at $P < 0.05$.
‡ Not significant ($P < 0.05$).

12-year UC tillage study

To determine the longer-term impacts of conservation tillage on productivity, profitability and soil properties, a study has been under way since 1999 at the UC

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Glyphosate-resistant Acala cotton was grown in a winter triticale, rye and pea cover crop with no tillage in Five Points, 2007.

West Side Research and Extension Center in Five Points. The study is comparing standard and conservation tillage systems for a cotton-tomato rotation, with and without a mixture of cover crops in a deep, relatively uniform clay loam soil. The cover crops are rainfed winter triticale (*Triticosecale* Wittm.), Merced ryegrain (*Secale cereale* L.) and common vetch (*Vicia sativa*). In the conservation tillage plots, cotton has been seeded directly each year into tomato beds that are not disturbed following harvest. All tractor and implement traffic is restricted to the furrows, and planting beds are not moved or tilled, except for shallow weed cultivations during each tomato season using a modified Sukup high-residue cultivator (Sheffield, IA). The number of tractor trips across the field was reduced by about 50% for tomato and 40% for cotton in the conservation tillage plots (table 3). Additional glyphosate herbicide sprays were required to kill the cover crops.

'Riata', a glyphosate-resistant (Roundup Ready) transgenic Acala cotton variety (Bayer Crop Science, Shafter, CA), was used until 2008 and 2009, when 'Phy 8212 RF', an experimental Roundup Ready Flex Pima variety (Phytogen/Dow, Corcoran, CA), was grown to evaluate these tillage systems for Pima cotton. The Acala variety 'Phy 725 RF' (Phytogen/Dow) was used in 2010 and 2011.

Yields. Yields of Acala cotton in the conservation tillage systems were generally lower than in the standard systems from 2001 through 2004 but similar to those in the standard systems from 2005 through 2007, 2010 and 2011 (fig. 2). Yields of the Pima variety were lower in 2008 and 2009 than Acala yields in other years. Pima has a relatively aggressive, indeterminate growth habit, which can be more difficult to manage for high yields unless the right combination of plant growth regulator and deficit irrigation management is used, and this seemed to affect the Pima yields.

Cost comparison. The number of tractor passes in the standard and conservation tillage plots without a cover crop was 16 and 9, respectively (table 3). This resulted in a fuel reduction of 12 gallons and 2 fewer labor hours per acre in the conservation tillage plots compared to the standard plots. The savings in fuel, labor and repairs amounted to approximately $70 per acre in 2011 dollars. The cover crop added four operations for the standard and conservation tillage treatments and resulted in an increase of about $50 per acre compared to plots with no cover crops. Consequently, the highest-cost system was standard tillage with a cover crop, followed by standard tillage without a cover crop. The two conservation tillage systems had the lowest costs. All systems were profitable in all years except the first year of the study, when yields were much lower due to a mite infestation from a neighboring field.

Early seeding. Yield increases in the conservation tillage plots after the first 4 years were due to more successful planting operations. In the 4th year, cotton seed was planted early into moist soil, which resulted in better early-season seedling vigor and higher plant populations and yields. Capping or pulling a shallow layer of dry soil directly over the seed line at planting — to preserve seed zone moisture during germination and early seedling growth — and then removing it when the seedlings are about to emerge, is standard practice in the western San Joaquin Valley. Because no soil cap is pulled over the seed line with conservation tillage, the timing of seeding is critical; seedlings need to rapidly develop a tap root that extends into deeper soil moisture before the surface soil dries out by evaporation, so seeding must take place when there is adequate soil moisture and good weather for seedling development and emergence.

TABLE 3. Comparison of standard and conservation tillage operations in cotton with and without a cover crop, Five Points, 2000–2011

	With cover crop		Without cover crop	
Tillage operation	Standard	Conservation	Standard	Conservation
Disk	■■*		■■	
Chisel	■		■	
Level (triplane)				
List beds	■		■■	
Spray herbicide (triflularin)	■		■	
Incorporate herbicide	■■		■■	
Spray herbicide (glyphosate)	■■	■■■■	■	■■■
Cultivate	■■		■	
Chain beds	■	■		
Plant cotton	■	■	■	■
Fertilize	■	■	■	■
Plant cover crop	■	■		
Mow cover crop	■	■		
Spray insecticides/growth regulators	■■	■■	■■	■■
Spray defoliant	■	■	■	■
Harvest	■	■	■	■
Times over field	20	13	16	9

* Each ■ indicates a separate operation.

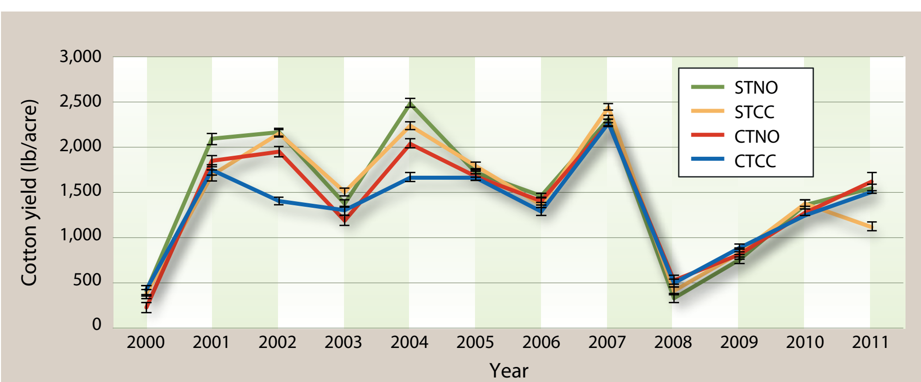

Fig. 2. Lint cotton yields in comparison study of conservation (CT) and standard (ST) tillage systems, with (CC) and without (NO) cover crops at UC West Side Research and Extension Center, 2000–2011.

TABLE 4. Tillage and cover crop system impacts on soil quality and diesel fuel use, Five Points, 2007–2008

Cropping system	Soil conditioning index (SCI) values	Soil tillage intensity rating (STIR)*	Diesel fuel use	Fuel cost for cotton-tomato rotation
			gal./acre	*$/acre*
Standard tillage, no cover crop	−0.71	261.0	32.0	128.6
Standard tillage, cover crop	−0.96	390.0	40.0	160.6
Conservation tillage, no cover crop	0.43	30.6	9.3	36.8
Conservation tillage, cover crop	0.52	37.1	11.0	43.3

Source: T. Gohlke (Portland, OR) and R. Bickel (Napa, CA), USDA NRCS.
* Average for tomato/cotton cycle or rotation.

As a result, seeding early into moist soil is a critical requirement of no-tillage cotton production in the San Joaquin Valley.

Soil improvements

The long-term nature of this UC tillage comparison is unique in California, and it has provided opportunities to evaluate the impacts of tillage and cover cropping on soil attributes and fuel use (table 4). The Soil Conditioning Index (SCI) has been proposed by researchers with the USDA NRCS (2003) as a predictor of the consequences of management on soil organic carbon or more specifically on particulate organic matter, which is a labile precursor of more stable forms of soil carbon. NRCS uses the SCI as one criterion for determining eligibility for Farm Bill conservation programs such as EQIP. In our study, the computed SCI values were negative for the two standard systems and positive for conservation tillage (table 4). Positive SCI values generally indicate that soil carbon — which is considered a keystone element or component of soil quality because of its role in increasing water- and nutrient-holding capacities — is increasing, while negative values suggest degrading trends (USDA NRCS 2003; Zobeck et al. 2007). Zobeck et al. (2007) suggested using a buffer of plus or minus 0.2 to 0.3 when reporting SCI values to account for variation associated with SCI estimates. The differences in SCI between standard and conservation tillage systems in our work were greater than these buffered SCI values, indicating significant differences in soil resource quality, a key determinant of crop productivity.

The Soil Tillage Intensity Rating (STIR) assesses the impact of tillage operations on soil quality and residue retention, which is important in reducing soil erosion and water evaporation (USDA NRCS 2003). It is calculated from the operational speed of tillage equipment, the particular type of tillage used, the depth of tillage and the percentage of soil surface area disturbed. It also is used as a scoring index for participation in Farm Bill conservation programs and cost-share eligibility.

No-tillage by definition requires a STIR value of 30 or less. Values in the USDA's national database typically range from 0 to 200, with a low score preferred. We believe that the STIR values in table 4 are the first published numbers for cotton tillage systems in the San Joaquin Valley using this assessment tool. Values are high for the standard systems, particularly those with a cover crop. These systems presumably would not qualify for cost-share support under conservation programs aimed at residue retention or soil quality preservation.

The UC studies have consistently shown that conservation tillage can yield as well as standard tillage in a cotton-tomato rotation.

Ultra-narrow row tillage

Ultra-narrow drill seeding of cotton into 60-inch tomato beds was evaluated through three cycles of a tomato-cotton rotation as part of the long-term study of conservation tillage at UC West Side Research and Extension Center. A 15-foot John Deere 1560 no-tillage drill with 7.5-inch between-row spacing was used to establish the ultra-narrow row system. Very high plant populations, exceeding 80,000 per acre (compared with the 48,000 to 60,000 typical of commercial cotton fields) have been achieved with this method. Compared to standard tillage, no-tillage, strip tillage and twin-row no-tillage plots in the same study, ultra-narrow rows resulted in cheaper crop establishment. In addition, raw yields were comparable to the highest-yielding system in each year. However, its gin turnout percentages were generally lower than other systems, and final yields were lower (table 5). It also required stripper-head harvesters, which are currently not widely available in the San Joaquin Valley.

As in the 12-year study, the yields with conservation tillage improved with time. By year 2 of the study, the yields of the no-tillage and strip tillage plots did not differ significantly from those of standard tillage; and in year 3 there were no significant differences between yields in any of the systems.

Yields versus profits

The UC studies have consistently shown that conservation tillage can yield as well as standard tillage in a cotton-tomato rotation. This finding agrees with a broad comparison of cotton tillage systems across seven states at 12 Monsanto Centers of Excellence sites from 1998 through 2002 (Buman et al. 2005). In the Monsanto work, differences in lint yield

TABLE 5. Cotton lint yields in three-rotation cotton-tomato tillage study, with cotton seeded after tomato harvest, Five Points, 2003–2007

Tillage system	2003	2005	2007
		lbs./acre	
Standard tillage	1,638a*	1,475a	1,885ns†
No-tillage	1,538b	1,464a	1,929ns
Strip tillage	1,348c	1,450a	1,887ns
Twin row, no-tillage	1,696a	1,371b	1,893ns
Ultra-narrow row, no-tillage	1,540b	1,280b	1,821ns

* Within the same column, different letters mark values significantly different at $P < 0.05$.
† Not significant ($P < 0.05$).

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A John Deere 1560 15-foot no-tillage drill is used to seed cotton in ultra-narrow rows at 7.5-inch spacing in Five Points, 2007.

between no-tillage, strip tillage, reduced tillage and conventional tillage systems were not significant. The 5-year average profit for the no-tillage system ranged from $7 to $66 per acre higher than for the other three systems. This work concluded that farmers and crop consultants should consider overall profit rather than just crop yield when evaluating alternative tillage practices.

Pink bollworm and tillage

Effective control of pink bollworm (*Pectinophora gossypiella*), a pest that damages cotton bolls and has cost the U.S. cotton industry billions of dollars, has been a long-standing priority of San Joaquin Valley cotton producers. The California pink bollworm control and eradication program (CDFA 2012) has been highly successful, but it requires intensive tillage, including the postharvest shredding of cotton stalks, some form of root undercutting or dislodging, and the mixing of residues with surface soil to guarantee that no living cotton plants remain in a field during the host-free period (mid- to late December through March 10). This sequence of tillage operations typically results in clean, residue-free fields following cotton harvest.

We are evaluating a variety of postharvest management options that can effectively manage pink bollworm and reduce soil disturbance in Five Points, in conjunction with the CDFA control and eradication program. Various root-puller or root-cutting implements may comply with mandated regulations and reduce overall tillage. One such implement is a root cutter designed by J. Diener, a Five Points farmer. It has rotating horizontal disk blades that are shallowly pulled through the soil, shearing off and dislodging cotton roots and stalks with less overall soil disturbance than typical conventional stubble-disking. A root puller made by Arizona Drip Systems (Coolidge, AZ) has angled disk blades that uproot and dislodge roots as it is drawn through the field. During the 8-acre, 12-year comparison study, no pink bollworm finds were recorded in traps monitored by the CDFA program.

Other crop rotations

Preceding or following cotton with crops such as wheat or triticale may work well in conservation tillage systems, provided that care is given to seeding operations to ensure adequate stands (table 6). In research studies, uniform stands of winter cover crops have been successfully grown by seeding directly into cotton that has only been shredded and root pulled (Mitchell, Klonsky et al. 2009). Other reasonable candidates in cotton-containing rotations using conservation tillage are transplanted crops, such as tomatoes and broccoli, and large-seeded crops, such as melons, that leave relatively little or easily decomposable residue. Tomatoes have proved successful (Mitchell, Klonsky et al. 2009), with good transplant survival and yields when irrigation is available to set the transplants after planting.

We are investigating other crops. Certain crops are more challenging in conservation tillage rotations, including very-small-seeded crops, such as onions; crops requiring specialized establishment equipment, such as garlic; and root and tuber crops that involve considerable harvest equipment and much soil disturbance, such as carrots and potatoes. Silage corn, which leaves relatively few soil residues, might be a suitable candidate for crop rotation with cotton. In any sustained conservation tillage production system, detailed planning is needed regarding equipment use and soil moisture conditions to avoid causing soil compaction.

Challenges and opportunities

The data that we have collected, as well as our recent experience with conservation tillage cotton in the San Joaquin Valley, and the far wider experience of researchers from the U.S. Cotton Belt (Bradley 1995), have been encouraging enough to warrant further evaluation and

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A stripper harvester is used to pick cotton in ultra-narrow rows in Five Points, 2007.

TABLE 6. Relative ease of sustaining conservation tillage system for cotton in rotation with various crops

Rotation crop	Ease of use, preceding and following cotton*
Tomato†	High
Wheat	High
Melons	High
Triticale	High
Corn	Medium
Safflower	High
Onions	Low
Garlic	Low
Broccoli†	High

* Includes amount of postharvest residue, manner of harvest, seed size and ease of seeding after cotton harvest.

† Transplanted rather than seeded.

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Standard postharvest cotton tillage includes shredding aboveground cotton plants and disking the residues as carried out in Firebaugh, 2007.

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With conservation tillage a crop is seeded directly into wheat stubble, shown in Five Points, 2009.

refinement of conservation tillage systems in California. A wide range of innovative equipment has been introduced to the region, which has functioned successfully under various conditions. Whether conservation tillage has a larger future depends on two critical factors: the need to achieve vigorous crop stands and the need to avoid soil compaction.

Inadequate plant populations and low seedling vigor have been the greatest problems associated with reduced yields in conservation tillage cotton in California to date. With no cap of dry soil pulled over the seed line at planting to preserve moisture in the seed zone, the risk of uneven emergence and weakened seedlings is great unless care is taken to avoid these problems. Further innovation in equipment modification could improve the soil cover of seeded crops. Currently, a relatively narrow range of soil moisture, temperature, aeration and impedance conditions must all be present for successful crop stands. The challenge is greater in flat fields than in fields with prepared beds because there is less opportunity to push away surface soil during the planting operation in order to reach stored soil moisture without creating ruts or gullies along the seed line.

To date, no rigorous determinations of subsurface compaction arising from tractor and implement traffic have been conducted in the San Joaquin Valley. The bulk of the work reported here has been of short duration, has used minimum tillage equipment that successfully alleviates compaction, or has relied on dedicated traffic and crop growth zones, which minimize compaction risks. To be sustainable over the long term, conservation tillage will likely need to use a combination of deliberate techniques to avoid compaction with zone or vertical tillage (Carter 1996). Because California cotton is grown in a broad range of soil types, more research is needed on the relationship between soil compaction and type, moisture content, load weight and repetition of tillage operations.

Provided that yield performance or more importantly bottom-line profitability is maintained and the risks associated with adopting a new tillage system are deemed reasonable, conservation tillage systems may become increasingly attractive to producers and more common in San Joaquin Valley cotton-growing areas.

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References

Abernathy GH, Cannon MD, Carter LM, Chancellor WJ. 1975. Tillage Systems for Cotton — A Comparison in the U.S. Western Region. California Agricultural Experiment Station Bulletin 870.

Baker JB, Southard RJ, Mitchell JP. 2005. Agricultural dust production and composition in standard and conservation tillage systems in the San Joaquin Valley. J Envir Qual 34:1260–9.

Bradley JF. 1995. Success with no-till cotton. In: Conservation Tillage Systems for Cotton: A Review of Research and Demonstration Results from across the Cotton Belt. Arkansas Agricultural Experiment Station Special Report 169. Jackson, MS. p 31–5.

Buman RA, Alessi BA, Bradley JF, et al. 2005. Profit and yield of tillage in cotton production systems. J Soil Water Conserv 60(5):235–42.

Carter LM. 1985. Wheel traffic is costly. T ASAE 28(2):430–4.

Carter LM. 1991. Zone production system for cotton: Soil response. T ASAE 34(2):354–60.

Carter LM. 1996. Tillage. In: *Cotton Production Manual*. UC ANR Pub 3352. Oakland, CA. p 175–86.

Carter LM, Rechel EA, Meek BD. 1987. Zone production system concept. In: Orzolek MD (ed.). *Controlled Traffic Cropping Systems for Management of Soil Compaction*. Acta Horticulturae 210. p 25–34.

Carter LM, Stockton JR. 1963. Minimum tillage possibilities. In: Proc Western Cotton Production Conference, Phoenix, AZ, March 16, 1963. Mesquite, TX: Cotton Gin Oil Mill Pr. p 34.

Carter LM, Stockton JR, Tavernetti JR, Colwick RF. 1965. Precision tillage for cotton production. T ASAE 8(2):177–9.

[CCTCSW] California's Conservation Tillage and Cropping Systems Workgroup. 2011. 2010 Tillage Survey. http://groups.ucanr.org/ucct.

[CDFA] California Department of Food and Agriculture. 2012. Pink Bollworm: Program Details. Sacramento, CA. www.cdfa.ca.gov/phpps/ipc/pinkbollworm/pbw_hp.htm.

Hutmacher RB, Vargas RN, Weir BL, et al. 2003. Sample Costs to Produce Cotton. UC Cooperative Extension. Davis, CA. http://coststudies/ucdavis.edu.

Madden NM, Southard RJ, Mitchell JP. 2008. Conservation tillage reduced PM_{10} emissions in dairy forage rotations. Atmos Environ 42:3795–808.

Mitchell JP, Klonsky KM, Miyao EM, Hembree KJ. 2009. Conservation Tillage Tomato Production in California's San Joaquin Valley. UC ANR Pub 8330. Oakland, CA.

Mitchell JP, Klonsky K, Shrestha A, et al. 2007. Adoption of conservation tillage in California: Current status and future perspectives. Aust J Exp Agr 47(12):1383–8.

Mitchell JP, Munk DS, Prys B, et al. 2006. Conservation tillage cotton production systems compared in the San Joaquin Valley. Cal Ag 60(3):140–5.

Mitchell JP, Pettygrove G, Upadhyaya S, et al. 2009. Classification of Conservation Tillage Practices in California Irrigated Row Crop Systems. ANR Pub 8364. Oakland, CA.

Stockton JR, Carter LM, Bassett DM, Yamada H. 1962. Precision tillage for cotton production. Cal Ag 16(1):10–1.

Upadhyaya SK, Lancas KP, Santos-Filho AG, Raghuwanshi NS. 2001. One-pass tillage equipment outstrips conventional tillage method. Cal Ag 55(5):44–7.

[USDA NRCS] US Department of Agriculture Natural Resources Conservation Service. 2003. Interpreting the Soil Conditioning Index: A Tool for Measuring Soil Organic Matter Trends. Tech Note No. 16. Soil Quality Institute. Auburn, AL. 6 p.

Zobeck TM, Crownover J, Dollar M, et al. 2007. Investigation of soil conditioning index values for southern High Plains agroecosystems. J Soil Water Conserv 62(6):433–42.

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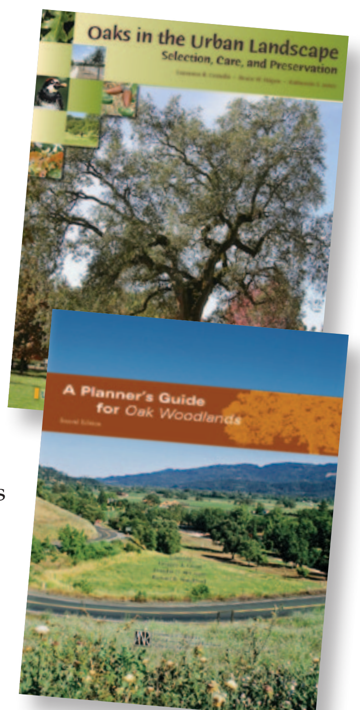

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Implications of eliminating the Williamson Act

Budget cuts have resulted in dramatic reductions of funding for the Williamson Act, California's land protection program that reduces property taxes for the owners of 15 million acres of farms and rangeland. In the next issue of *California Agriculture* journal, researchers report the results of a study in which ranchers were asked their plans under a hypothetical scenario including the elimination of all Williamson Act contracts. More than 70% of the rangeland parcels enrolled in Williamson Act contracts contained habitat important for statewide conservation goals, and survey respondents reported that they would sell 20% of their total 496,889 acres under the proposed scenario. A majority (76%) of the ranchers who reported that they would sell land predicted the buyers would develop it for nonagricultural uses, suggesting substantial changes to California's landscape in a future without the Williamson Act.