JULY–SEPTEMBER 2008 • VOLUME 62 NUMBER 3

California Agriculture

New specialty crop:

Building a better blueberry

Also:

Native plants for gardeners

Healthy walnut orchards

Glyphosate-resistant weeds

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

Focus on the future: Staying relevant in a changing California

Daniel M. Dooley
Vice President,
UC Agriculture and
Natural Resources

Editor's note: A distinguished water attorney and fifth-generation family farmer, Dan Dooley took the helm of UC's statewide agricultural and natural resources programs in January. Dooley was raised in the San Joaquin Valley and attended UC Davis and the McGeorge School of Law.

California and its population are changing rapidly, and our research institutions must reposition themselves to address these changes. The University of California's Agriculture and Natural Resources (ANR) division can and should be a catalyst for critical thinking about how science can shape a more prosperous future for our state and our people.

On my travels across California in the past few months, I have been reminded of what UC research and education means for our state. For over a century, our scientists and Cooperative Extension educators have made discoveries, field-tested new technologies and research breakthroughs, and delivered this information to local communities.

In doing so, we have helped Californians produce nutritious and abundant food supplies; sustain rich and diverse landscapes; conserve plants, animals and ecosystems; and enrich their daily lives. Combined with the cultural diversity and innovative spirit of our people, these UC contributions help make California a spectacular place to live.

However, to maintain this synergy between science and the California spirit, we must prepare for the future as diligently as we have fostered progress in the past. As the world's premier public, multidisciplinary research institution, UC is uniquely positioned to predict and analyze significant changes affecting Californians, be a leader in forecasting their consequences and help develop creative solutions.

For example, demographic shifts resulting from an increasingly urban population will make for a very different California. Competition for natural resources — water, land, air — will become even more intense as our state adds tens of millions of residents. Our farmers and ranchers will face new challenges that will test their ability to produce the abundant, high-quality, nutritious food that Californians have come to rely on, even take for granted. Our natural resources, especially forests, watersheds and wildlife, will also face greater pressures from a rapidly changing California.

However, I firmly believe that UC will be at the forefront in shaping the future if California invests in maintaining the university's world-class research, public service and teaching programs. Our scientists and students, given adequate support, will make new discoveries and scientific breakthroughs that contribute solutions to four of the most pressing challenges facing the state — the long-term viability and economic sustainability of farm and food systems, future energy supplies, the availability of water and climate change.

Agriculture continues to be a major economic engine for the state and an important source of employment for a growing population. Since 1948, California has led the nation in agricultural production. We are the top producer of more than 40 agricultural commodities and have increased our share of U.S. farm cash receipts from 9.5% in 1960 to 13% in 2006. California agriculture is expected to top $37 billion in cash receipts and support nearly 700,000 jobs in 2008.

In the future, though, agriculture will be disproportionately affected by the state's population growth. Today's 38 million Californians are expected to number 60 million by 2050. Projections indicate that 11 of the 15 fastest-growing counties are also major agricultural counties and the conversion of prime agricultural land is accelerating. A challenge will be to maintain our national lead in the production of high-quality, high-demand specialty crops on a shrinking land base

Urban Californians also are likely to find themselves competing for water and energy with agriculture, fish and wildlife, unless we develop new sources, increase conservation and make more efficient use of these critical resources. The growing threat of global climate change is placing additional demands on California's water and energy infrastructure. How to provide enough water and energy to ensure that the needs of agriculture and urban populations are met, while maintaining viable natural ecosystems, will be a real challenge.

Finally, California is becoming more diverse, with Hispanics expected to be in the majority by 2042. UC will need to be responsive and sensitive to the needs of new residents from many backgrounds and ethnicities if we are to be relevant. ANR is already exploring better ways to deliver information on nutrition, food safety, food production and processing, and healthy lifestyles to a significantly changing population. We know we will need to employ new technologies to communicate more effectively, but which methods are optimal?

To answer these and other challenges, our division is beginning a long-term planning process in consultation with our campus partners. Our goal is to enable UC to continue to provide the scientific and technological breakthroughs that California needs to compete in a global economy; ensure a safe, nutritious food supply; conserve natural resources; and keep Californians healthy.

Led by a steering committee of stakeholders, campus leaders and members of the UC Board of Regents, we will set priorities, identify gaps in the resources, and develop a roadmap to maintain and enhance the preeminence of UC in agriculture and natural resource science and innovation.

This effort will be supported by a series of working groups that will include partners from across the UC system and the communities we serve. We are reaching out because I believe that UC must be defined by future opportunities — not rest on past accomplishments — if we are to make a real difference in the prosperity and health of future generations.

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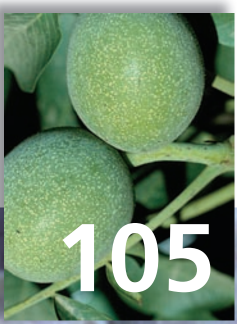
Cover: New varieties that require fewer chilling hours have made it possible to grow blueberries in California. More than 4,500 acres of this valuable specialty crop are currently in production (see pages 90 and 91). *Photo: Vanessa Bremer*

Research articles

News departments



About California Agriculture

California Agriculture is a quarterly, peer-reviewed journal reporting research, reviews and news. It is published by the Division of Agriculture and Natural Resources (ANR) of the University of California. The first issue appeared in December 1946, making it one of the oldest, continuously published, land-grant university research journals in the country. The circulation is currently about 15,000 domestic and 1,800 international.

Mission and audience. *California Agriculture*'s mission is to publish scientifically sound research in a form that is accessible to a well-educated audience. In the last readership survey, 33% worked in agriculture, 31% were faculty members at universities or research scientists, and 19% worked in government agencies or were elected office holders.

Current indexing. *California Agriculture* is indexed by Thomson ISI's Current Contents (Agriculture, Biology and Environmental Sciences) and SCIE, the Commonwealth Agricultural Bureau databases, Proquest, AGRICOLA and Google Scholar. In addition, all peer-reviewed articles are posted at the California Digital Library's eScholarship Repository.

Authors. Authors are primarily but not exclusively from UC's ANR; in 2005 and 2006, 14% and 34% (respectively) were based at other UC campuses, or other universities and research institutions.

Reviewers. In 2005 and 2006, 13% and 21% (respectively) of reviewers came from universities and research institutions or agencies outside ANR.

Rejection rate. Our rejection rate is currently 26%. In addition, in two recent years the Associate Editors sent back 11% and 26% for complete resubmission 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 a third reviewer. The Associate Editor makes the final decision, in consultation with the Managing and Executive Editors.

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Letters

Living with light brown apple moth

As a retired entomologist who worked for California health departments for many years, I read "Light brown apple moth's arrival in California worries commodity groups" (April-June 2008) with great interest.

If the data provided is accurate, then two reasonable conclusions can be reached. First, despite the 2005 California Department of Food and Agriculture (CDFA) survey failing to find *Epiphyas postvittana*, it has probably been present in California for a very long time. Second, using currently available technology the moth cannot be eradicated. Given the extremely high level of commerce between Hawaii and California, it is likely that the moth has been introduced regularly.

The failure to detect its presence is due largely to difficulties with identification. Another factor in failure to detect must surely be suggested. The light brown apple moth cannot have been causing a great deal of loss. The onset of damage that is not attributable to a known cause is the most common way that pests are discovered. Dangerous pests are not routinely discovered serendipitously by one of the few people in the world who can identify them.

The article by Garvey states that the U.S. Department of Agriculture has earmarked about $74.5 million for California to combat light brown apple moth in 2008. Those funds could be better spent on long-term research, or to directly help in situations with confirmed infestations.

Randall Blair
Retired Entomologist
Paso Robles

Thanks for the balanced overview of the light brown apple moth in *California Agriculture* (April-June 2008). There is too much hysteria and misinformation about the "insect of mass destruction" and how it can reasonably be managed with minimal risk to humans and their environment.

I am a librarian at UC Berkeley's Public Health Library and have been researching the light brown apple moth and CheckMate nonstop for weeks in response to patron requests. It has been difficult to get both sides of the story.

For instance, there is limited information about CheckMate, the Suterra product that was used in the aerial spraying programs in Monterey and Santa Cruz, because the manufacturer is protecting the formulation as proprietary information. There was no analysis of possible health effects, no environmental impact report, no risk communication efforts to inform the public, no reporting system so that citizens could report health complaints. We do know the active and inert ingredients. Its efficacy is unproven. The usual pesticide registration process has been bypassed at the federal level because the light brown apple moth threat is considered an "emergency."

Although CDFA is trying to "eradicate" this pest, some scientists believe it is already established. Should that be the case, there are known, effective integrated pest management practices, both in New Zealand, where it is an invasive species, and in Australia, where it is a native pest.

For now, Santa Cruz County Superior Court Judge Paul Burdick has halted spraying in that county until an environmental impact report has been completed. The larger issue is that as long as we insist on having fresh produce regardless of the season we will probably keep introducing new pests into our country.

Charleen Kubota
Librarian, Public Health Library
UC Berkeley

Editor's note: Shortly before press time, state and federal officials halted plans to aerially apply pheromones in urban areas, previously a part of the eradication effort against the light brown apple moth. They will use a combination of other tactics instead.

Food safety and postharvest technology

"Growers removing conservation practices to protect food safety on California's Central Coast" (April-June 2008) presented important findings on a subject at the forefront of growers' minds: how to develop on-farm food safety practices in harmony with environmental stewardship.

This is a complex issue, and its resolution will require collaboration of the scientific, industrial and regulatory communities. The good news is that UC's multidisciplinary faculty, such as those found within ANR-supported centers like the Postharvest Technology Research & Information Center, can provide exactly what is needed to address such thorny issues. UC must pursue research that can help California growers assure the safety of fruits and vegetables in a sustainable manner — adopting practices that all stakeholders can support.

For information on how to assure the safety of fruits and vegetables in a sustainable manner, and for a listing of upcoming workshops, go to http://postharvest.ucdavis.edu.

James R. Gorny, Executive Director
Postharvest Technology Research
& Information Center, UC Davis

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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 6701 San Pablo Ave., 2nd floor, Oakland, CA 94608 or calag@ucop.edu. Include your full name, phone number and address. Letters may be edited for space and clarity.

Glyphosate resistance is increasing in California

Because of its broad-spectrum, economical weed-control ability, glyphosate (the active ingredient in RoundUp, Touchdown, Buccaneer, Durango and other product names) has become a popular weed management tool for agricultural crops and in nonagricultural settings such as parks, schoolyards, and public and natural areas. However, in recent years at least 14 glyphosate-resistant weed species have been reported, threatening the loss of this effective herbicide. As a result, the Weed Science Society of America (WSSA) issued the following warning May 19:

"[Glyphosate's] widespread, repeated and often sole use for weed management has selected weeds that have become glyphosate-resistant and are thus not controlled by this herbicide. WSSA . . . cautions against following a single approach to weed management, which can result in resistant weeds."

Anil Shrestha, IPM weed ecologist at the UC Kearney Agricultural Center, says that although crops genetically engineered to resist glyphosate (called "RoundUp Ready") have been the primary resistance concern in the United States and some other countries, as of now no confirmed cases of glyphosate-resistant weeds have been reported in Roundup Ready crops grown in California (primarily cotton and corn).

However, glyphosate-resistant weeds have been reported in California orchards, vineyards and noncrop areas, Shrestha says. These include rigid ryegrass (*Lolium rigidum*), horseweed (*Conyza canadensis*) and hairy fleabane (*Conyza bonariensis*) (see page 116).

Furthermore, poor control of several other weed species with glyphosate is occasionally reported to UC personnel, Shrestha says. "Because of its ease in use, environmental safety and effective control of weeds, it is important to maintain the viability of glyphosate in California." Experts recommend using a variety of weed control tactics, including combining glyphosate with other postemergent herbicides.

More information:

"Herbicide resistance: definition and management strategies" (ANR Pub 8012)
http://anrcatalog.ucdavis.edu/pdf/8012.pdf

Weed Science Society of America
http://www.wssa.net

Study finds more fresh, local foods on hospital trays

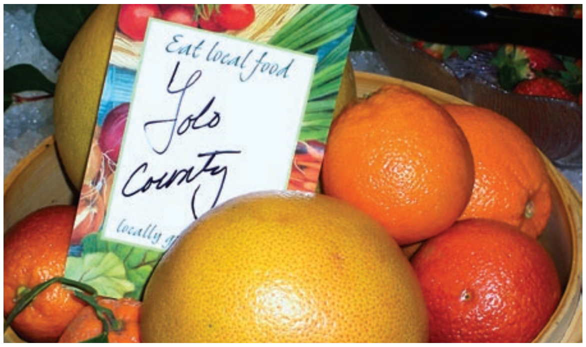
UC researchers recently studied farm-to-hospital initiatives in the Bay Area and found a growing movement to put locally produced food on patient trays and cafeteria menus. They say that buying from local farmers and ranchers is part of a trend toward better quality and flavor in hospital meals, both to satisfy consumer demand and address concerns about dietary contributions to chronic disease.

"Just replacing food-service cans with locally grown vegetables won't curb high rates of obesity and heart disease, but it may encourage patients and café customers to increase their daily intake of vegetables," says study co-author Gail Feenstra. "And if there's one piece of firm advice from nutritionists, it's to eat more fruits and vegetables."

The report, "Emerging Local Food Purchasing Initiatives in Northern California Hospitals," is available online at http://sarep.ucdavis.edu/cdpp/fti.

Feenstra is food systems analyst for the UC Davis Agricultural Sustainability Institute (ASI) and the statewide Sustainable Agriculture Research and Education Program (SAREP). Her co-author is graduate student Elizabeth Sachs.

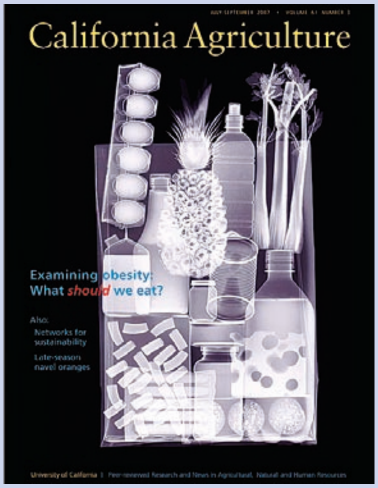
Hospitals have the buying power to make a big difference in local food networks, Feenstra said. "They buy more than $12 billion of food every year."



Elizabeth Sachs/UC SAREP

Cal Ag staff wins Silver ACE

California Agriculture's July-September 2007 issue, "Examining obesity: What *should* we eat?" has received a Silver award from the Association for Communication Excellence in Agriculture, Natural Resources, and Life and Human Sciences (ACE), in the Technical Publications category. The award recipients are Managing Editor Janet Byron, Art Director Davis Krauter and Executive Editor Janet White.



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The issue included four peer-reviewed research articles on obesity and outreach, as well as related news coverage and an editorial. *California Agriculture* gratefully acknowledges UC Berkeley nutrition specialist Patricia B. Crawford, who was faculty chair of the issue, and all the researchers who contributed. To see the award-winning issue, go http://californiaagriculture.ucop.edu/0703JAS/toc.html.

Large nesting birds threaten arboretum trees

With thousands of nesting egrets and herons threatening the health of trees in the UC Davis Arboretum's Shields Oak Grove, wild-bird experts are testing unusual but humane means to discourage the birds.

The Shields Oak Grove has been in existence since 1963 but big, colonial wading birds did not begin nesting there until 2000. The rookery quickly grew to one of the largest nesting colonies in Yolo County. Last year, more than 2,400 egrets and herons nested or roosted there, producing more than 850 chicks.

During nesting season, the grove is permeated with the smell of excrement, or guano, of four bird species: cattle egrets, black-crowned night herons, great egrets and snowy egrets. The guano of thousands of those birds coats the oak trees' branches, twigs and leaves like white paint. The ammonia in the guano is enough to kill some leaves outright. Others die because they are deprived of the sunlight needed for photosynthesis.

Furthermore, rainfall and irrigation leach guano salts into the soil, where they are taken up by the roots and carried through the tree's circulatory system to all the leaves.

As the number of birds grows, so does the number of trees being affected, says Ellen Zagory, director of horticulture for the UC Davis Arboretum.

"Ammonia is toxic and causes defoliation. Guano is opaque, so it blocks photosynthesis and causes defoliation. Salts stunt the growth of roots and shoots, and cause margin burn on the leaves and defoliation," Zagory says. "Complete defoliation of a branch over several years means that branch dies." Ultimately, dead branches can lead to weak and dying trees.

Balancing trees and birds

In hopes of finding a sustainable balance for both trees and birds, the arboretum's oak and wildlife management team began field-testing two nesting deterrents in early March. First, arboretum staff removed all remnants of last year's nests from a group of 15 oak trees. Mana Hattori, a researcher at the UC Davis Museum of Wildlife and Fish Biology, will compare subsequent nesting activity in those 15 trees with activity in 15 similar control trees that were left alone.

Beginning next week, in a different part of the grove, Hattori will test another method that has been successful with nuisance colonies elsewhere in the United States: She will shine a laser light at cattle egrets when they land in the trees.

Andy Engilis, museum curator and a wild-bird expert on the team, says the light is not harmful to the egrets: "It basically spooks them and they fly off." The laser will be aimed at only cattle egrets that have not begun nesting. It will not be used on the other species of birds, which already have eggs and chicks.

"If this works, it gives us a method we can use in the future," Engilis says. "We are trying to protect a bird resource that has state value and a grove of trees that is very important, and we're trying to find an equilibrium that will work with both groups."

Large wading birds, including the great egret, began nesting in the Shields Oak Grove at UC Davis in 2000. The rookery now contains thousands of birds, which threaten hundreds of mature oaks in the grove.

Valuable resources

The Shields Oak Grove contains the largest collection of mature oaks in the southwestern United States — 304 trees representing 87 types of oak species, varieties and hybrids, some of which are rare and endangered. It is a partner in the national oak collection of the North American Plant Collections Consortium.

Herons and egrets are similarly valued resources. In 2006 and 2007, the team's gentle nesting disincentives included the structural pruning of trees; removing some redundant and crowding trees; removing the remnants of the previous years' nests; and tying shiny Mylar streamers and balloons to the treetops. The number of nests built by three of the four species — the black-crowned night herons, great egrets and snowy egrets — leveled out at about 320.

But the fourth species, the cattle egret, increased its nests from 21 in 2005 to 495 in 2007. Not native Californians, cattle egrets originated in Africa, traveled to South America and became established in the 1930s, then rapidly spread north, reaching Northern California by the mid-1990s.

"In other parts of California, such as the Salton Sea, cattle egrets have swamped out other nesting species," Engelis says. "They nest in very dense colonies. When they find a good area, they will come in big numbers, even to the detriment of other species." — *Sylvia Wright*

Safe alternatives to replace invasives in California gardens

An innovative partnership called "PlantRight" is working to limit the sale of garden plants that can invade natural areas, and instead offer alternatives that are not risky to native ecosystems.

"Nonnative species can cause enormous havoc on the environment," California Secretary of Agriculture A.G. Kawamura said during the kick-off for PlantRight's public outreach campaign at the UC Davis Arboretum on April 1. "And invasives are our number one threat to food and agriculture in California."

The current outreach campaign is focused on 19 invasive horticultural plants in the Central Valley that the partnership identified as substantial risks to natural areas. (See www.PlantRight.org for maps covering all of California.)

"We partnered with University of California scientists to answer key questions about invasive plant species," says PlantRight project manager Terri Kempton of Sustainable Conservation, a nonprofit that collaborates with industry to find solutions to environmental problems. "We based all of our decisions on sound science, which provided neutral ground that we could agree on."

In 2004, Sustainable Conservation formed a partnership — called California Horticultural Invasives Prevention (Cal-HIP) — with nurseries, retailers, landscape professionals, researchers, gardeners and government agencies. These included UC Master Gardeners, The Nature Conservancy, the California Invasive Plant Council, the American Nursery and Landscaping Association and others.

Invasive horticultural plants and recommended alternatives for the Central Valley, *Sunset* Zones 7–9

Invasive plant	Recommended alternative
Arundo/giant reed (*Arundo donax*)	Clumping bamboos (e.g., *Bambusa multiplex* 'Golden Goddess,' *B. oldhamii*) New Zealand flax (*Phormium tenax*)
Blue gum eucalyptus (*Eucalyptus globules*)	Bald cypress (*Taxodium distichum*) Fernleaf Catalina ironwood (*Lyonothamnus floribundus asplenifolius*) Noninvasive eucalyptus (*Eucalyptus* spp.)
Brooms (*Cytisus scoparius, C. striatus, Genista monspessulana, Retama monosperma, Spartium junceum*)	Forsythia (*Forsythia* x *intermedia*) Shrubby cinquefoil (*Potentilla fruticosa*) Yellow bush daisy (*Euryops pectinatus*)
Chinese tallow tree (*Sapium sebiferum*)	Chinese pistache (*Pistacia chinensis*) American sweet gum/liquidambar (*Liquidambar styraciflua*) Red maple (*Acer rubrum* 'October Glory')
Pampas grass; unnamed cultivars (*Cortaderia jubata* and *C. selloana*)	Deer grass (*Muhlenbergia rigens*) Giant rye (*Leymus condensatus* 'Canyon Prince') Pink muhly grass (*Muhlenbergia capillaris*)
Periwinkle (*Vinca major*)	Hardy geranium (*Geranium* 'Rozanne') Serbian bellflower (*Campanula poscharskyana*) Star jasmine (*Trachelospermum asiaticum*) Sweet box groundcover (*Sarcococca hookerana humilis*)
Russian olive (*Elaeagnus angustifolia*)	Arizona cypress (*Cupressus arizonica*) Desert willow/desert catalpa (*Chilopsis linearis*) Fruitless olive (*Olea europaea* 'Swan Hill', 'Majestic Beauty')
Saltcedar (*Tamarix ramosissima*)	Australian willow/geijera (*Geijera parviflora*) Desert willow/desert catalpa (*Chilopsis linearis*) Western redbud (*Cercis occidentalis*)
Scarlet wisteria (*Sesbania punicea*)	Brazilian flame bush (*Calliandra tweedii*) Crape myrtle (*Lagerstroemia* spp.)

Source: www.PlantRight.org

The problem with invasive plants

With about $3.79 billion in annual production sales in 2006, the nursery industry recently bypassed grapes to become the state's number two agricultural product (after dairy). The goal of Sustainable Conservation's collaborative effort was to reach agreement on invasive plants that shouldn't be sold in certain regions of California — potentially affecting the nursery industry's bottom line.

"We really had to engage the horticultural industry," says Joseph DiTomaso, UC Cooperative Extension weed specialist. "In the past there had been a lot of reluctance to work together."

According to Sustainable Conservation, more than half of California's invasive varieties arrived via gardens and landscaping.

A well-known, almost iconic example is ice plant, which proliferates along the California coast. Ice plant species were imported from the Mediterranean as ornamentals and were planted for erosion control. They now grow wild on vast expanses of ocean frontage, choking out native vegetation and increasing the salt content of the soil. California devotes millions of dollars and thousands of volunteer hours every year to control ice plant.

Ellen Zagory/UC Davis Arboretum

The PlantRight program emphasizes that garden plants need not endanger rare ecosystems to be beautiful and gardenworthy. *Above*, the UC Davis Arboretum's Storer Garden.

Holly Crosson/UC Davis Arboretum

▲ **Superintendent Warren Roberts (far left) led a tour in April of the Storer Garden for California Secretary of Agriculture A.G. Kawamura (fifth from left) and other friends of the PlantRight program.**

”Invasive plants reproduce at high rates and dramatically alter ecosystems by crowding out native species of plants and animals,” Kempton says. “This is an area where individual choices really affect wildlands.” Invasive plants may also promote flooding and increase fire risks.

For example, brooms are hardy, shrublike species that form dense stands on hillsides, virtually eliminating native habitats and producing up to 12,000 seeds per plant. Instead of invasive brooms, Cal-HIP recommends planting forsythia and four other yellow-blooming plants in the Central Valley. In the place of giant reed, which grows thickly along waterways and ruins bird habitat, Cal-HIP recommends clumping bamboos or New Zealand flax. For scarlet wisteria, a riparian-loving plant that is poisonous to birds, reptiles and mammals, gardeners can plant crape myrtle, island bush snapdragon and several others (see table).

“Fortunately, there are plenty of beautiful, safe alternatives to invasives, so it’s easy for gardeners to find plants that meet all their specific needs,” Kempton says.

Developing scientific criteria

DiTomaso notes that of some 60,000 plants in the United States, only several dozen invasive species cause ecological problems in California.

UC scientists helped Cal-HIP develop scientific criteria for defining invasiveness. Carl Bell of UC Cooperative Extension served on the Cal-HIP committee from its inception, and DiTomaso took Bell’s place last year. Other UC participants were Holly Crosson of the UC Davis Arboretum and Bethallyn Black of the UC Master Gardener program.

The criteria for defining invasiveness included the plant’s distribution, rate of spread, characteristics and reproduction.

“Cal-HIP has taken a good tactic in focusing on plants where science has shown that they’re invasive,” Crosson says. “Everyone on the committee feels that the research has to be done and that decisions aren’t made unless they are science-based.”

UC researchers have helped to clarify, for example, that all species of pampas grass are invasive, while other studies are looking at interactions between noninvasive sweet broom and highly invasive French broom.

Sustainable, responsible horticulture

PlantRight’s current public outreach campaign includes a speakers’ bureau, the distribution of nearly 25,000 brochures and an interactive Web site. UC Master Gardeners and the UC Davis Arboretum will also help to get the word out. “The PlantRight message fits right into the arboretum’s messages on sustainable horticulture,” Crosson says. “Being a responsible steward as a gardener means reducing water use, picking plant species that are regionally appropriate and pest- and disease-resistant (see page 97), and not planting invasives.”

Lowe’s recently joined the PlantRight effort and is currently reviewing their plant inventory in California stores. Other “big-box” retailers are expected to follow suit, Kempton says. With 60% of all garden plants sold through these large retailers, their involvement will be critical to PlantRight’s success.

Keeping certain plants off the market in areas where they can do damage is key, Kempton says, but the ultimate goal of PlantRight is to let gardeners know that they can have a beautiful garden and protect the environment at the same time. “Our program is based 100% on freedom of choice. These plants got out into the environment because we chose to put them there. This is one area where individual people can make a difference by choosing not to plant invasives in their gardens.” — *Janet Byron*

For more information:

PlantRight
www.PlantRight.org

UC Master Gardeners
www.mastergardeners.org

UC Davis Arboretum
http://arboretum.ucdavis.edu

Brenda Dawson/UC Small Farm Program

Greg Paganelli, of Washington, tastes a blueberry variety ('Rebel') picked that morning from the Kearney fields during a May field day.

Solutions sought to protect valuable blueberries from citrus thrips

After blueberry growers in the San Joaquin Valley reported that citrus thrips were causing extensive damage to their crops, a research team led by UC Cooperative Extension farm advisor David Haviland developed monitoring and treatment guidelines to help growers avoid using unnecessary pesticides.

In 2006, Haviland and his research team began a 3-year study of citrus thrips damage to blueberries with funding from the UC Statewide Integrated Pest Management Program.

"Citrus thrips are best known for the scarring damage they cause to navel oranges in the San Joaquin Valley, but with the recent plantings of blueberries, this pest has taken damage to a whole new level," Haviland says.

UC blueberry researchers estimate that California has more than 4,500 acres of commercial blueberry plantings (see page 91). Most early blueberry acreage planted in California is on smaller farms, while larger parcels are currently being converted.

Managing thrips

Haviland says that management of citrus thrips is critical, given the high value of blueberries and potential damage in the thousands of dollars per acre. "Current practices are to spray fields multiple times with insecticide after harvest through fall. However, with the propensity of citrus thrips to develop resistance to insecticides, and spinosyn-based insecticides being the only effective products registered for blueberries, alternate approaches are needed."

Unlike flower thrips, which prefer to feed within blossoms, citrus thrips prefer new growth. This makes blueberries an excellent host because they produce new, tender growth at the end of their shoots from June through October.

Citrus thrips feeding on blueberry foliage results in a wide range of symptoms including crinkled or misshapen leaves, stem scarring, stem discoloration, shortened internodes and death of the shoot tip. In some cases, death of the tip causes the buds at the bases of leaves to begin to grow, giving the shoot the appearance of an upside-down witch's broom.

Haviland and his team showed that an average of 35 thrips on a shoot tip for a 1-month period in August caused a 52% reduction in the length of new shoots. However, damage didn't stop there. Blueberry fruit during the spring develops at the tips of the shoots from the previous year. This means that citrus thrips feeding causes reduced growth that results in less fruiting wood, and, therefore, less fruit.

Harvest data confirmed that for every 10 citrus thrips per shoot tip over a 1-month period in August 2006, there was a 5.3% reduction in yield at harvest in 2007. For the field where the research took place, this was the equivalent of an 18.4% yield loss in the untreated fruit.

The UC team is developing an IPM program for this destructive pest. To date, they have developed information on the seasonal biology of citrus thrips in blueberries, a monitoring program and treatment guidelines. They are also investigating alternatives to insecticides, such as the repeated use of high-pressure water to knock immature thrips off of the plants, and the use of *Beauveria bassiana*, a parasitic fungus that acts as on the pupal stage of thrips that reside in the soil.

Competition in a new market

With more blueberry acreage coming into production, a series of blueberry-themed workshops and field days was held in May in the Central Coast, South Coast and Central Valley. The events were aimed at introducing this specialty crop to growers, and planning for increased market competition.

David Haviland/UCCE Kern County

Thrips damage to blueberry.

UC farm advisors say that methods for staying competitive in the blueberry market will vary by region.

"Growers need to realize that added acreage some place else means more competition and possibly fewer places to sell our blueberries," says Manuel Jimenez, UC Small Farm Program advisor in Tulare County.

"Even though demand continues to go up, I think the supply on our side has been going up very, very fast in a short period of time. All that new blueberry acreage is coming into production now."

— *Stephanie Klunk, Brenda Dawson and Editors*

San Joaquin Valley blueberries evaluated for quality attributes

by Vanessa Bremer, Gayle Crisosto, Richard Molinar, Manuel Jimenez, Stephanie Dollahite *and* Carlos H. Crisosto

Blueberry production in California was estimated in 2007 at around 4,500 acres and is rapidly increasing. Common southern highbush cultivars with low chilling-hour requirements are being grown from Fresno County southward, including 'Misty', 'O'Neal', 'Emerald', 'Jewel', 'Star' and others. We characterized the quality parameters (soluble solids concentration, titratable acidity, ratio of soluble solids concentration to titratable acidity, firmness and antioxidant capacity) of six southern highbush blueberry cultivars grown at the UC Kearney Agricultural Center in Parlier, in the San Joaquin Valley, for three seasons (2005–2007). We also conducted in-store tests to evaluate their acceptance by consumers who eat fresh blueberries. We found that the southern blueberry cultivars currently grown under warm San Joaquin Valley conditions are producing blueberry fruit that is of acceptable quality to consumers and profitable to growers.

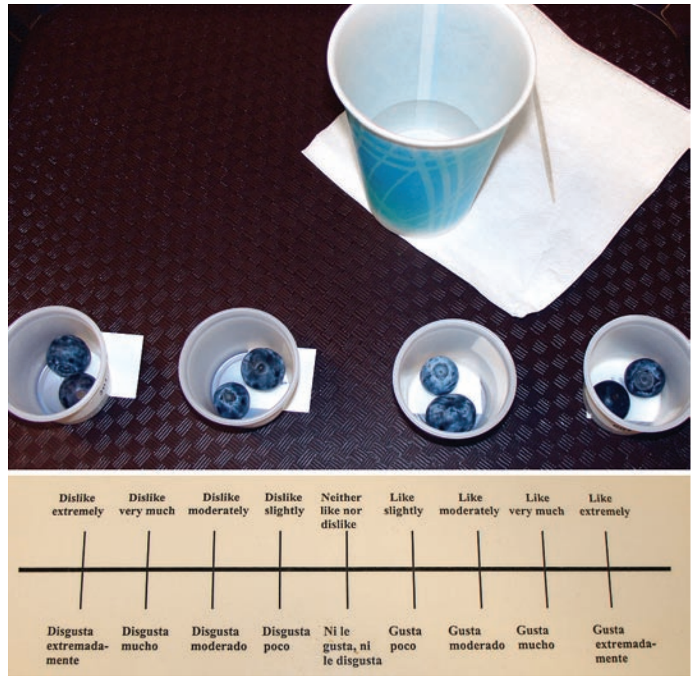
New blueberry cultivars that require fewer hours of chilling have made it possible to grow this specialty crop profitably in hot, dry places such as the San Joaquin Valley. *Above*, a blueberry field day at the UC Kearney Agricultural Center in Parlier.

Highbush blueberries (*Vaccinium corymbosum*), native to the northeastern United States, are important commercial fruit (Jimenez et al. 2005) and are the most planted blueberry species in the world (Strik and Yarborough 2005). In the United States, blueberries traditionally have been grown in cooler northern regions; however, the development of new southern cultivars with low chilling-hour requirements (the accumulated number of hours below 45°F [7.2°C] necessary to break dormancy) has made possible the expansion of blueberry production to the southern United States and California (Jimenez et al. 2005).

Blueberry production in California was estimated in 2007 at around 4,500 acres (1,821 hectares) and is rapidly increasing. Common southern cultivars grown include 'Misty' and 'O'Neal', but other improved southern highbush cultivars are now being grown from Fresno southward, such as 'Emerald', 'Jewel' and 'Star' (Hashim 2004). Southern highbush "low-chill" cultivars are notable for their productivity, fruit quality and adaptation (Draper 2007), and require only 150 to 600 chill-hours, making them promising cultivars for the San Joaquin Valley's mild winters (600 to 1,200 chill-hours annually). Since 1998, we have conducted long-term productivity and performance evaluations of these cultivars at the University of California's Kearney Agricultural Center in Parlier (Jimenez et al. 2005).

North American production of highbush blueberry has been increasing since 1975, due to expansion of harvested area and yields through improvements in cultivars and production systems. In 2005, North America represented 69% of the world's acreage of highbush blueberries, with 74,589 acres (30,185 hectares) producing 306.4 million pounds (139,000 metric tons). Acreage and production increased 11% and 32%, respectively, from 2003 to 2005. The U.S. West, South and Midwest experienced the highest increases in acreage. In 2005, 63% of the world's production of highbush blueberries went to the fresh market. North America accounts for a large part of global high-

Consumers at a Fresno supermarket participated in taste tests of new southern highbush blueberry cultivars.



Blueberry samples were presented in random order for consumers to taste and rate on a 9-point hedonic scale (dislike extremely to like extremely).

bush blueberry production, representing 67% of the fresh and 94% of the processed markets (Brazelton and Strik 2007).

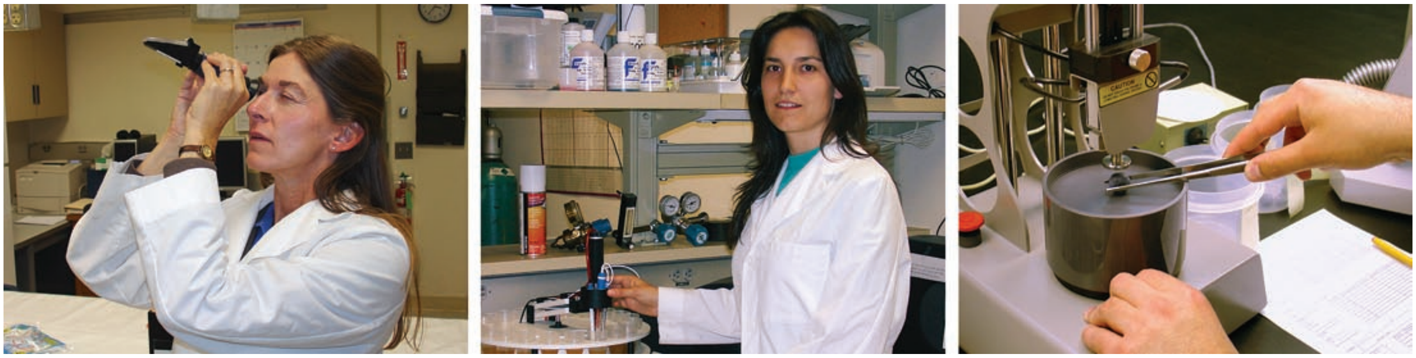
Blueberry consumption is increasing, which is encouraging increased production. As a result, fresh blueberries are becoming a profitable specialty crop, especially in early production areas such as the San Joaquin Valley (Jimenez et al. 2005). In general, a consumer's first purchase is dictated by fruit appearance and firmness (texture). However, subsequent purchases are dependent on the consumer's satisfaction with flavor and quality, which are related to fruit soluble solids (mainly sugars), titratable acidity (organic acids), the ratio of soluble solids to titratable acidity, flesh firmness and antioxidant activity (Kader 1999).

Vaccinium species differ in chemical composition, such as sugars and organic acids. The sugars of the larger highbush blueberry cultivars that are grown in California are fructose, glucose and traces of sucrose. Lowbush blueberries (*V. angustifolium*) — which are wild, smaller and grow mostly in Maine — lack sucrose. (Kalt and McDonald 1996). The composition of organic acids is a distinguishing characteristic among species. In highbush cultivars, the predominant organic acid is usually citric (~ 83%), while the percentages of succinic, malic and quinic acids are 11%, 2% and 5%, respectively. However, in "rabbiteye" blueberries (*V. ashei*) the predominant organic acids are succinic and malic, with percentages of 50% and 34%, respectively, while citric acid accounts for only about 10% (Ehlenfeldt et al. 1994). These different proportions of organic acids affect sensory quality; the combination of citric and malic acids gives a sour taste, while succinic acid gives a bitter taste (Rubico and McDaniel 1992).

In addition to flavor, consumers also value the nutritional quality of fresh fruits and their content of energy, vitamins, minerals, dietary fiber and many bioactive compounds that are beneficial for human health (Kader 1999). Fruits, nuts and vegetables are of great importance for human nutrition, supplying vitamins, minerals and dietary fiber. For example, they provide 91% of vitamin C, 48% of vitamin A, 27% of vitamin B6, 17% of thiamine and 15% of niacin consumed in the United States (Kays 1997). The daily consumption of fruits, nuts and vegetables has also been related to reductions in heart disease, some forms of cancer, stroke and other chronic diseases. Blueberries, like other berries, provide an abundant supply of bioactive compounds with antioxidant activity, such as flavanoids (flavonols, anthocyanins and others) and phenolic acids (Schotsmans et al. 2007). For example, a study performed in rats showed that when they were fed diets supplemented with 2% blueberry extracts, age-related losses of behavior (Alzheimer's disease and other) and signal transduction were delayed or even reversed, and radiation-induced losses of spatial learning and memory were reduced (Shukitt-Hale et al. 2007). Some studies have shown that the effects of consuming whole foods are more beneficial than consuming compounds isolated from the food, such as dietary supplements and nutraceuticals.

Because fruit consumption is mainly related to visual appearance, flavor and antioxidant properties, we

Fresh blueberries are becoming a profitable specialty crop, especially in early production areas such as the San Joaquin Valley.



▲ **After harvest, blueberries were tested for, *left,* soluble solids concentration (shown, Gayle Crisosto with refractometer), *center,* titratable acidity (shown, Vanessa Bremer with automatic titrator) and, *right,* firmness (shown, fruit texture analyzer), as well as other qualities.**

decided to evaluate fruit quality attributes, antioxidant capacity and consumer acceptance of the early-season blueberry cultivars currently being grown in California. We characterized the quality parameters (soluble solids concentration, titratable acidity, ratio of soluble solids to titratable acidity, firmness and antioxidant capacity) of six southern highbush blueberry cultivars grown in the San Joaquin Valley for three seasons (2005–2007), and evaluated their acceptance by consumers who eat fresh blueberries.

Highbush blueberry evaluation

Field plots. For the quality evaluations at UC Kearney Agricultural Center, we used three patented southern highbush blueberry cultivars — 'Emerald' (US Plant Patent 12165), 'Jewel' (US Plant Patent 11807) and 'Star' (US Plant Patent 10675), and three nonpatented cultivars — 'Reveille', 'O'Neal' and 'Misty'. The plants were started from tissue culture and then grown for two seasons by Fall Creek Farm and Nursery in Lowell, Ore. Before planting these cultivars in 2001, the trial plot was fumigated to kill nut grass (*Cyperus rotundus* and *C. esculentus*). Because blueberries require acidic conditions, the plot's soil was acidified with sulfuric acid, which was incorporated to a depth of 10 to 12 inches (25.4 to 30.5 centimeters) with flood irrigation, resulting in a pH ranging from 5.0 to 5.5. A complete (NPK) granular fertilizer (15-15-15) was broadcast-applied at a rate of 400 pounds per acre (448 kilograms per hectare).

The plants were mulched with 4 to 6 inches (10.2 to 15 centimeters) of pine mulch and irrigated with two drip lines on the surface of the mulch, one on each side of the plant row. Irrigation frequency was two to three times per week in the spring and daily during June and July. The emitter spacing was 18 inches (45.7 centimeters), with each delivering 0.53 gallon (2 liters) per hour of water acidified with urea sulfuric acid fertilizer to a pH of 5.0.

The plot received an application of nitrogen in the first season, as well as in subsequent growing seasons. The rate was 80 pounds (36.3 kilograms) nitrogen per acre at planting, 60 pounds (27.2 kilograms) the second year, 90 pounds (40.8 kilograms) the third year and 120 pounds (54.4 kilograms) the fourth year. Annual pest control was limited to one application of Pristine fungicide (a combination of the active ingredients pyraclostrobin and boscalid) in February for botrytis management, and two or three herbicide treatments of paraquat (Gramoxone). In year three, the plants received one insecticide treatement of spinosad (Success) for thrips management.

Twenty-eight plants per cultivar were planted in a randomized block design using seven plants per block (row) as an experimental unit, replicated in four rows. Rows were spaced 11 feet (3.4 meters) apart, with the plants in the rows spaced 3 feet (0.9 meter) apart, with a space of 4 feet (1.2 meters) between plots. Fruit was harvested at times when it would have been commercially viable if it had been in a commercial field. Fruit from each of the seven plant blocks was harvested and a composite sample of 80 random berries per each replication was used for quality evaluations.

Quality measurements. Berries were randomly selected from each replication for quality evaluation at the first harvest time for each respective season (2005–2007). During the 2007 season, in addition to the initial quality evaluations, harvested berries were stored at 32°F (0°C) in plastic clam shells, and measured for firmness 15 days after harvest and for antioxidant capacity 5, 10 and 15 days after harvest. Three replications per cultivar (2005–2007 seasons) were measured for each quality parameter. The initial firmness of 10 individual berries per replication was measured with a Fruit Texture Analyzer (FTA) (Güss, GS.14, Strand, South Africa) (Slaughter and Rohrbach 1985). Each berry was compressed on the cheek with a 1-inch (2.5 centimeters) flat tip at a speed of 0.2 inch per second (5 millimeters) to a depth of 0.16 inch (4 millimeters) and the maximum value of force was expressed in pounds force (lbf) (1 lbf = 4.5 Newtons).

Sixty berries per replication were then wrapped together in two layers of cheesecloth and squeezed with a hand press to obtain a composite juice sample. The juice was used to determine soluble solids concentration (SSC) with a temperature-compensated handheld refractometer (model ATC-1, Atago Co., Tokyo, Japan) and expressed as a percentage. Twenty-one hundredths of an ounce (6 grams) of the same juice sample was used to determine titratable acidity (TA) with an automatic titrator (TIM850 auto-titrator, Radiometer Analytical, Lyon, France) and reported as a percentage of citric acid. Some samples that had a high viscosity were centrifuged with a superspeed centrifuge (SerVall type SS-1, U.S.A.) at 15,000 rpm for 5 minutes, in order to get liquid juice for soluble solids concentration and titratable acidity measurements (both methods were compared and no differences were observed [data not published]). The ratio of soluble solids concentration to titratable acidity was calculated.

Antioxidant analysis. Antioxidant capacity (Trolox Equivalent Antioxidant Capacity [TEAC]) was measured in the 2005 and 2007 seasons. Eighteen-hundredths of an ounce (5 grams) of berries (not used for quality measurements) per replication was used to determine the level of antioxidants by the DPPH free-radical method (Brand-Williams et al. 1995). Samples were extracted in methanol to assure a good phenolic representation, homogenized using a polytron (Ultra-Turrax TP 18/101 S1, Junke & Kunkel, Staufen, Germany) and centrifuged (Sorvall RC5C, Du Pont Company, Wilmington, Del.) for 25 minutes. The supernatant was analyzed against the standard, Trolox, a water-soluble vitamin E analogue, and reported in micromoles Trolox equivalents per gram of fresh tissue (μmoles TE/g FW).

Lab assistant Megan Bishop prepares blueberry samples for antioxidant analysis.

Consumer tests. An in-store consumer test was conducted on 'Jewel', 'O'Neal' and 'Star' blueberry cultivars in 2006, and on the six blueberry cultivars studied in 2007, using methods described previously (Crisosto and Crisosto 2001). The fruit samples were held for 2 days after harvest at 32°F (0°C) prior to tasting. One hundred consumers who eat fresh blueberries, representing a diverse combination of ages, ethnic groups and genders, were surveyed in a major supermarket in Fresno County.

Each consumer was presented with a sample of each blueberry cultivar in random order at room temperature, 68°F (20°C). A sample consisted of three fresh whole blueberries presented in a 1-ounce (30 milliliters) soufflé cup labeled with a three-digit code. At the supermarket, the samples were prepared in the produce room out of sight from the testing area. For each sample, the consumer was asked to taste it, and then asked to indicate which statement best described how they felt about the sample on a 9-point hedonic scale (dislike extremely to like extremely). Consumers were instructed to sip bottled water between samples to cleanse their palates. Consumer acceptance was measured as both degree of liking (on a scale of 1 to 9) and percentage acceptance, which was calculated as the number of consumers liking the sample (score > 5.0) divided by the total number of consumers within that sample (Lawless and Heymann 1998). In a similar manner, the percentage of consumers disliking (score < 5.0) and neither liking nor disliking (score = 5.0) the sample was calculated.

Statistical analysis. Quality values (firmness, SSC, TA, SSC:TA and TEAC) and data on degree of liking were analyzed with analysis of variance (multifactor ANOVA) and LSD mean separation ($P \leq 0.05$) with the SAS program.

TABLE 1. Production of six southern highbush blueberry cultivars (2005–2007)*

Cultivar	2005	2006	2007
		lb/acre	
Emerald	10,747	18,494	19,623
Jewel	8,411	26,966	23,228
Star	3,821	9,968	17,198
Reveille	7,081	7,039	8,313
O'Neal	3,830	7,232	9,708
Misty	7,375	8,128	11,157

* Yield was calculated from 21 feet of row including seven plants spaced 3 feet apart.

Blueberry cultivar performance

Production. Among the studied cultivars, 'Emerald' and 'Jewel' had the highest productivity for 2005 to 2007 (table 1). However, 'Star' had an unexpectedly high productivity in 2007. Yield increases for all varieties were due to the maturity of the plants. At planting, the tissue-culture plants were 2 years old; as they matured, they all produced larger yields. The harvest period for 'Star' began the first week of May and ended after the third harvest. Most other cultivars required five or more harvests, 1 week apart. Based on the berry size (table 2), the cultivars studied would be separated into large berry ('Emerald', 'Jewel' and 'Star') and medium berry ('Reveille', 'O'Neal' and 'Misty'). The cultivars studied have an erect plant stature, except for 'Misty', which has a spreading stature that makes hand-harvest difficult.

Fruit quality. Quality attributes such as soluble solids concentration, titratable acidity, soluble-solids-to-titratable-acidity ratio and firmness were significantly different among cultivars and seasons (table 3). There was wide variability in soluble solids concentration among cultivars. 'Reveille' had the highest average value (14.4%) of the 2005 to 2007 seasons, followed by 'Misty' (12.3%), 'Emerald' (12%) and 'Star' (11.9%). 'Jewel' (11.7%) and 'O'Neal' (11.4%) had the lowest soluble solids concentration within this group.

Titratable acidity within cultivars was less variable, and only 'O'Neal' had a significantly lower average value (0.54%) than the rest of the tested cultivars. Titratable acidity varied from 0.70% to 0.80% within this group with the exception of 'O'Neal'. Cultivars segregated into three groups based on their soluble-solids-to-titratable-acidity ratio. Because of its low titratable acidity, 'O'Neal' had the highest ratio, while 'Jewel' had the lowest ratio due to its high titratable acidity. The rest of the cultivars formed an intermediate group in which the soluble-solids-to-titratable-acidity ratio ranged from 17 to 20.3. 'Jewel' and 'O'Neal' also had the lowest firmness (1.2 lbf), while 'Reveille' and 'Misty' had the highest (1.6 lbf). 'Emerald' and 'Star' were significantly different than these two groups, forming an intermediate group (1.5 lbf).

Quality attributes were also significantly affected by the season. Soluble solids concentration across all cultivars was highest in 2007 and lowest in 2006, while titratable acidity was highest in 2006. Soluble-solids-to-titratable-acidity ratio and firmness were significantly higher in 2007 than the other years. There was a significant interaction between cultivar and season for all these quality attributes (table 3).

The lowest soluble solids concentration was 10.8% in 2006 for 'O'Neal' and the highest was 15.8% for 'Reveille' in 2007. During this 3-year period, all of the cultivars yielded soluble solids concentrations higher than 10%, which has been proposed as a minimum quality index for blueberries (Kader 1999). Titratable acidity was similar among cultivars in these three seasons except for 'O'Neal' in 2007, which reached 0.3%, and 'Jewel' and 'Emerald' in 2006 with about 1.0%. 'O'Neal' (40.5) and 'Reveille' (22.9) had the highest soluble-solids-to-titratable-acidity ratio, followed by the rest of the cultivars with ratios from 11.4 to 20.6. During this 3-year period, 'Jewel' and 'O'Neal' were the softest cultivars, and 'Misty' and 'Reveille' the firmest.

Antioxidant capacity was significantly different among the cultivars but not between seasons (table 3). There was a wide variability of TEAC within cultivars. 'Misty' had the highest average TEAC (19.6 μmol TE/g FW) followed by 'Reveille' (17.3) and 'Emerald' (16.1). 'Star' (12.4), 'O'Neal' (12.6) and 'Jewel' (11.0) had the lowest TEAC within this group. Like the rest of the quality attributes, there was a significant interaction between cultivars and seasons for antioxidant

TABLE 2. Characteristics of six southern highbush blueberry cultivars

Cultivar	Plant stature	Harvest period*	Fruit size†	Berry grade‡	Hand-harvest ease
Emerald	Erect	Early/midseason	50–80	Large	Moderately easy
Jewel	Erect	Early	60–100	Large	Moderately easy
Star	Erect	Early	60–70	Large	Very easy
Reveille	Very erect	Early	100–130	Medium	Moderate
O'Neal	Erect	Early	100–130	Medium	Easy
Misty	Spreading	Early/midseason	80–130	Medium	Difficult

* Harvest period specifies initiation of harvest. Early = initial harvest; early/midseason = 7 days later.
† Number of berries per 6 oz. (0.18 liter) cup.
‡ Based on average fruit size: extra large, < 64 berries/cup (6 oz.); large, 64–91 berries/cup (6 oz.); medium, 92–134 berries/cup (6 oz.).
Source: Jimenez et al. 2005.

TABLE 3. Quality attributes of six southern highbush blueberry cultivars growing in the San Joaquin Valley, 2005–2007 (values per cultivar and season)

Cultivar	SSC *	TA †	SSC:TA	Firmness‡	TEAC §
	%	*% citric acid*	*ratio*	*lbf*	(*μmol TE/g FW*)
2005					
Emerald	12.1 cdef ¶	0.63 ab	18.4 b	1.60 ab	19.1 ab
Jewel	11.9 cdef	0.67 ab	18.1 b	1.07 d	10.3 d
Misty	12.2 cdef	0.70 ab	16.6 b	1.57 ab	21.9 a
O'Neal	11.8 def	0.60 ab	19.0 b	1.30 bcd	13.6 cd
Reveille	14.3 ab	0.80 a	18.1 b	1.40 bcd	13.8 cd
Star	12.9 bcde	0.77 a	16.4 b	1.57 ab	12.1 d
2006					
Emerald	11.6 def	0.90 a	13.2 b	1.43 bcd	N/A
Jewel	10.9 ef	1.00 a	11.4 b	1.13 cd	N/A
Misty	11.1 ef	0.57 ab	20.6 b	1.37 bcd	N/A
O'Neal	10.8 f	0.77 a	14.5 b	1.13 cd	N/A
Reveille	13.3 bdf	0.70 ab	20.0 b	1.57 ab	N/A
Star	11.1 ef	0.70 ab	17.4 b	1.50 abc	N/A
2007					
Emerald	12.3 cdef	0.60 ab	20.0 b	1.60 ab	13.2 cd
Jewel	12.3 cdef	0.73 ab	17.2 b	1.30 bcd	11.7 d
Misty	13.7 bc	0.83 a	17.3 b	1.87 a	17.4 bc
O'Neal	11.5 def	0.27 b	40.5 a	1.27 bcd	11.7 d
Reveille	15.8 a	0.70 ab	22.9 ab	1.90 a	20.7 ab
Star	11.6 def	0.67 ab	17.1 b	1.50 abc	12.7 d
LSD 0.05	1.88	0.48	18.07	0.41	4.4
P value	0.001	0.001	< 0.0001	< 0.0001	0.0042

* Soluble solids concentration.
† Titratable acidity.
‡ Firmness represents the maximum value of force expressed in pounds force (lbf) (1 lbf = 4.5 Newtons) required to compress the fruit 0.16 inches (4 mm) using a fruit texture analyzer with a 1-inch (2.5-centimeters) flat tip at a speed of 0.2 inch/sec (5 mm/sec).
§ TEAC (Trolox Equivalent Antioxidant Capacity).
¶ Same letters within the same column indicate no significant difference between means.

TABLE 4. Acceptance of six southern highbush blueberry cultivars by U.S. consumers in consumer test during 2007 season

Cultivar	Degree of liking*	Acceptance	Neither like nor dislike	Dislike
	1–9	%		
Emerald	6.2 cd†	72.3	11.9	15.8
Jewel	6.7 b	82.2	4.9	12.9
Misty	6.9 b	84.2	6.9	8.9
O'Neal	5.9 d	67.3	12.9	19.8
Reveille	7.4 a	92.1	2.0	5.9
Star	6.6 bc	80.2	8.9	10.9
LSD 0.05	0.44	—	—	—
P value	< 0.0001			

* Degree of liking: 1 = dislike extremely, 2 = dislike very much, 3 = dislike moderately, 4 = dislike slightly, 5 = neither like nor dislike, 6 = like slightly, 7 = like moderately, 8 = like very much, 9 = like extremely.
† Same letters within the same column indicate no significant difference between means.

capacity (data not shown). Storage of the six blueberry cultivars at 32°F (0°C) for 15 days did not affect either antioxidant capacity or firmness, except for 'O'Neal' and 'Misty', whose firmness was reduced slightly but not significantly (data not shown).

Consumer acceptance. During the 2006 season, our in-store test results indicated that consumers liked the three tested cultivars slightly to moderately, with an acceptance range of 73.3% to 80%. There were no significant differences in degree of liking between 'Jewel', 'O'Neal' and 'Star'. In these three cultivars the percentage of consumers disliking these fruit reached about 17% (data not shown).

During the 2007 season, there were significant differences in degree of liking between the six cultivars tested (table 4). In this test, degree of liking varied from liking slightly to moderately. 'Reveille' had the highest (7.4) and 'O'Neal' the lowest (5.9) degree of liking with an acceptance of 92.1% and 67.3%, respectively. Degree of liking of 'Misty' and 'Jewel' was significantly lower than 'Reveille', but higher than 'Star' and 'Emerald'. Acceptance was near 80% for 'Jewel', 'Misty' and 'Star', while only 67% for 'O'Neal' and 72% for 'Emerald'. The percentage of consumers that disliked these cultivars varied from 5.9% to 19.8%; 'Reveille' and 'Misty' had the lowest dislike percentage and 'O'Neal' the highest.

Degree of liking for 'Jewel' and 'Star' were similar (from slight to moderate) during the two seasons. For 'O'Neal', the degree of liking decreased from like slightly-moderately to like slightly. This reduction in consumer acceptance can be explained by the change of titratable acidity from 0.6% to 0.8% in previous years down to 0.3% in 2007 that only occurred in 'O'Neal'. This reduction of titratable acidity for 'O'Neil' was independent of soluble solids concentration, which remained between 10.8% and 11.8% for the 2005 to 2007 seasons.

These results indicated that blueberries with very low titratable acidity (0.3%), despite soluble solids concentrations between 10% and 12%, are not acceptable to consumers. A similar situation has been observed in white and yellow flesh peaches and nectarines with very low acidity (less than 0.4%) (C. and G. Crisosto, personal communication). This reduction in consumer acceptance also points out that the ratio of soluble solids to titratable acidity is not a good indicator for blueberry taste when titratable acidity is low. We are not sure of the reasons for the low titratable acidity in 2007 of 'O'Neal' fruit, which appears to be independent of other cultivars. The 2007 season was characterized by high chilling accumulation and a hotter than normal spring, which could have affected 'O'Neal' ripening.

Choosing a variety

The six southern highbush blueberry cultivars studied ('Emerald', 'Jewel', 'Star', 'Reveille', 'O'Neal' and 'Misty') growing in the San Joaquin Valley had soluble solids concentration levels above the 10% proposed for a minimum quality standard. Titratable acidity ranged from 0.6% to 0.9%, with the exception of 0.3% (2007) for 'O'Neal'. Firmness ranged from 1.2 to 1.6 lbf. 'Reveille' was the cultivar with the highest soluble solids concentration, firmness and degree of liking. Antioxidant capacity ranged from 10 to 22 μmoles TE/g FW, with 'Misty' and 'Reveille' the cultivars with higher antioxidant capacity for the 2005 and 2007 seasons. Antioxidant capacity and firmness of the cultivars studied was not affected by storage up to 15 days at 32°F (0°C). Blueberries with very low titratable acidity, despite acceptable soluble solids concentration, had lower consumer acceptance and degree of liking, indicating that the soluble-solids-to-titratable-acidity ratio is not a good indicator of consumer acceptance for blueberries.

For San Joaquin Valley conditions, these cultivars are all good options for our fast-growing, early fresh blueberry market.

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References

Brand-Williams W, Cuvelier ME, Berset C. 1995. Use of a free radical method to evaluate antioxidant activity. Lebensmittel Wissenschaft Technologie 28:25–30.

Brazelton D, Strik BC. 2007. Perspective on the U.S. and global blueberry industry. J Am Pom Soc 61(3):144–7.

Crisosto CH, Crisosto GM. 2001. Understanding consumer acceptance of early harvested 'Hayward' kiwifruit. Postharvest Biol Technol 22:205–13.

Draper A. 2007. Blueberry breeding: Improving the unwild blueberry. J Am Pom Soc 61(3):140–3.

Ehlenfeldt MK, Meredith FI, Ballington JR. 1994. Unique organic profile of rabbiteye vs. highbush blueberries. HortScience 29(4):321–3.

Hashim J. 2004. Blueberry production gaining in California. Western Farm Press. http://westernfarmpress.com/mag/farming_blueberry_production_gaining.

Jimenez M, Carpenter F, Molinar RH, et al. 2005. Blueberry research launches exciting new California specialty crop. Cal Ag 59(2):65–9.

Kader AA. 1999. Fruit maturity, ripening, and quality relationship. Acta Horticulturae (ISHS) 485:203–8.

Kalt W, McDonald JE. 1996. Chemical composition of lowbush blueberry cultivars. J Am Soc Hort Sci 121(1):142–6.

Kays SJ. 1997. *Postharvest Physiology of Perishables Plant Products*. Athens, GA: Exon Pr. 532 p.

Lawless HT, Heymann H. 1998. *Sensory Evaluation of Food: Principles and Practices*. Food Science Texts Series. NY: Chapman Hall. 827 p.

Rubico SM, McDaniel MR. 1992. Sensory evaluation of acids by free-choice profiling. Chemical Senses 17(3):273–89.

Schotsmans W, Molan A, MacKay B. 2007. Controlled atmosphere storage of rabbiteye blueberries enhances postharvest quality aspects. Postharvest Biol Technol 44:277–85.

Shukitt-Hale B, Carey AN, Jenkins D, et al. 2007. Beneficial effects of fruit extracts on neuronal function and behavior in a rodent model of accelerated aging. Neurobiol Aging 28(8):1187–94.

Slaughter DC, Rohrbach RP. 1985. Developing a blueberry firmness standard. Trans Am Soc Agric Eng 28(3):986–92.

Strik B, Yarborough D. 2005. Blueberry production trends in North America, 1992 to 2003 and predictions for growth. HortTechnol 15:391–8.

RESEARCH ARTICLE

Field trials identify more native plants suited to urban landscaping

by S. Karrie Reid and Lorence R. Oki

California native plants that performed well at the UC Davis Arboretum were tested for their potential usefulness in Central Valley gardens. These "All-Stars," such as the California lilac 'Valley Violet' (shown), were able to thrive in hot, dry conditions, resist pests and diseases, and attract beneficial wildlife such as bees and birds.

There is a growing need in the state of California for landscape plants that require fewer inputs of water and chemicals. To address this issue, a program was initiated at UC Davis to test the landscape potential of California native plants not currently in widespread horticultural use. Ten unused or underused California native plants were screened in open-field conditions for low water tolerance during summer 2006. In all cases, there were no significant differences in the summer growth or physical appearance between four irrigation levels. Six species maintained a favorable appearance throughout the season and were advanced to demonstration gardens in seven climate zones throughout the state, where Master Gardeners are performing further assessments on their performance. These irrigation and climate zone trials are part of an ongoing program coordinated by UC Cooperative Extension, the UC Davis Arboretum and the California Center for Urban Horticulture to introduce more low water-use and low chemical-use plants through partnerships with the commercial horticultural industry.

For gardeners, California's climate both charms and challenges. Its charms include rainless summers with warm, sunny days and mild nights, and brief, mild winters. But most of these charms are also challenges. The long, hot summers with no precipitation require frequent irrigation, and the low humidity can further increase the water demand and pest susceptibility of humidity-loving plants. The brief, mild winters can render plants that require a long seasonal chill unsatisfactory in either fall color or fruit production, and allow many pests that would be killed elsewhere by winter freezing to survive and multiply from one year to the next. Because so many commonly used landscape plants are ill-adapted to these climatic conditions, large inputs of water, pesticides and fertilizers are needed to keep them looking their best.

With constantly increasing population pressures in the state, there is an increasing demand for water (Hanak and Davis 2006). Due to overwatering and the frequent use of pesticides and artificial fertilizers, an increase in undesirable chemicals in urban runoff is a growing and serious problem (Bailey et al. 2000; Weston et al. 2005; Wilen et al. 2001). In addition to all this, whereas other large states such as Texas have only four U.S. Department of Agriculture (USDA) plant hardiness zones (USNA 2006), California is home to at least seven USDA zones and 24 climate zones as described in *Sunset Western Garden Book* (Brenzel 2007). Nonetheless, large chain nurseries in particular often sell the same plants from one end of the state to the other, ensuring that many customers who bought something that was lovely in the garden center will eventually be disappointed with a plant unsuitable to their part of the state. So how does one create a lovely landscape with such difficult challenges?

The obvious answer is simply to garden with plants that have greater drought-tolerance, fewer pest problems and an adaptation to milder winters. In fact, in recent years there has been a trend in both public landscapes and home gardens to use more plants with these characteristics. These plants, usually native to California or other areas of the world with Mediterranean-type climates, are sometimes referred to as "low-input" because they require little supplemental water and no chemicals to look their best. Their proper maintenance leaves no negative impact on the environment. The horticulture industry, however, thrives on a constant input of new and beautiful plants to tantalize its customers year to year, and despite the growing demand, plants in the "low-input" category have been relatively few and slow in coming to the mainstream nursery market.

Those retail nurseries that do offer or specialize in native plants are often known only to a small, motivated market of knowledgeable gardeners who seek them out. Most are located in coastal areas, away from the large tracts of developing Central Valley urbanization, where polluted runoff into watersheds is an issue. Some are inaccessible to much of the public either by location or limited hours, and have limited distribution to the landscape trade.

Many California native plants would be beautiful in urban landscapes, but they have been underused in mainstream retail nurseries and the landscape industry because relatively few species have been available in the numbers needed for large-scale retail distribution. Most of the work on native-plant propagation protocols has been used to produce species for reforestation and revegetation by conservation agencies and affiliates, where the market is driven more by governmental than consumer forces.

Little attention, however, has been paid to developing commercially viable propagation protocols for the ongoing addition of new, low-input species to the nursery market, partly because of misconceptions among nurserymen and landscapers that all natives are difficult to propagate, and that few are attractive enough to be appealing to consumers. Nothing could be further from the truth. There are many native species that would be year-round assets to any garden, and any difficulty in propagation is simply a protocol waiting to be discovered.

There are many native species that would be year-round assets to any garden.

A workable answer to all these concerns is a statewide, coordinated, cooperative, low-input plant introduction program. Many other states and regions of the country have long-established, successful, plant introduction programs that benefit all stakeholders by combining the talents, knowledge and energy of university researchers, extension specialists, arboretum and botanical garden personnel, and members of the wholesale and retail horticulture industry. Just such a program is under way at UC Davis. UC Cooperative Extension (UCCE) researchers, UC Davis Arboretum staff and the California Center for Urban Horticulture (a nonprofit organization and university-based center at http://ccuh.ucdavis.edu) are partnering with members of the commercial horticulture industry to provide a channel for the ongoing introduction of beautiful new low-input plants to a wide landscape horticulture market.

Although this introduction program is in its infancy, it will entail four basic stages: (1) initial selection, (2) a low water-tolerance field trial, (3) zone garden trials and (4) commercial introduction. The overriding goal of the project is to provide consumers with a source of beautiful landscape materials that will thrive in a wide variety of California climate zones with little input of water or chemicals. A corollary goal is to provide the nursery industry with a source of new and interesting, economically advantageous and environmentally sound plant revenue. With increasing pressure from state and regional water-quality control boards for zero runoff in the nursery industry (CalEPA 2007), plants requiring fewer inputs will be a welcome addition.

TABLE 1. Species in plant trial, from UC Davis Arboretum All-Stars and potential All-Stars

Common name (species)	Plant type	Result
Apache plume (*Fallugia paradoxa*)	Evergreen woody perennial	Eliminated: untidy appearance and free-seeding
California beach aster (*Lessingia filaginifolia*)	Herbaceous evergreen groundcover	Eliminated: froze in winter 2005
California lilac 'Valley Violet' (*Ceanothus maritimus*)	Evergreen woody perennial	Advanced
Coast gum plant (*Grindelia stricta*)	Low-growing herbaceous perennial	Eliminated: died in heat or froze in winter 2005
Creeping sage (*Salvia sonomensis*)	Herbaceous ground cover	Eliminated: rotted in spring transplant 2005 or froze in winter 2005
Eyelash grass or blue grama grass (*Bouteloua gracilis*)	Warm-season bunch grass	Advanced
Serpentine columbine (*Aquilegia eximia*)	Evergreen herbaceous perennial	Advanced
Rosy coral bells (*Heuchera rosada*)	Evergreen herbaceous perennial	Advanced
San Diego sedge (*Carex spissa*)	Sedge	Advanced
Seaside daisy (*Erigeron* 'Wayne Roderick')	Low-growing herbaceous perennial	Eliminated: froze in winter 2005

Selecting candidate plants

The starting point for this endeavor was the UC Davis Arboretum "All-Stars" program. Over the years, arboretum staff have taken note of plants that thrived in their Central Valley location on limited water, and developed All-Stars plant lists to help visitors identify plants that would be suitable for their own Central Valley gardens. All-Stars species must meet several criteria: (1) thriving over a number of years in the hot, interior valley location of the UC Davis Arboretum under a low watering regimen (generally twice a month) after establishment, (2) looking attractive during at least three seasons, (3) resisting pests and diseases and (4) optimally, though optionally, attracting or fostering beneficial wildlife such as bees and other beneficial insects, and birds. Some of these 50 plants could be found in any garden center, a few were available from small retail nurseries, and some were only available at arboretum plant sales.

From the All-Stars list as well as a list of an additional 50 potential All-Stars, we chose 10 species for the first low-water-tolerance field trial (table 1). These 10 species were selected for a variety of potential landscape uses and plant forms, including: ground covers (creeping sage [*Salvia sonomensis*] and California beach aster [*Lessingia filaginifolia*]); herbaceous perennials (serpentine columbine [*Aquilegia eximia*], Seaside daisy 'Wayne Roderick' [*Erigeron* 'Wayne Roderick'], coast gum plant [*Grindelia*

Ten UC Davis Arboretum All-Star species were evaluated for water usage, survival and growth. Five were advanced to the next trial stage (those shown plus eyelash grass) for testing by UC Master Gardeners.

stricta] and rosy coral bells [*Heuchera rosada*]); woody perennials (California lilac 'Valley violet' [*Ceanothus maritimus*] and Apache plume [*Fallugia paradoxa*]); and ornamental grasses (blue grama grass [*Bouteloua gracilis*] and San Diego sedge [*Carex spissa*]).

These 10 species are naturally found in a variety of ecosystems such as coastal woodlands and prairies, Sierra grasslands and dry hillsides. Some of these first selections for the trials were propagated by arboretum or university staff, and some were purchased from specialty native nurseries. Although all of these species had performed well in the arboretum, it should be noted that much of the arboretum has rich, sandy-loam soil and mature trees that provide windbreaks and shade in some places during portions of the day. In contrast, our irrigation trials were conducted in an unprotected open field with a somewhat heavy, clay-loam soil that is more typical of most Central Valley gardens, thereby providing a more rigorous test of the species' wind, sun, temperature and water tolerances.

Low water-use trials

A field was prepared to test 240 plants (24 of each species) on a UC Davis research farm in USDA Zone 9 (*Sunset* Zone 14). Plants were placed 2 yards apart along rows that were 2 yards apart, with 20 plants per row in each of 12 rows. This allowed the simultaneous testing of six individual plants on each of four different water treatments for each of the 10 species. The rows were covered with 3 to 4 inches of bark mulch, and two 2-gallon-per-hour drippers were buried beneath the mulch in the root zone of each plant.

The plants were placed according to a randomized complete block pattern in three blocks throughout the field. Each row was furnished with four water lines to deliver one of the water treatments to each plant after they were established. It is important that even drought-tolerant plants be given supplemental water until well-established, because the development of an adequate root system is a key component of drought-tolerance (Padilla and Pugnaire 2007). The 10 species were planted in fall 2004, and frost-killed specimens of creeping sage were replaced in spring 2005. All plants were irrigated regularly during summer 2005 to allow the root systems to establish adequately. Likewise, the plants were also watered during long, rain-free periods in the winter of 2005 to 2006.

Experimental irrigation treatments were carried out during the 2006 growing season. The four irrigation levels were based on percentages of reference evapotranspiration (ETo) as described in Water Use Classification of Landscape Species III (WUCOLS)

TABLE 2. Irrigation frequencies for native plant trial, based on reference evapotranspiration (ETo) water-use percentages

% ETo of treatment	Irrigation frequency during 2006 growing season
	· · · · · · · *days* · · · · · · ·
80	13–18
60	16–23
40	26–34
20	58 (twice during the season)

(Costello et al. 2000). ETo was defined as the amount of water evaporated from a 4- to 7-inch-tall, cool-season grass in open field conditions. WUCOLS classifies landscape plants according to how much water they need compared to cool-season turfgrass, which is high water-use and needs 80% of ETo to look green and healthy in the summer growing season.

In our trial, we used the following percentages of ETo: 20% (low), 40% (low-medium), 60% (high-medium) and 80% (high). We wanted to assess not only if these plants were truly drought-tolerant, but also if they could survive under garden conditions where they might be combined with higher water-use species or adjacent to a high water-use lawn.

The average water-holding capacity of the soil was determined from soil samples collected at field capacity (the amount of water held in the soil after excess moisture from complete saturation is allowed to drain, usually after 24 to 72 hours) along a transect across the field. Irrigation was measured to replace half of the soil's water-holding capacity in the root zone of each treatment to a depth of 1.5 feet. Since some of the moisture in the soil is held too tightly to soil particles for plant uptake, plant water stress is usually avoided by providing an irrigation when 50% of field capacity has been depleted. This amounted to 21.2 gallons of water per plant delivered over a period of approximately 5.25 hours. We used ETo values calculated by the California Irrigation Management Information System (CIMIS), which comprises data collection stations in various locations throughout the state that measure precipitation, relative humidity, solar radiation, temperature and wind speed. The California Department of Water Resources provides values daily for ETo online for the public (www.cimis.water.ca.gov). During the May to October 2006 irrigated growing season, the Davis CIMIS station was accessed daily via the Internet, and the ETo values were placed into a water budget worksheet to calculate the four percentages of accumulated water deficit. From this data, the subsequent need for irrigation in any one of the water-use treatments could be determined.

In brief, all the plants received the same amount of water at each irrigation, but how often they received it was determined by their water-use percentage of ETo treatment (table 2). This low water-tolerance screening is somewhat unique to the needs of a California introduction program, since most states do not deal with complete drought from May to November each year.

Assessing plant performance

A plant growth index can be used to quantify the comparative growth of plants under different conditions. During the budgeted deficit irrigation beginning in June 2006, plant height and width measurements were taken monthly and used to calculate an average growth index for each species at each water level, using the following formula:

$$\frac{h + [(l+w)/2]}{2}$$

(Irmak et al. 2004). Height (h) was measured from the ground to the tallest leaf, and length (l) and width (w) were measured at right angles along the row (in a north-south direction) and across the row (in an east-west direction), respectively, using the outermost leaf in each direction.

From these measurements, a relative growth index was calculated for each species at each irrigation level on each measurement date using the following formula: current mean growth index divided by original mean growth index. General appearance, flowering and the presence or lack of pest problems were also noted for each treatment throughout the growing season. This information was used to help determine if a plant was worthy of moving into the next stage of the trial: testing in county demonstration gardens throughout California. Appearance alone did not eliminate a plant from advancement, such as in the case of shade-loving plants that were grown in the full sun.

UC Master Gardeners from around California, including Janet Cangemi (left) and Madeleine Mitchell of Fresno County, are now growing the native plants that were advanced in the trial and collecting data on their performance.

Survival of trial species

After the first summer of regular irrigation followed by wintering over in open field conditions, four species had suffered 50% or greater mortality, leaving six species in sufficient numbers to collect data (table 1). The species that did not survive the first year were coast gum plant, California beach aster, seaside daisy and creeping sage. The species that did survive were Apache plume, California lilac 'Valley Violet', serpentine columbine, rosy coral bells, eyelash grass and San Diego sedge.

The first three species that did not survive are native to warm coastal areas, as reflected by their common names. Although they had grown well in the UC Davis Arboretum for years, the unmitigated summer heat and cooler winter temperatures of our field-trial site proved too inhospitable for them. The fourth species that did not survive, creeping sage, was bitten back by frost in winter 2005 and did not transplant well into the clay-loam field soil in spring. However, the few creeping sage plants that did survive spread up to 9 feet in two directions across bare paths where the soil did not stay moist. It is native to well-drained slopes and is probably a good choice for restoration in its native range in the coastal and Sierra foothills, but was not deemed a good selection for most Central Valley gardens with space restrictions and heavier soils.

Growth and appearance

Apache plume. One of the six species that survived in the UC Davis open field, Apache plume, did not advance to the next stage of zone garden trials. It is a woody shrub with small, dissected leaves and a profusion of pink staminate flowers that lend it a fuzzy appearance when in bloom. While the September 2006 plant growth index was higher with moderate levels of irrigation than with either low or high levels (2.3 versus 1.8, respectively), this difference was statistically insignificant (fig. 1A). This species bloomed heavily over a long period of time, and showed no signs of disease or pest damage. However, Apache plume also had some undesirable characteristics. Large branches tended to flop over, yielding an untidy, open habit as the season progressed, and the abundant seeds self-sowed rather freely in dry paths and mulched beds.

California lilac 'Valley Violet'. The second woody shrub was a UC Davis Arboretum selection of California lilac that has become our banner species, 'Valley Violet'. This California lilac performed beautifully at any watering level, which was unexpected since so many other species of this genus will not tolerate summer water. It should be noted that July 2006 was exceptionally hot, even for Davis (19 days above 95°F, 10 days between 100°F and 110°F+), and yet the lilac's appearance was unaffected even at the lowest level of summer water. Steady increases in relative plant growth index over the season from 1.15 to 1.45 were observed for all irrigation levels, with no significant difference between the treatments (fig. 1B). In the spring, this plant bloomed in profusion from the base of its branches to the tips and was unbothered by pests or disease. This California lilac, with its yearlong deep-green color and staggering spring floral display, was eagerly accepted by all the demonstration gardens involved in the next phase of the trial.

Serpentine columbine and rosy coral bells. Two of our herbaceous species, serpentine columbine and rosy coral bells, are naturally found in shady woodland locations. Consequently, they all showed a loss in plant growth index at all irrigation levels during the hottest part of the growing season in our exposed site, with values between 0.7 and 0.9 (figs. 2A and 2B). However, there were no statistically significant differences between the irrigation treatments, leading us to conclude that during the hottest months, protection from the sun was more critical to the success of these species than the availability of water. Interestingly, under the highest watering regimen, two of the six columbines died by the end of July and two more died by the end of August, possibly showing an intolerance of wet soil during the hot season. However, the remaining two columbines were already beginning to recover by September when tempera-

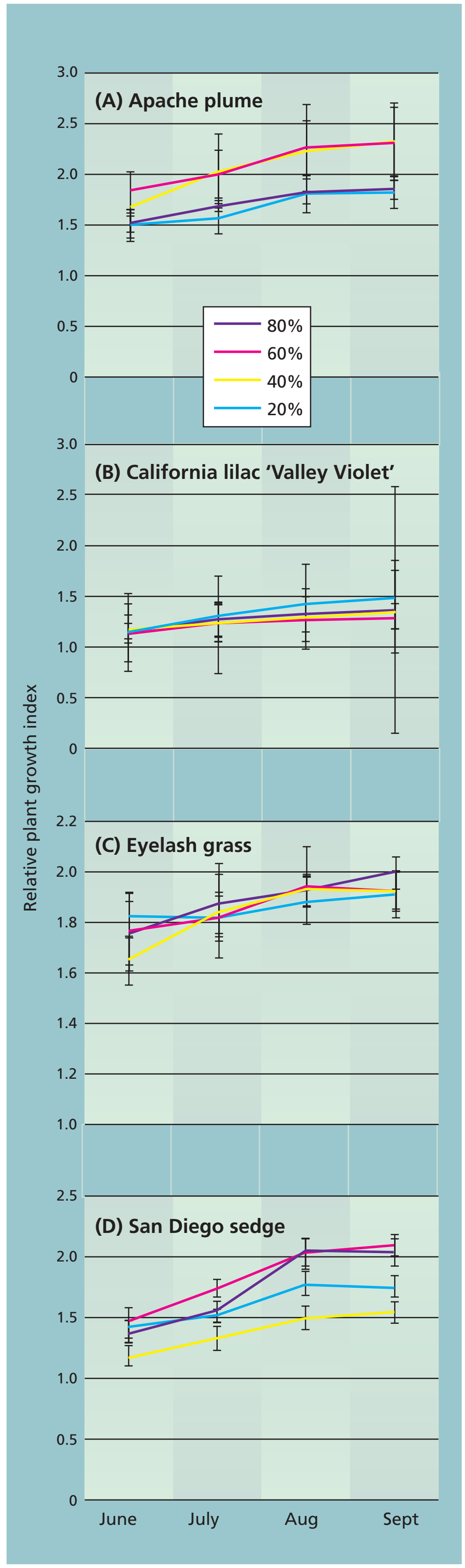

Fig. 1. Relative summer plant growth index for (A) Apache plume, (B) California lilac, (C) eyelash grass and (D) San Diego sedge. Bars represent 1 standard error.

tures began to drop, and all irrigation levels for both of these woodland herbaceous species showed dramatic recovery by the following June.

Noteworthy in both species was the prolific flower display, far beyond what was observable with specimens in shady locations in the nearby Arboretum during the same year. While both the coral bells and columbine leaves showed signs of sunburn and necrosis during the summer, their flowering seemed to benefit from the availability of light during the winter and spring months. Both were attractive to bees and syrphid flies, but were unbothered by pests or diseases. So, even though our test site's exposure was damaging to foliage, their mere survival under these conditions, combined with their spring beauty and attraction of beneficial insects, caused us to advance them to the next phase of the trial with a recommendation for planting sites with at least afternoon shade during the summer. Plants suited to dry shade are sorely lacking in the nursery trade, making serpentine columbine and rosy coral bells good introduction candidates.

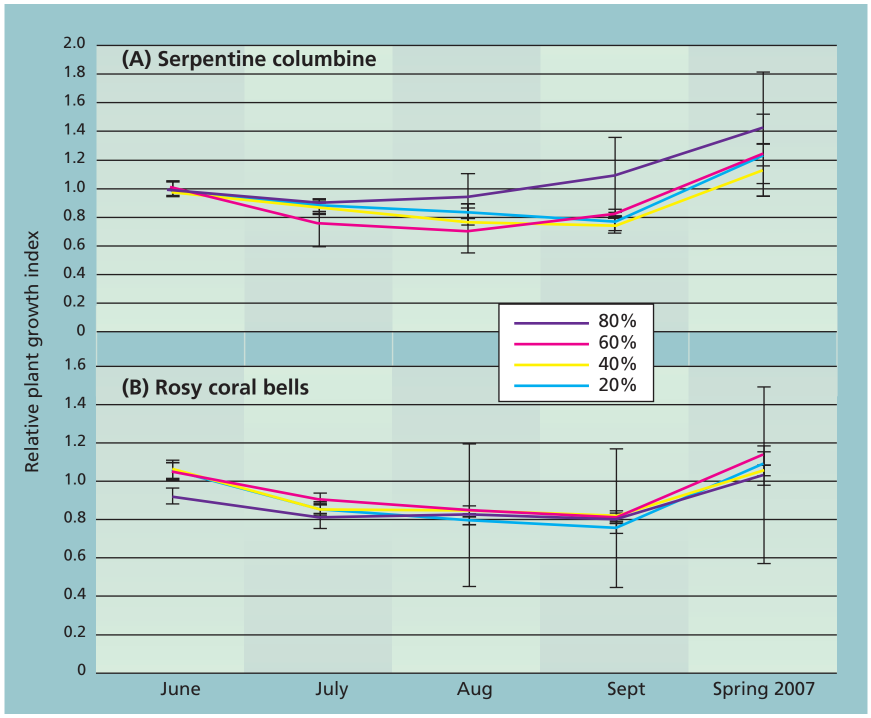

Fig. 2. Relative summer growth index and spring recovery for (A) serpentine columbine and (B) rosy coral bells. Bars represent 1 standard error.

Eyelash grass. Also called blue grama grass, eyelash grass is a bunch-type grass with a wide native range in prairies throughout North America. The amount of water it received in our trial made no significant difference in the amount of summer growth, with a September relative plant growth index of 1.9 to 2.0 (fig. 1C). Regardless of the amount of water, this species maintained a neat, fountain-form habit desirable for an ornamental grass, and had no pest or disease problems. For these reasons, we advanced eyelash grass to the zone garden trials.

San Diego sedge. San Diego sedge showed an unexpected toughness and drought tolerance for a plant that grows along streams in the wild. It sent up handsome flower spikes that matured to an attractive, buff-colored seed head held above sword-shaped leaves. None of these seeds has been observed to self-sow in the field, making it unlikely to be invasive in dry areas. At all irrigation levels, the plants showed consistent, positive changes in plant growth indices until the end of August, when growth leveled off, presumably in favor of seed production (fig. 1D).

San Diego sedge plants irrigated at the two lowest water levels (low and low-medium) did show slightly lower relative growth indices as the season progressed, with those given the second lowest water level (low-medium) inexplicably displaying the lowest relative plant growth index. However, the only statistically significant differences were between the low-medium and high-medium treatments in September (1.5 and 2.1, respectively). Plants at all irrigation levels became more attractive as the season progressed, and they were pest-free and disease-free. There was no consistent pattern to which watering level the plants preferred, making San Diego sedge a good candidate for a strong structural element in a variety of garden situations.

Zone garden trials

The key to the next stage of this endeavor was the Master Gardener Program, which is coordinated by UC Cooperative Extension. Because these programs are located in most counties throughout the state, they are uniquely situated to grow and collect data on the plants that are advanced from the first phase of the trials. Many counties have demonstration gardens, which make perfect sites for both data collection and exposure to the public.

The counties (and cities) currently participating in the second phase of the native plant trials are Shasta (Redding), Placer/Nevada (Grass Valley), Alameda (Livermore), Santa Clara (Palo Alto), Mariposa (Mariposa), Fresno (Fresno) and San Diego (Pt. Loma and Fallbrook) (fig. 3). The sites include coastal, inland valley and low mountain gardens, but all are within the boundaries of the climate zones recognized as "Mediterranean." As plants became available beginning in fall 2006 through fall 2007, each site was provided with six plants each of several prospective species advanced from the irrigation trial.

Master Gardeners in these areas have planted, tended and collected data on the plants provided. They are taking monthly measurements using the same protocol as the plant growth index used in the field trial. Soil types have been noted, irrigation frequency is being tracked and any unusual weather events noted. In addition, each garden is supplied with data sheets that allow them to rate each plant on a scale of 1 to 5 (poor to excellent) each month in five categories: foliage, flowering, pest resistance, disease resistance and overall vigor. Table 3 and figure 4 provide examples of the first year's compiled observations for rosy coral bells.

Over the course of the next few years, these data and observations will be cumulatively compiled across sites to determine if each plant has wide adaptability and appeal. Here especially, the Master Gardeners' experience will be invaluable. They will be able to render an opinion on a plant's garden-worthiness, as well as the response of the public to it over the course of its life in their garden. A plant thought interesting to an enthusiast may be completely unappealing to the average gardener, and might well prove unmarketable except at plant sales. That is not the plant we are looking for.

On the other hand, if a plant performs well and has wide appeal, we can create demand from an educated gardening public for these environmentally friendly introductions before they are even in the retail outlets. In addition, the wide range of demonstration garden situations will give us a more comprehensive set of cultural recommendations for growers, landscapers and home gardeners. Some of the Master Gardener groups have already begun sharing information on the program and its plants through garden signage, newsletters and local radio programs.

Propagation and production

In most regions of the country, propagation and production development is the purview of the commercial wholesale nursery industry. In Georgia, growers are invited to the university-managed test gardens each year to take cuttings of plants they are interested in and are encouraged to use their expertise to propagate and produce them (Armitage and Green 2001). In Arkansas, the nursery industry actually provides the university with the initial plants for their introduction trials, and the university provides them with the results (Lindstrom et al. 2001).

In our case, we are trying to persuade both the commercial industry and the public to use environmentally responsible, low-input plants with which they may be unfamiliar. Because of this, some of the initial propagation hurdles may have to be cleared by university and extension research. The highly successful Texas Coordinated Educational and Marketing Assistance Program (CEMAP) is a good model for cooperation between the university and the ornamental horticulture industry (Mackay et al. 2001). If a plant passes the various climate zone trials but is difficult to propagate, university and extension researchers tackle the problem until the best method is discovered. Graduate researchers at UC Davis and arboretum staff are continuing propagation research on our plants. Additionally, a commercial master propagator is currently working on protocols for several species, contributing the expertise of one who understands the requirements of mass production.

Fig. 3. Locations of Master Gardener demonstration gardens participating in the second phase of native plant trials.

TABLE 3. Rosy coral bells average annual ratings by Master Gardeners, fall 2006–fall 2007 (scale of 1–5, poor to excellent)

County (*Sunset* Zone)	Alameda (14)	Fresno (8)	Mariposa (7-central)	Nevada/ Placer (7-north)	San Diego 1 (24)	San Diego 2 (23)	Santa Clara (17)	Average
Foliage	3.6	4.3	4.4	4.8	4.6	2.9	4.5	4.1
Flowering	3.5	3.8	4.7	4.2	4.5	2.9	3.3	3.8
Pest resistance	4.9	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Disease resistance	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Overall vigor	3.3	4.2	4.7	5.0	4.8	2.7	4.7	4.2
Average	4.0	4.5	4.7	4.8	4.8	3.7	4.5	4.4

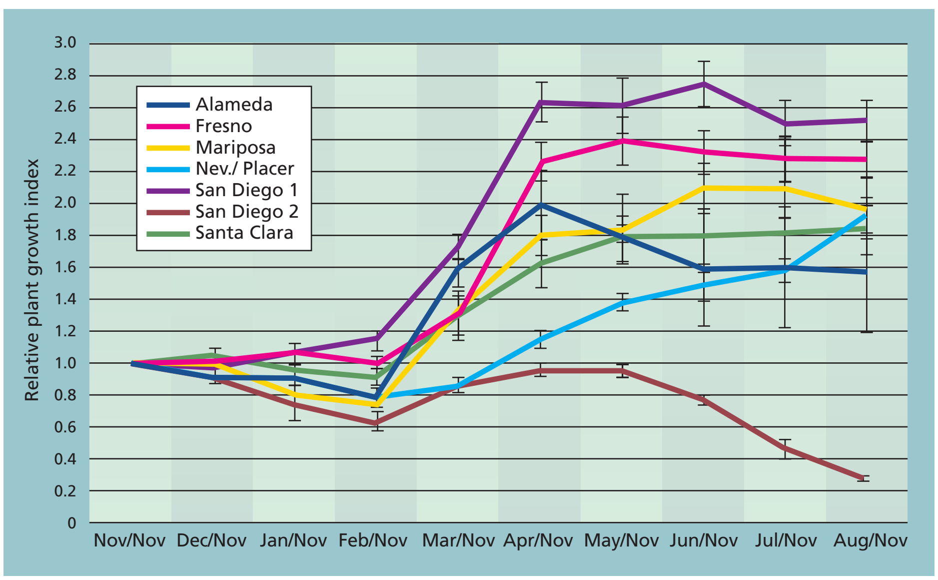

Fig. 4. Relative plant growth index for rosy coral bells in seven demonstration gardens, fall 2006–fall 2007. Bars represent 1 standard error.

Meeting market demand

Once a plant is ready for marketing, production schedules will be worked out to ensure sufficient supply to meet the expected demand at introduction. The National Arboretum has a regional cooperative program whereby growers and universities in seven southeastern plant-hardiness zones evaluate and increase the stock of plants slated for introduction (Dunwell et al. 2001). To ensure that these new plants are carefully screened, the National Arboretum controls their release through Material Transfer Agreements and centralized data analysis. After that, all the parties with an interest are involved in all aspects of testing and production, especially stock increase. In this way they can be assured of supply to meet the demand once a release date is announced (Pooler 2001).

In the hope of implementing at least part of the National Arboretum's model, the California Center for Urban Horticulture and its director Dave Fujino are currently acting as coordinators for the program's coalition, which comprises the UC Davis Arboretum, UCCE researchers, the previously mentioned commercial master propagator, several wholesale growers, a distributor and a horticultural marketing expert, all of whom have generously donated their time and resources. With the help of all parties, the first set of UC Davis Arboretum All-Stars is expected to be released in fall 2009.

Looking ahead

In the future, we hope to broaden the coalition of cooperating entities to include other botanical gardens, California Native Plant Society members, other university and junior college faculty with expertise in this area, and more members of the nursery and landscape industry with an interest in growing, selling and planting low-input plants. This model is based on several successful program examples such as those in Texas and Oklahoma, where candidates for field trials are put forth at annual meetings of large advisory committees composed of members from academia, extension services, botanical gardens and arboreta, professional landscape and nursery associations, and individual industry representatives. In these states, this group analyzes the results of the trials as well, and decides which plants are actually worthy of introduction (Anella et al. 2001; Mackay et al. 2001). Their goal, like ours, is to identify and promote plants that do well with minimal inputs throughout most of the state. In this way, all the parties who benefit from the trials and subsequent introductions can be included in the process from start to finish.

California consumers are increasingly aware of the need for environmentally sustainable horticultural practices. A large part of this sustainability is the use of plants requiring no chemical inputs and less water, mitigating the chemical load in watersheds and the waste of our precious water. The UC system — with its associated Cooperative Extension, Master Gardeners and California Center for Urban Horticulture — is ideally suited to establish and coordinate a cooperative effort with the nursery and landscape industries to introduce California native and other low-input plants to this new generation of consumers. Though this program is in its infancy, it holds great promise for fulfilling its goals of providing both producers and consumers with a large variety of beautiful plant materials, with greatly reduced negative impacts to the urban environment, for years to come.

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References

Anella LB, Schnelle MA, Maronek DM. 2001. Oklahoma proven: A plant evaluation and marketing program. HortTechnol 11(3):381–4.

Armitage AM, Green M. 2001. The university trial garden as a tool for evaluating and introducing new plant materials. HortTechnol 11(3):368–72.

Bailey HC, Deanovic L, Reyes E, et al. 2000. Diazinon and chlorpyrifos in urban waterways in Northern California, USA. Env Toxicol Chem 19:82–7.

Brenzel KN. 2007. *Sunset Western Garden Book* (8th ed.). Menlo Park, CA: Sunset Pub. 768 p.

[CalEPA] California Environmental Protection Agency. 2007. State Water Resources Control Board. Water Quality. Irrigated Agricultural Waivers Program. www.waterboards.ca.gov/agwaivers/index.html.

Costello LR, Matheney NP, Clark JR. 2000. A Guide to Estimating Irrigation Water Needs of Landscape Plantings in California. The Landscape Coefficient Method and Water Use Classification of Landscape Species. UC Cooperative Extension and California Department of Water Resources. www.owue.water.ca.gov/docs/wucols00.pdf.

Dunwell WC, Fare D, Arnold MA, et al. 2001. Plant evaluation program for nursery crops and landscape systems by the Southern Extension and Research Activities/Information Exchange Group-27. HortTechnol 11(3):373–5.

Hanak E, Davis M. 2006. Lawns and water demand in California. Cal Econ Pol 2(2):1–24. Public Policy Institute of California, San Francisco, CA.

Irmak S, Haman DZ, Irmak A, et al. 2004. Measurement and analyses of growth and stress parameters of *Viburnum odoratissimum* grown in a multi-pot box system. HortScience 39(6):1445–55.

Lindstrom JT, Robbins JA, Klingaman GL, et al. 2001. The University of Arkansas Plant Evaluation Program. HortTechnol 11(3):362–4.

Mackay WA, George SW, Davis TD, et al. 2001. Texas Superstar and the Coordinated Educational and Marketing Assistance Program (CEMAP): How we operate. HortTechnol 11(3):389–91.

Padilla FM, Pugnaire FI. 2007. Rooting depth and soil moisture control Mediterranean woody seedling survival during drought. Functional Ecol 21(3):489–95.

Pooler MR. 2001. Plant breeding at the US National Arboretum: Selection, evaluation and release of new cultivars. HortTechnol 11(3):365–7

[USNA] US National Arboretum. 2006. Web Version of the USDA Plant Hardiness Zone Map. USDA Misc Pub No 1475, 1990. www.usna.usda.gov/Hardzone/index.html.

Weston DP, Holmes RW, You J, Lydy JJ. 2005. Aquatic toxicity due to residential use of pyrethroid insecticides. Env Sci Technol 39(24):9778–84.

Wilen CA, Robinson G, Osborn S. 2001. Survey of residential pesticide use in an urbanized area of Southern California. HortScience 36(3):613.

RESEARCH ARTICLE

Pheromone-based pest management can be cost-effective for walnut growers

by Kimberly P. Steinmann, Minghua Zhang, Joseph A. Grant, Carolyn Pickel *and* Rachael E. Goodhue

Many organophosphate and pyrethroid insecticides currently used by California walnut growers have been linked to negative environmental or human health impacts, increasing the probability of use restrictions and phase-outs. We assessed the acceptability of alternative reduced-risk strategies by comparing their costs to those of pest management programs currently in use among San Joaquin County walnut growers. To do this, we analyzed data from the California Department of Pesticide Regulation's legally mandated Pesticide Use Reports on actual pesticide applications for 3 years, from 2002 to 2004. While many factors other than cost influence growers' pest management choices, we found that alternative strategies can be cost-competitive with conventional approaches, depending on the pest pressure and savings due to reductions in secondary pest outbreaks.

Important pests of walnuts include codling moth, walnut husk fly, navel orangeworm, aphids and mites. Alternative, reduced-risk pest control strategies, such as pheromone "puffers" for codling moth (shown), were compared with strategies currently in use by walnut growers in the San Joaquin Valley.

California produces 99% of walnuts nationwide, and this commodity is ranked 14th in the state with an annual value of $610 million (USDA 2006). The most important walnut pests that can cause significant economic loss are codling moth (*Cydia pomonella*) and, in certain areas, walnut husk fly (*Rhagoletis completa*). Webspinning mites (*Tetranychus* spp.) and aphids (primarily *Chromaphis juglandicola*) can also cause economic damage if not controlled by natural predators. The current management of these pests is based on periodic treatments with organophosphates, pyrethroids, growth-regulating insecticides and miticides.

However, many products frequently used by walnut growers are being reevaluated for reduction or elimination by regulatory bodies due to adverse human health or environmental risks. For example, 22 of the 30 active ingredients used to control walnut arthropod pests such as codling moth, walnut husk fly, aphids and mites from 2002 to 2004 could be affected by proposed changes stemming from the federal Food Quality Protection Act (FQPA) of 1996. In addition, nine of these 30 active ingredients are currently listed as impairing California water bodies under the Clean Water Act of 1972, and more are likely to be listed as water quality monitoring is extended to additional insecticides and miticides (US EPA 1997, 2002; CDPR 2005).

Because some of these pesticides are broad spectrum and have long residual activity, they kill beneficial insects as well as the targeted pests. The loss of beneficial insects can result in outbreaks of secondary pests such as mites and aphids, necessitating additional treatments and further increasing the potential for negative environmental impacts (Agnello et al. 2003; Prischmann et al. 2005; Zalom et al. 2001).

Stemming from impending regulatory changes as well as growers' heightened awareness of environmental and worker safety, new technologies have emerged in the form of alternative, lower risk products for controlling arthropods. These include pheromone mating disruption, biopesticides and growth-regulating insecticides. Mating disruption works through the inundation of an orchard with synthetic chemicals designed to mimic pheromones that are released by females to attract males of a species, thus decreasing the male's ability to locate a female and successfully mate. Biopesticides are microbial and biochemical controls with microorganisms naturally antagonistic toward pests, while insect growth regulators disrupt hormone functions responsible for molting, maturation and other insect life-cycle processes. Although varying in their modes of action, these new, narrow-spectrum alternatives selectively control pests and are less disruptive to beneficial insects and mites. Many of these new approaches also reduce the risk that orchard pesticide applications will adversely affect wildlife, water quality and human health (US EPA 2006).

Recent studies have documented the effectiveness of certain alternative strategies for controlling codling moth and walnut husk fly in walnuts (Coates et al. 2001; Flora et al. 1999; Pickel et al. 2007; Van Steenwyk et al. 2005), and growers have begun integrating some of these approaches into their orchard management programs. However, alternative approaches may be more expensive due to an increased number of applications, higher material costs, a greater time commitment for orchard pest monitoring, and lower numbers of pest species controlled per application. Because growers will not broadly adopt alternative technologies unless they are effective and economical, we compared the costs of selected alternative strategies to those of conventional strategies for controlling key pests of walnuts.

Conventional strategies and costs

The first step in comparing the economic feasibility of alternative and conventional strategies was to define the specific products, use rates and application costs associated with each strategy. To define conventional strategies, we used actual grower data from the California Department of Pesticide Regulation's Pesticide Use Reports (PUR), a public database of legally mandated pesticide application reports (CDPR 2005). The PUR database offers a wealth of information about California growers' pesticide use, including active ingredients, amount per acre applied and number of applications per season. This allowed us to compile comprehensive, detailed and accurate representations of individual grower's pest management strategies based on reported pesticide use in the study area.

We analyzed PUR data for walnut orchards in San Joaquin County for 2002 through 2004. San Joaquin County is California's leading walnut-producing county, with just under 32,000 acres of orchards accounting for about 16% of the annual walnut crop value statewide (CASS 2004). From 2002 to 2004, 372 to 384 San Joaquin County walnut growers reported pesticide use in the PUR database (CDPR 2005).

For each of the 3 years studied, we created a subset of the PUR database that included only those growers who appeared to have treated solely for codling moth, or for codling moth plus other pests, based on product choice and timing criteria. Codling moth was the focal pest for defining the project's PUR subset for analysis, given its economic importance as a walnut pest and the promise of pheromone mating disruption as an effective control. However, for each grower in the subset, the grower's pest management strategy was defined as all of the arthropod pest controls used throughout the entire season on all orchards listed under a grower's PUR identification number. Therefore, the pest management strategies of a single grower could have been included for 1, 2 or all 3 years, depending on whether they treated for codling moth in a given year. As a result, there were approximately 220 pest management strategies analyzed each year, with a total of 661 strategies over the 3 years combined.

Integrated pest management, along with new technologies such as pheromone mating disruption, biopesticides and growth-regulating insecticides, help to protect farmworkers and the environment. Retired Butte County farm advisor Bill Olson monitors for codling moth by hanging traps in walnut orchards.

We calculated the costs of conventional strategies reported in the PUR database using the amounts of product applied per acre and their 2003 prices, and adding a standardized cost for each application in a treatment that covered fuel, labor and maintenance. We assumed that all pesticide applications were made by a conventional orchard air-blast sprayer. Multiple pesticides reported by a grower on the same date and same acreage were assumed to be combined into a single "tank mix" application. All insecticide and miticide costs were then summed to arrive at a total pest-management strategy cost per acre for each grower's conventional strategy in each year.

Sarah Goldman Smith

While many walnut growers are trying out alternative pest-control strategies, the analysis of California Pesticide Use Reports from 2002 to 2004 found that actual adoption rates are low. *Left to right*, Rick Enos of Carriere Farms, Tom Larsen of Suterra, Bill Carriere, Christine Abbott of Suterra and Glenn County farm advisor Bill Krueger learned about pheromone puffers at Carriere Farms in Glenn County.

TABLE 1. Average annual conventional pest-management strategy costs of San Joaquin County walnut grower sample

Grower chemical class	Strategies analyzed	Average cost/acre*
	no. (average/yr.)	*$*
Combination	262 (87)	160 a†
Organophosphate	350 (117)	124 b
Pyrethroid	49 (16)	73 c
All classes	661 (220)	134

* Data pooled over the 3 years (insignificant effect of year on cost).

† Means in columns with different letters differ ($P < 0.05$), least squares mean test with square-root transformation to meet normality and homogeneity of variance assumptions.

We compared costs for the entire subset of pest management strategies in the PUR database for a given year, as well as divided the subset into three groups based on the predominant chemical class of FQPA-targeted insecticides used to control codling moth, aphids and walnut husk fly: organophosphate, pyrethroid or a combination of the two. Therefore, while a single grower could potentially contribute up to three pest-management strategies to the analysis, the chemical class could vary annually, depending on the grower's product choice in a given year.

Combining the 3 years studied, 53% of all growers' pest management strategies were classified as organophosphate, 7% were pyrethroid and 40% were combinations of the two (350, 49 and 262 strategies, respectively). Control costs varied widely within each group depending on the products used, their rates and the number of applications per season, but there were significant differences among the groups' total costs (table 1). Combination strategies had the highest average annual control costs at $160 per acre, followed by organophosphate at $124 per acre and pyrethroid at $73 per acre.

Alternative strategies and costs

Based on recent research and the advice of experts, we created alternative pest-management strategies that are both low environmental risk and considered effective for controlling codling moth, aphids and walnut husk fly at levels commonly encountered in the study area (table 2). All the strategies were based on the control of codling moth using pheromone mating disruption (E,E,-8,10-Dodecadien-1-ol) dispensed with bulk aerosol "puffers," which saturate the orchard atmosphere with pheromone for up to 180 days through regularly timed releases (Suterra, LLC).

Recent research has shown that in orchards with low or moderate populations, pheromone puffers can provide control of codling moth equivalent to that of conventional pesticides (Pickel et al. 2007). For orchards with severe codling moth infestations, one or more supplemental insecticide applications may be necessary to achieve control comparable to that of conventional spray programs. We created and analyzed two pheromone-based alternative strategies judged capable of providing control under varying degrees of codling moth pressure: one in which pheromone puffers were the only method of control, and another of puffers plus a single supplemental application of the insect growth regulator methoxyfenozide (Intrepid).

Both alternative strategies also included a single application of chlorpyrifos (Lorsban) to control aphids. Chlorpyrifos is an organophosphate of regulatory concern, but there were no effective reduced-risk products available for controlling aphids in walnuts at

TABLE 2. Alternative strategies to control codling moth, aphids and walnut husk fly

Alternative strategy	Sprays	Codling moth	Aphid	Walnut husk fly	Cost per acre
	no.				*$*
Low codling moth pressure and no husk fly	1	Pheromone puffer Puffer installation labor	Chlorpyrifos (Lorsban 4E)		108
Low codling moth pressure and husk fly	3	Pheromone puffer Puffer installation labor	Chlorpyrifos	Spinosad (Success) Corn gluten meal (NuLure)	193
High codling moth pressure and no husk fly	2	Pheromone puffer Puffer installation labor Methoxyfenozide (Intrepid 2F)	Chlorpyrifos		164
High codling moth pressure and husk fly	4	Pheromone puffer Puffer installation labor Methoxyfenozide	Chlorpyrifos	Spinosad Corn gluten meal (NuLure)	248

the time of the study. The chlorpyrifos rate used for our alternative strategies is adequate to provide good control of aphids while reducing the risks of disrupting biological control in the orchard, as well as off-site environmental effects. To control walnut husk fly (in addition to codling moth), our alternative strategies included two alternate-row applications of spinosad (Success), a selective microbial insecticide, along with a feeding-attractant corn gluten meal bait (NuLure). This bait was also included with the chlorpyrifos application for aphids, so as to attract walnut husk fly and allow chlorpyrifos to simultaneously serve as both a walnut husk fly and aphid control. Navel orangeworm was not analyzed because its life cycle did not significantly overlap with codling moth's, and most growers in the county did not consider it an important pest.

The alternative strategies compare favorably in cost to conventional strategies currently in use by a large portion of walnut growers in the study area.

TABLE 3. Products, rates, prices and application number for alternative strategies

Control	Application rate	Price	Applications per season
	no. or amount/acre	*$*	*no.*
Puffer (pheromone)	1 (per 2 acres)	120/puffer	1
Methoxyfenozide (Intrepid 2F)	1 pint	40/pint	1
Chlorpyrifos (Lorsban 4E)	4 pints	5.59/pint	1
Spinosad (Success)	0.2 pint	105.75/pint	2
Corn gluten meal (NuLure)	3 pints	2.99/pint	3
Labor for puffer installation		10/acre	1
Orchard sprayer application*		15.57/application	1–4

* Assumed equal for all growers (Buchner et al. 2002).

Study assumptions

Although the PUR does not require growers to report what pests a pesticide application is meant to control, we inferred which pests were targeted based on the product used, time of application, advice of experts and results of a 2005 survey of San Joaquin walnut growers about their specific problem pests and the products they use to control these pests (Steinmann et al., unpublished). Because growers sometimes use the same materials and application timings for controlling codling moth and aphids, treatments for these pests could not be distinguished from one another in our analysis. All growers were therefore assumed to control for aphids as well as codling moth.

Similarly, we could not determine if a grower had high or low codling moth pressure based on the PUR data. Given the focus of this paper on codling moth and pheromone mating disruption, we decided to assess the sensitivity of our results to codling moth pressure by running the analysis under two blanket assumptions. The first analysis assumed that *all growers* have a low-to-moderate codling moth pressure, and therefore puffers were enough to control codling moth. The second analysis assumed that *all growers* have high codling moth pressure, and therefore the insect growth regulator methoxyfenozide was also required to control codling moth effectively.

Walnut husk fly treatments in our alternative strategies were applied to every other tree row, based on the results of recent efficacy studies (Van Steenwyk et al. 2005). The calculated costs of four alternative strategies for controlling codling moth and aphid alone — or codling moth, aphid and walnut husk fly — ranged from $108 to $248 per acre, depending on codling moth pressure and other target pests (tables 2 and 3). Mite controls were not included in these hypothetical alternative-strategy cost values, so that they could be added selectively based on varying biological control effectiveness assumptions.

Mite control

In a variety of field and orchard crops, broad-spectrum insecticides may disrupt the biological control of mites, triggering secondary mite outbreaks that necessitate further pesticide use (Agnello et al. 2003; Prischmann et al. 2005; Zalom et al. 2001). In many instances, substituting more-selective insecticides has helped reduce the severity of these secondary mite infestations and in turn the overall costs of managing orchard pests. While such effects have neither been confirmed nor ruled out for walnuts so far, reductions in mite control costs could significantly increase the economic feasibility of alternative approaches.

To predict how reduced miticide use would affect the economic feasibility of our alternative strategies for controlling codling moth, aphid and walnut husk fly, we assessed three possible mite management outcomes:

(1) Eliminated. Biological control maintains mites below economically damaging levels; grower's miticide costs, per the PUR database, were not added to the costs of the alternative strategies.

(2) Reduced. The narrow-spectrum nature of the alternative strategy allowed for some improvement in biological mite control; half of the grower's reported miticide costs were added to the costs of the alternative strategies.

(3) Unchanged. The use of alternatives had no effect on mites; all of the grower's reported miticide costs were added to the costs of the alternative strategies.

Economic feasibility

While many factors influence growers' choices of pest management strategies, we chose to assess the feasibility of alternative over conventional strategies by comparing their costs. To estimate the share of growers who would consider an alternative strategy economically feasible, we proposed that growers would adopt the strategy if its cost was equal to or less than that of their current conventional strategy. Using this criterion for economic feasibility, we calculated the percentages of growers' pest management strategies for which costs are greater than or equal to that of the various alternative strategies. The implication is that these alternative strategies would be economically feasible for controlling codling moth, aphid, mite and walnut husk fly under matching presence and abundance of these pests in their orchards.

TABLE 4. Percentage of pest management strategies in each chemical class with costs greater than or equal to costs of alternative strategies with varying levels of reduction in mite control costs

	Mite control costs		
Chemical class	Eliminated	Reduced	Unchanged
	. . . .	%	
Low-to-moderate codling moth pressure			
Combination	62	48	25
Organophosphate	52	31	16
Pyrethroid	12	8	4
All classes	53	36	19
High codling moth pressure			
Combination	19	7	4
Organophosphate	7	3	1
Pyrethroid	2	0	0
All classes	12	4	2

Under the best-case scenario with low-to-moderate codling moth pressure, coupled with no secondary pest mite infestation, the pest control costs for 53% of the reported pest management strategies were greater than or equal to the cost of the associated alternative strategy (table 4). Breaking the conventional strategies down by chemical class, we found that costs were greater than or equal to the alternative strategy for 62% of those that combined organophosphate and pyrethroid, 52% of organophosphate strategies and 12% of pyrethroid strategies.

However, under the assumption of high codling moth pressure requiring a supplemental insecticide application, coupled with no secondary pest mite infestation, only 12% of the conventional pest-control strategies were more costly than or equal to the alternative strategies. Again, breaking the conventional strategies down by chemical class, costs were greater than or equal to the alternative strategies for 19% of combination strategies, 7% of organophosphate strategies and only 2% of pyrethroid strategies.

The feasibility of alternative strategies also dropped when we added half or all of PUR-derived mite control costs to reflect poorer biological control of these pests. With low codling moth pressure, adding half of the reported mite control costs reduced the economic feasibility of the alternative strategies from 53% to 36%. When all of the reported mite-control costs were added, the alternative strategies' economic feasibility dropped even further to 19%. When codling moth pressure was low-to-moderate and half of the miticide costs could be saved, only 48% of combination strategies, 31% of organophosphate strategies and 8% of pyrethroid strategies had costs greater than or equal to those of the alternative strategies. When mite control costs were unchanged, these figures dropped further to 25%, 16% and 4%, respectively.

Finally, for high codling moth pressure, adding half of mite control costs dropped the alternative strategies' economic feasibility from 12% to 4%. When full mite control costs were included, economic feasibility dropped even further to only 2%. When miticide costs were reduced by half, 7%, 3% and 0% of combination, organophosphate and pyrethroid strategies, respectively, had costs greater than or equal to those of alternative strategies. When miticide costs remained unchanged, these figures were 4%, 1% and 0%, respectively.

In three important respects, our alternative strategies were constructed conservatively and, as such, may be more acceptable among walnut growers than our findings indicate. First, recent findings from large-scale pheromone puffer trials in walnuts suggest that repeated use over several years can reduce codling moth to acceptable levels even in orchards with high populations (Pickel et al. 2007). Second, we assumed that all growers use a low-dose application of chlorpyrifos to control aphids, but not all orchards are treated for aphids each year. In a 2006 survey of San Joaquin County walnut growers, for example, only 48% of respondents reported treating for aphids (Steinmann et al., unpublished). Third, we assumed that alternatives must have an equal or lower cost than conventional strategies to be acceptable, but growers may elect to use alternative strategies even if they are more costly than conventional approaches.

For example, in a 2002 survey of San Joaquin County walnut growers by the UC Sustainable Agriculture Research and Education Program (SAREP), 56% of 299 respondents agreed "somewhat to strongly" with the statemen, "It's worth using practices that reduce my overall chemical use even when it might take a little more expense" (Beverly Ransom et al., unpublished). Similarly, a 1999 analysis of U.S. Midwestern corn and soybean farmers showed that they would be willing to pay an average of $8.25 per acre more for alternative farming practices that reduced risks to the environment (Lohr et al. 1999). The reasons for such willingness may include real or perceived reductions in risks to worker health, orchard ecology or the environment, and the proximity of the farming operation to urban areas, homes and schools.

Low adoption rates

Our analysis of PUR-reported pesticide use showed that many growers have not adopted alternative pest-management strategies despite their willingness to incur slightly higher costs when surveyed in 2002. Over the 3 years of our study, for example, only 13% to 17% of growers used at least one application of an alternative product during the growing season. Of these growers, 58% to 63% used more than one application of broad-spectrum insecticide in addi-

Jack Kelly Clark

Codling moth (adult, shown) is a major pest of walnuts and other orchard crops.

tion to the alternative products. Only 5% to 7% had strategies that included broad-spectrum materials at lower rates that were roughly equivalent to those used in our alternative strategies.

There are many possible reasons for the low rate of adoption among growers, including lack of familiarity, higher material costs, risk of lower yields and revenues due to lower efficacy, and new requirements for increased monitoring and attention to the timing of applications. Our results suggest that the alternative strategies we analyzed compare favorably in cost to conventional strategies currently in use by a large portion of walnut growers in the study area, dependent on the effectiveness of biological control. The highest percentages of conventional pest-management strategies that could be most feasibly replaced by an alternative strategy appear to be those employing a combination of organophosphates and pyrethroids throughout the season, followed by those using predominantly organophosphates.

Due to their low cost, pyrethroid strategies would be the least likely to be replaced by alternative strategies. The low cost and high efficacy of pyrethroid insecticides, in conjunction with the current regulatory focus on restricting the use of organophosphates, have made pyrethroids an attractive option for growers. However, the future availability of pyrethroids is threatened by recent studies on the adverse environmental impacts of these materials and on the risk that increased use may accelerate pest resistance (Belden and Lydy 2006; Brun-Barale et al. 2005).

Adoption of alternative strategies

Our results suggest that significant reductions in pesticide use could be achieved through the broader adoption of alternative strategies in the study area. For example, over the three study years, 21,665 acres were treated at an average use rate of 3.75 pounds per acre of FQPA-targeted insecticides and miticides. Under our best-case alternative strategy of low-to-moderate codling moth pressure and the complete elimination of miticides, this rate could be reduced by 43% to 2.13 pounds per acre. Even under the worst-case scenario of high codling moth pressure and unchanged miticide costs, the use of FQPA-targeted pesticides would be reduced by around 6%.

These results open new doors toward potential areas of study that can foster improvements in many already-existing alternative pest controls. As research continues to unveil the interactive dynamics of pests, natural predators and their orchard environment, as well as new ways to manipulate these interactions, there is great potential for increasing the use of existing reduced-risk products and for the development of new ones. Although many unknowns remain, our analysis suggests that alternative, narrow-spectrum pest control strategies such as pheromone puffers may be both economically and environmentally viable in the long run, contributing to sustainable walnut production that is beneficial to growers, consumers and the environment.

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References

Agnello AM, Reissig WH, Kovach J, Nyrop JP. 2003. Integrated apple pest management in New York State using predatory mites and selective pesticides. Ag Ecosys Env 94:183–95.

Belden JB, Lydy MJ. 2006. Joint toxicity of chlorpyrifos and esfenvalerate to fathead minnows and midge larvae. Env Toxicol Chem 25(2):623–9.

Brun-Barale A, Bouvier JC, Pauron D, et al. 2005. Involvement of a sodium channel mutation in pyrethroid resistance in *Cydia pomonella* L, and development of a diagnostic test. Pest Manage Sci 61:549–54.

Buchner RP, Edstrom JP, Hasey JK, et al. 2002. Sample Costs to Establish a Walnut Orchard and Produce Walnuts, Sacramento Valley, Sprinkler Irrigated. UC Cooperative Extension. WN-SV-02 http://coststudies.ucdavis.edu/files/walnutsac2002.pdf. 19 p.

[CASS] California Agricultural Statistics Service. 2004. 2003 California Walnut Acreage Report. www.nass.usda.gov/Statistics_by_State/California/Publications/Fruits_and_Nuts/200405walac.pdf.

[CDPR] California Department of Pesticide Regulation. 2005. Pesticide Use Reports Database. http://calpip.cdpr.ca.gov/cfdocs/calpip/prod/infodocs/about-pur.cfm (accessed January 2005).

Coates W, Van Steenwyk R, Nomoto RM. 2001. Evaluations of insecticides for codling moth control in walnuts — 2000. California Walnut Marketing Board Research Reports 2000. Sacramento, CA. http://walnutresearch.ucdavis.edu/2000/2000_257.pdf. p 257–68.

Flora EA, Olson BD, Bisabri B. 1999. Spinosad effect on Dipterous pests of fruit and potential as a fruit protectant. Proc 73rd Annual Western Orchard Pest and Disease Management Conf. Washington State Univ, Portland, OR. http://entomology.tfrec.wsu.edu/wopdmc/1999PDF/4-Chemical/Chemical%2099-23.pdf. p 79–81.

Lohr L, Park T, Higley L. 1999. Farmer risk assessment for voluntary insecticide reduction. Ecol Econ 30:121–30.

Pickel C, Grant JA, Welter SC, et al. 2007. Using aerosol pheromone "puffers" for area-wide suppression of codling moth in walnuts: Year 2 and demonstration of aerially applied pheromone laminate flakes. California Walnut Marketing Board Research Reports 2006. Sacramento, CA. http://walnutresearch.ucdavis.edu/2006/2006_137.pdf. p 137–53.

Prischmann DA, James DG, Wright LC, et al. 2005. Effects of chlorpyrifos and sulfur on spider mites (Acari: Tetranychidae) and their natural enemies. Biologic Control 33:324–34.

[USDA] US Department of Agriculture. 2006. Summary of County Agricultural Commissioner's Reports, 2004–2005, National Agricultural Statistics Service, California Field Office, Sacramento, CA. www.nass.usda.gov/Statistics_by_State/California/Publications/AgComm/200508cavtb00.pdf.

[US EPA] US Environmental Protection Agency. 1997. Federal Register. Environmental Documents, Raw and Processed Food Schedule for Pesticide Tolerance Reassessment. www.epa.gov/fedrgstr/EPA-PEST/1997/August/Day-04/p20560.htm.

US EPA. 2002. CWA Section 303(d) List of Water Quality Limited Segment: Central Valley Regional Water Quality Control Board. www.waterboards.ca.gov/tmdl/docs/2002reg5303dlist.pdf.

US EPA. 2006. Pesticides: Health and Safety. Reducing Pesticide Risk. Reduced Risk/Organophosphate Alternative Decisions for Conventional Pesticides. www.epa.gov/pesticides/health/reducing.htm (accessed January 2006).

Van Steenwyk RS, Zolbrod K, Nomoto R, Fernandez TK. 2005. Control of walnut husk fly using reduced risk products. California Walnut Marketing Board Research Reports 2004. Sacramento, CA. http://walnutresearch.ucdavis.edu/2004/2004_159.pdf. p 159–78.

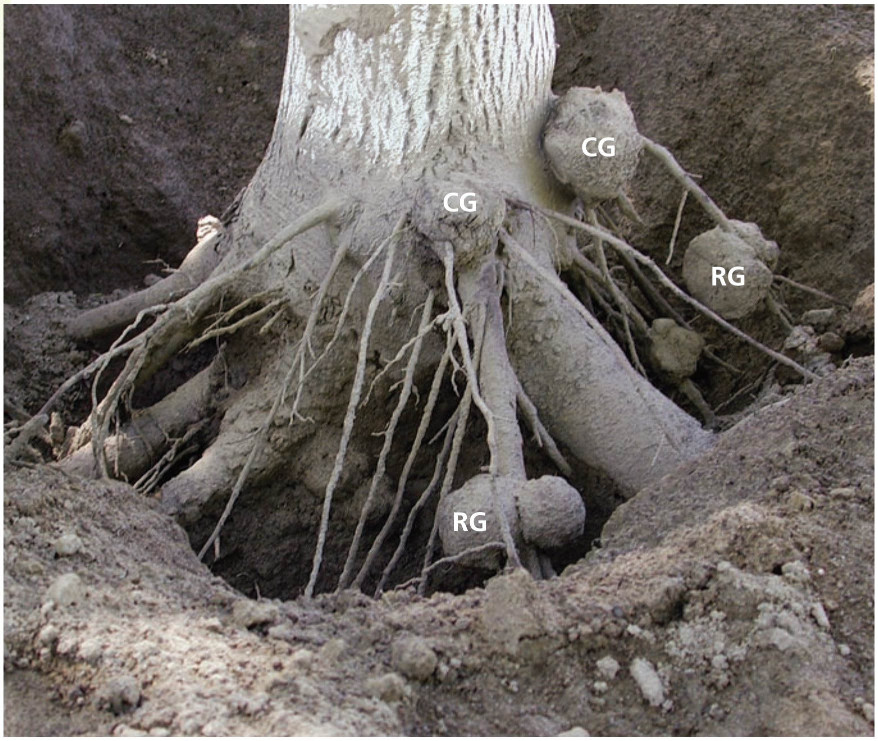
Zalom FG, Stimmann MW, Arndt TS, et al. 2001. Analysis of permethrin (cis- and trans-isomers) and esfenvalerate on almond twigs and effects of residues on the predator mite *Galendromus occidentalis* (Acari: Phytoseiidae). Env Entomol 30(1):70–5.

RESEARCH ARTICLE

Crown gall can spread between walnut trees in nurseries and reduce future yields

by Lynn Epstein, Sukhwinder Kaur, James R. McKenna, Joseph A. Grant, William H. Olson *and* Wilbur O. Reil

While walnut trees on Juglans hindsii x J. regia 'Paradox' rootstocks are highly susceptible to crown gall, it is unknown whether this bacterial disease is acquired in the nursery or the orchard. We selected two groups of gall-free trees in nurseries, those adjacent to trees with and without galls. Two years after being transplanted in the orchard, trees in the group adjacent to those with galls had significantly greater — more than four times more — crown gall incidence than those adjacent to trees without galls (14% versus 3%). In addition, trees in prolonged (17-day), bare-root, unrefrigerated storage before transplanting were associated with higher crown-gall incidence. We also found that crown gall can decrease walnut tree productivity. For every quarter of trunk circumference that was galled, there was a 12% decrease in cumulative nut yield over the first 4 years of production.



Crown galls (CG) and root galls (RG) are caused by *Agrobacterium* spp. Root galls generally have little impact, but crown galls may affect walnut tree growth and yield.

The United States is the largest producer of walnuts in the world, with nearly all the walnut acreage concentrated in California. In California, walnuts (*Juglans regia,* the 'English' walnut) are commonly grafted onto 'Paradox' rootstocks, which have a *J. regia* male parent and a black walnut female parent, generally *J. hindsii* (Potter et al. 2001). While 'Paradox' is vigorous and performs well in a variety of conditions, this rootstock is extremely susceptible to crown gall disease (McKenna and Epstein 2003).

Young galls are somewhat soft and spongy, not hard, and lack annual growth rings. Although large, gnarled galls sometimes are visible at ground level, most galls are belowground on the crown (the juncture between the main roots and the trunk), or scattered along the roots. In contrast to galls on the crown, galls on the roots are generally smaller, and appear to have little impact on most trees (see photo).

Crown gall on walnuts is caused by two species of bacteria: *Agrobacterium tumefaciens* and *A. rhizogenes* (Young et al. 2001). *A. tumefaciens* is also known as *A. tumefaciens biovar 1*, *A. radiobacter* and *Rhizobium radiobacter*, while *A. rhizogenes* is also known as *A. tumefaciens biovar 2* and *R. rhizogenes*. In California, *A. tumefaciens* is a more common causal agent of crown gall in 'Paradox' than *A. rhizogenes* (Kaur and Epstein, unpublished), although the reverse may be true in Oregon or other locales (Moore and Canfield 1996).

Interactions between *A. tumefaciens* and various host plants have been investigated extensively on a molecular level. However, scientists know less about the impact of the disease and how the pathogen survives and spreads in nature. In 1912, Smith et al. stated that crown galls are "injurious to the plant in varying degrees, depending on the species, on the parts attacked, on the size and vigor of the individual, etc. They are most injurious to young and rapidly growing plants."

According to the literature, the impact of crown gall on fruit and nut trees varies. For example, Garrett (1987) reported that crown gall had no consistent impact on the growth of cherry trees, while others have reported that the disease causes stunting of pecans (Bouzar et al. 1983) and peaches (Htay and Kerr 1974), and mortality of peaches and cherries (Kainski 1964). However, we are unaware of reports in which the effect of gall on yield has been quantified. This information is essential for developing cost-effective recommendations for the prevention and treatment of this disease.

Crown gall affects nut and fruit trees in both nurseries and orchards. Based on observations of stone fruit trees, Moore (1976) and Alconero (1980) suggested that some infections are "latent," occurring in the nursery, but only developing galls after transplantation. Using more modern technology of DNA sequencing, Pionnat et al. (1999) concluded that pathogenic *A. tumefaciens* was transmitted on asymptomatic rootstocks of roses, and that the transmitted pathogen then caused disease in some buyers' fields. However, it is not known whether the infections occurred in the nursery or after transplanting.

We present an experiment and an observational study in which pretransplant practices affected subsequent crown gall disease in walnut orchards. In addition, we quantified the negative impact of crown gall on the yield of young walnut trees.

TABLE 1. Effect of location of 'Paradox' walnut seedlings in the nursery on subsequent development of crown gall in an orchard*

Next to a tree with a gall in the nursery?	Wounded before transplanting?	Trees with gall(s) at the crown†	Trees with gall(s) on the root‡	Trees with galls§
		%		
No	No	2	16	17
No	Yes	3	21	24
Yes	No	13	21	26
Yes	Yes	14	26	34

* Data analyzed by log linear models.

† A model in which a gall at the crown was independent of both nursery position and wounding was rejected ($P = 0.005$). Similarly, a model with gall dependent on wounding but not on nursery position was rejected ($P = 0.0002$). However, a model with gall dependent on nursery position but not on wounding was not rejected ($P = 0.88$).

‡ No significant ($P > 0.05$) effects within this column.

§ A model in which a gall was independent of both nursery position and wounding was barely rejected ($P = 0.0495$). A model with gall dependent on nursery position but not on wounding was not rejected ($P = 0.22$). Similarly, a model with gall dependent on wounding but not on nursery position was not rejected ($P = 0.088$).

The pathogen can be acquired in the nursery, but a visible gall is not produced until after transplantation.

Nursery location and wounding

Study design. In January 1999, we selected two groups of 200 trees without galls during tree harvest at a commercial walnut nursery in California. The first group of nongalled trees had grown next to trees without galls, and the second group had grown next to trees with galls. The selected trees were stored in sawdust beds.

Immediately before transplanting in March 1999, half of the trees in each group were wounded in the crown and taproot region by making 10 sweeping, horizontal cuts with a serrated blade; some of the cuts also extended onto the lateral roots. Trees were wounded because the pathogen infects wounded cells, and our (largely incorrect) expectation was that wounded trees would have more disease than unwounded trees. Trees were transplanted into a field with no history of crown gall at the UC Davis Armstrong Farm. The trees were planted in a randomized block design with one replicate of each of the four treatments in 100 blocks. In November 2000, the trees were dug up, the roots were washed and the incidence of crown gall was recorded.

Nursery location. The transplanted 'Paradox' trees that had been next to trees with galls were significantly more likely to have galls at the crown than transplanted trees that had been next to gall-free trees in the nursery (14% versus 3%; table 1). The location history of a tree in the nursery did not have a significant effect on the incidence of galls on the roots, but did have a significant effect at $P < 0.05$ on the incidence of galls overall. We found that the location history of the tree in the nursery can have a significant effect on the incidence of galls in an orchard, demonstrating that the pathogen can be acquired in the nursery, but a visible gall is not produced until after transplantation.

Wounding. The wounding treatment had no effect on the incidence of galls on the crown, but did have a slight effect on the incidence of galls overall because of a slightly higher incidence of galls on wounded than unwounded roots. McKenna and Epstein (2003) demonstrated that galls are associated with wounds that penetrate into the cambium or perhaps the phloem. In the crown, the cambium is the thin layer between the bark and the hardwood, and the phloem is a thin layer on the inside of the bark.

In our experience, wounds incurred during the normal course of harvesting and transplanting trees from commercial nurseries are rarely sufficiently deep to induce a gall, particularly in the crown region. To date, we have had four trials in which root-pruned transplants from a nursery were planted and dug again after 2 years (tables 1 and 2) (McKenna and Epstein 2003; Kaur and Epstein, unpublished). Galls were rarely present in locations with root-pruned transplants, even though the

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Most California walnut orchards are 'English' walnuts grafted onto 'Paradox' rootstock, which is highly susceptible to crown gall disease.

TABLE 2. Effect of pretransplant handling on subsequent crown gall incidence on 'Paradox' walnut rootstocks planted in three locations

Trial type	County	Gall location	Initial nursery-storage group*		
			A	B	C
			· · · · · · *trees with gall, %* · · · · · ·		
Screening†	Fresno	Crown or roots	8	9	49
Screening†	Fresno	Crown	0	3	21
Orchard trial‡	Yolo	Crown	5	6	12
Orchard trial‡	San Joaquin	Crown	10	8	21

* In winter 1997-1998, 0.24%, 2.4% and 1.1% of trees were galled in nursery sites A, B and C, respectively. Nongalled trees from sites A, B and C were stored nonrefrigerated and bare-root for 3, 6 and 17 days, respectively, on pallets before "healing in." For each trial, trees were planted in 1998 in a completely randomized block design with each replicate containing one or, less frequently, two trees from each initial nursery-storage group.

† Trees were dug, washed and rated for gall in February 2000. Pairwise comparisons using 2 and $P = 0.05$ adjusted by the Bonferroni method to $P = 0.016$ indicate that trees from the initial nursery-storage group C had significantly ($P = 0.0001$) more gall on either the crowns and/or roots than trees from other groups, and that gall incidence in trees originating from groups A and B was not significantly different from each other ($P = 0.6$ and $P = 0.05$ for either the crown or roots, and crown only, respectively).

‡ Galls protruding above the soil were evaluated in fall 2002. Analysis by log-linear models indicated that nursery-storage group ($P = 0.0001$) and location of orchard trial ($P = 0.001$) significantly affected post-transplantation incidence of crown gall; no interaction terms are required in the model ($P = 0.71$). Pairwise comparisons of gall on trees originating from different nursery-storage groups, using $P = 0.05$ adjusted by the Bonferroni method to $P = 0.016$, indicated that trees originating in nursery-storage group C had significantly ($P \leq 0.0002$) greater gall incidence than trees from the other two groups. Also, trees originating from groups A and B did not differ ($P = 0.56$).

biological control agent K84 *(A. rhizogenes)* was never used. In contrast, galls frequently formed at natural wounds such as sites where roots emerged, and they occasionally formed where suckers emerged.

Storage impacts on disease

Study design. In September 1996, three nursery sites (A, B and C) in Stanislaus County were fumigated with 425 pounds per acre of methyl bromide and chloropicrin (75:25) to kill pests, pathogens and weeds. In November 1996, each site was planted with seeds from a variety of 'Paradox' source trees, and the parentage mix was the same at all three sites. In 1998, 3,219 to 3,973 trees per site from sites A, B and C were dug on Feb. 23, Jan. 21 and Jan. 10, respectively. After digging, trees were washed and inspected for gall, and those with galls were discarded, as is standard nursery practice. Nongalled trees from sites A, B and C were stored bare-root in open-air conditions on pallets in unrefrigerated barns for 3, 6 and 17 days, respectively. These temporary, open-air storage times varied primarily due to El Niño rains, which delayed transfer to "healing-in" beds. During storage, the tree roots were wetted with a hose three times per day.

After storage, trees from sites A, B and C were placed in healing-in beds for 6, 35 and 35 days, respectively. To heal-in, trees were buried upright in trenches of sandy soil that had been fumigated with methyl bromide and chloropicrin. Next, trees were washed free of soil and placed in a single commercial cold-storage facility for 8, 14 and 90 days, respectively.

After storage, the trees were planted in Yolo, San Joaquin and Fresno county sites. The Yolo and San Joaquin county trials were planted in portions of commercial orchard sites that had a completely randomized block design with four blocks, with various seed sources as the treatment. Each treatment contained seedlings produced from the nuts of a single tree. There were either three trees per replicate with one tree from each initial nursery-storage group, or six trees per replicate with two trees from each initial nursery-storage group. For each seed source, nursery storage was randomized in the post-transplantation trial.

Before planting, the Yolo County orchard site was fumigated with methyl bromide and chloropicrin, and transplants were treated with the biological control agent K84 (Galltrol, AgBioChem Inc., Orinda, Calif.). The San Joaquin County site, formerly planted with field and row crops, was not fumigated before planting and the transplants were treated with K84 before planting. In fall 2002, trees (n = 119 to 127 per initial nursery-storage group) with galls that protruded above the soil were counted in both orchards. The Fresno County site was a nematode screening trial in soil amended with two species of nematodes that infect walnuts, *Pratylenchus vulnus* and *Meloidogyne incognita*. The

This budded walnut on 'Paradox' rootstock has both crown and root galls. Nurseries do not sell trees with visible galls, but may sell trees with roots that were in direct contact with galls and hence the pathogen.

This 2-year-old tree on 'Paradox' rootstock had no gall and was treated with the biocontrol agent K84 at planting. Soil was removed from around the crown to show the gall. Circumstantial evidence indicates that the pathogen was acquired in the nursery.

Some galls on the crown eventually break through the soil, but often are not visible in undisturbed soil until 3 or more years after infection. An application of the biocontrol agent K84 in the nursery and/or the orchard only prevents crown gall disease in certain situations, such as when the pathogen is exposed to and sensitive to K84.

Janine K. Hasey

Severe crown gall in a young walnut orchard causes tree stunting and yield reductions. This gall was only visible after soil removal.

A 2-year-old walnut tree on 'Paradox' rootstock transplanted into soil infested with the pathogen *Agrobacterium tumefaciens* shows crown galls. Galls were primarily located at the sites of natural wounds such as root emergence, and were rarely observed on pruning wounds or cuts.

For each quarter of crown circumference affected by gall, there was a 12% decrease in cumulative yield.

soil was not fumigated and K84 was not used. In February 2000, trees (n = 154 to 217 per initial nursery-storage group) were dug, washed and inspected for crown gall.

Open-air storage. When the 1-year-old trees were dug at the nurseries, gall incidence was relatively low: 0.24% in site A, 2.4% in site B and 1.1% in site C. Site A had been in pasture for the past 20 years, and sites B and C had been in a walnut–cover crop and peach–cover crop rotation, respectively, for the past 10 years. Gall incidence was significantly greater for trees at nursery B than at nursery C ($P = 0.0001$), and greater in trees at nursery C than at nursery A ($P = 0.0001$, pairwise comparisons using X^2 and $P = 0.05$ adjusted by the Bonferroni method to $P = 0.016$).

In all three post-transplantation orchard trials, trees that originated in nursery-storage group C had significantly more gall than trees from the other two groups (table 2). These trees had been stored in the open air for 14 and 11 days longer than those from sites A and B, respectively. This suggests that prolonged open-air storage in warm, moist conditions was a critical factor associated with the increased galls in trees from site C. Rather than resulting from latent infections, the galls in our study with prolonged, unrefrigerated storage were more likely to have resulted from *Agrobacterium* cells that multiplied on the root surface and then were spread during wetting with a hose.

Galls decrease growth, yield

Study design. Two-year-old 'Paradox' seedlings (half-inch diameter) grafted with the *J. regia* selection 'UC76-80' were planted in a trial in Chico, Calif., in 1996. No galls were seen on the crown or roots, and the trees were washed and treated with the biological control agent K84. In 1997, about 1% of the 480 trees appeared to be stunted. After soil was removed from their crowns with water, crown galls were seen on many of the trees. The trees were rated on a scale of 0 to 3 for the extent of gall on the crown circumference: "0" for no gall, "1" for gall on a quarter or less of the crown, "2" for gall on between a quarter and half of the crown and "3" for gall on between half and three-quarters of the crown. Five trees in each category were randomly selected. The original soil excavated from each tree was returned to that tree. Tree circumference 4 inches below the graft union was recorded yearly, and dry nut yield per tree was recorded when bearing commenced in 1999. In 2002, soil was removed from the crown area with pressurized air, and the crown was assessed for how much of its circumference was affected by gall.

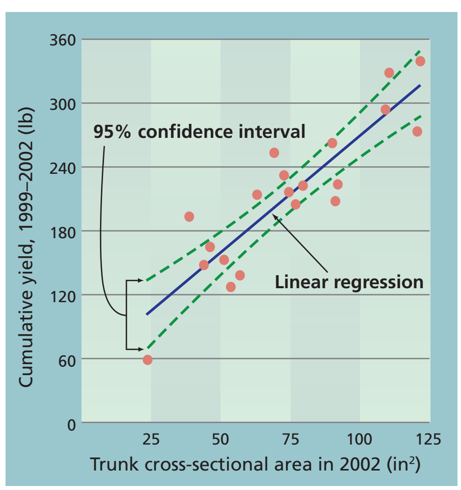


Fig. 1. Cumulative yield between 1999 and 2002, and trunk cross-sectional area in 2002 ($R^2 = 0.79$, $P = 0.0001$, $y = 2x + 52$), for 20 randomly selected (in 1997, 1 year after transplanting) walnut trees on 'Paradox' rootstock, with varying severity of crown gall.

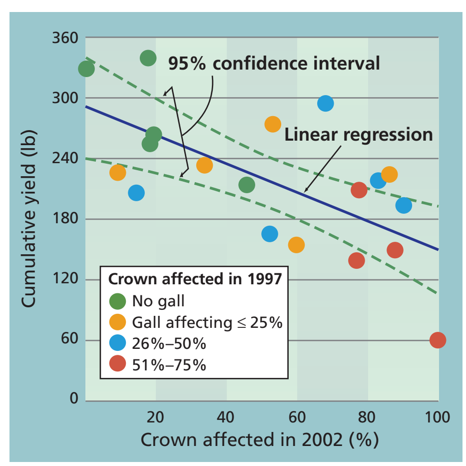


Fig. 2. Cumulative yield between 1999 and 2002 and percent crown circumference with a gall in 2002 ($R^2 = 0.44$, $P = 0.0014$, $y = -1.3x + 273$), for 20 randomly selected (in 1997, 1 year after transplanting) walnut trees on 'Paradox' rootstock, with varying severity of crown gall.

Growth and yield. Trunk circumference and cross-sectional area are proportional to tree size, and are an accepted way of comparing tree growth. Linear regression was used to examine how trunk cross-sectional area was affected by the extent of crown gall in 2002. Trees with more crown gall had decreased wood production in their trunks ($P = 0.009$, $R^2 = 0.32$, $y = -0.49x + 101$). Consequently, we conclude that crown galls result in less trunk wood.

In addition, the 2002 trunk cross-sectional area was significantly correlated with cumulative walnut yield for the first 4 years of production from 1999 to 2002 (fig. 1) ($P = 0.0001$, $R^2 = 0.79$, $y = 2x + 52$). Consequently, we conclude that trunk girth is a good predictor of nut yield and that trees with less girth will have a lower average yield.

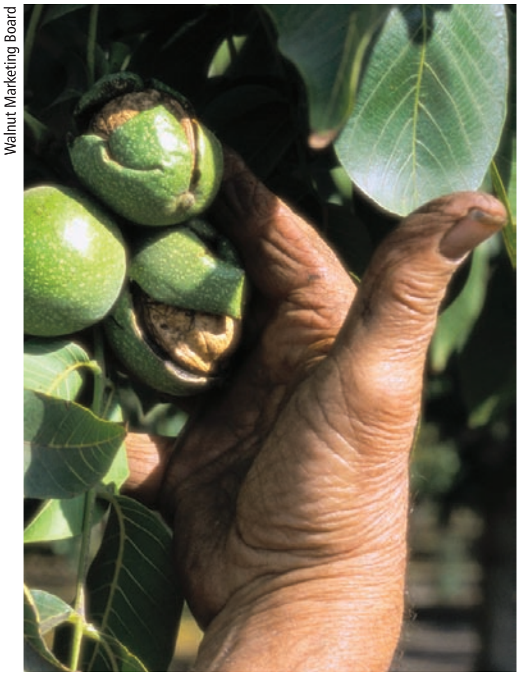
Linear regression was used to examine how cumulative yield was affected by the extent of crown gall in 2002 (fig. 2) ($P = 0.0014$, $R^2 = 0.44$, $y = -1.3x + 273$). We found that 44% of the variance in cumulative walnut yield from 1999 to 2002 could be attributed to the amount of gall circumscribing the crown in 2002. For each quarter of crown circumference affected by gall, there was a 12% decrease in cumulative yield.

The data also showed that the extent of initial gall and final gall were correlated ($P = 0.0001$, $R^2 = 0.57$, $y = 21x + 22$). That is, the amount of crown engulfed in gall 1 year after planting was a reasonable predictor of the amount that would be engulfed in gall 5 years later. In contrast to galls on the crown, those on the roots were poor predictors of yield (data not shown). Consequently, while we conclude that gall on the crowns of young walnut trees has a significant effect on cumulative yield, galls on the roots do not.

Managing galls

Extrapolating from these results, if walnut growers remove soil a year after planting and see crown galls in a high proportion of the trees, they can then predict the reduction in nut yield in the first 4 years of production. Nut yield will be reduced by up to 17% if gall affects less than one-quarter of the crown, by 18% to 36% if gall affects between one-quarter and half of the crown, and by 36% to 54% if gall affects between half and three-quarters of the crown.

Consequently, 1- to 4-year-old trees with severe gall should be replaced. We generally recommend surgical removal of crown galls on less severely infected trees that are 1 to 4 years old. More detailed recommendations and methods are described in the UC IPM Management Guidelines for Crown Gall on Walnut (UC IPM Online 2007).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◀ **The study found that walnut yields were reduced roughly in proportion to the extent of crown gall disease. Growers should replace young trees with severe crown gall (1 to 4 years old), and surgically remove galls from those that are less severely affected.**

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References

Alconero R. 1980. Crown gall of peaches from Maryland, South Carolina, and Tennessee and problems with biological control. Plant Dis 64:835–8.

Bouzar H, Moore LW, Schaad NW. 1983. Crown gall of *Agrobacterium* strains and potential for biological control in Georgia. Plant Dis 67:310–2.

Garrett CME. 1987. The effect of crown gall on growth of cherry trees. Plant Pathol 36:339–45.

Htay K, Kerr A. 1974. Biological control of crown gall: Seed and root inoculation. J Appl Bacteriol 37:525–30.

Kainski JM. 1964. Bacterial crown gall disease on plants in Kansas. Plant Dis Rep 48:664–8.

McKenna JR, Epstein L. 2003. Relative susceptibility of *Juglans* species and interspecific hybrids to *Agrobacterium tumefaciens*. HortScience 38:435–9.

Moore LW. 1976. Latent infections and seasonal variability of crown gall development in seedlings of three *Prunus* species. Phytopathol 66:1097–101.

Moore LW, Canfield M. 1996. Biology of *Agrobacterium* and management of crown gall disease. In: Hall R (ed.). *Principles and Practice of Managing Soilborne Plant Pathogens*. St. Paul, Minn.: APS Pr. p 153–91.

Pionnat S, Keller H, Héricher D, et al. 1999. Ti plasmids from *Agrobacterium* characterize rootstock clones that initiated a spread of crown gall disease in Mediterranean countries. Appl Environ Microbiol 65:4197–206.

Potter D, Gao F, Baggett S, et al. 2001. Defining the sources of Paradox: DNA sequence markers for North American walnut (*Juglans* L.) species and hybrids. Scientia Hort 94:157–70.

Smith EF, Brown NA, McCulloch L. 1912. The structure and development of crown gall: A plant cancer. USDA Bull No 255. Government Printing Office, Washington, DC.

UC IPM Online. 2007. Pest Management Guidelines – Walnut Crown Gall. UC Statewide Integrated Pest Management Program. http://ucipm.ucdavis.edu/PMG/r881100211.html (updated 12/07).

Young JM, Kuykendall LD, Martinez-Romero E, et al. 2001. A revision of *Rhizobium* Frank 1889, with an emended description of the genus, and the inclusion of all species of *Agrobacterium* Conn 1942 and *Allorhizobium undicola* de Lajudie et al. 1998 as new combinations: *Rhizobium radiobacter*, *R. rhizogenes, R. rubi, R. undicola* and *R. vitis*. Intl J System Evol Microbiol 51:89–103.

Glyphosate-resistant hairy fleabane documented in the Central Valley

by Anil Shrestha, Bradley D. Hanson
and Kurt J. Hembree

In recent years, growers and pest consultants have reported poor control of the weed hairy fleabane in some areas of the Central Valley. Hairy fleabane seeds were collected from Esparto, Fresno and Reedley, Calif., and greenhouse-grown seedlings were treated at several different glyphosate rates and compared with an untreated control. None of the Esparto or Fresno plants survived glyphosate rates greater than 0.78 pounds acid equivalent per acre (lb ae/ac), while some of the plants from Reedley survived even the highest rate of glyphosate tested (12.4 lb ae/ac). The dose required to reduce plant dry weights by 50% (GR_{50}) of the Esparto plants ranged from 0.28 to 0.30 lb ae/ac, whereas the GR_{50} of the Fresno and Reedley plants ranged from 0.26 to 0.61 and 0.92 to 2.88 lb ae/ac, respectively. This study showed that the hairy fleabane plants from Reedley were much more tolerant of glyphosate than either of the other two biotypes and, based on the GR_{50}, the level of resistance ranged from 3- to 10-fold greater.

Hairy fleabane plants survived glyphosate (Roundup Weathermax) applications on a reservoir bank in Fresno County. Over-reliance on herbicides with the same mode of action often leads to resistance.

Hairy or flax-leaved fleabane is a major weed infesting roadsides, ditchbanks, orchards, vineyards and fallow areas in California. This weed belongs to the Asteraceae family and is an annual or short-lived perennial native to South America (Noyes 2000). At the seedling stage, hairy fleabane (*Conyza bonariensis*) looks very similar to horseweed (*Conyza canadensis*) and can often be found growing in the same locations. The most common methods used to control hairy fleabane in California include the use of pre- and postemergent herbicides, fall and/or spring cultivation, and hand-pulling. Generally, broad-spectrum postemergent herbicides, primarily glyphosate (Roundup), are used to control these weeds in orchards, vineyards and noncrop areas in California (Shrestha et al. 2007).

Glyphosate is considered the world's most important herbicide because it provides broad-spectrum weed control and has favorable environmental characteristics and low mammalian toxicity (Baylis 2000; Woodburn 2000). These characteristics, combined with its cost-effectiveness, have led to frequent applications of glyphosate in perennial cropping systems and noncrop areas in California (Shrestha et al. 2007). However, reliance on herbicides with the same mode of action for extended periods can contribute to weed shifts and the selection of biotypes with resistance to herbicides (Christoffers 1999; Holt 1992) (see page 86). As a result of this selection pressure, cases of glyphosate-resistant rigid rye-grass (*Lolium rigidum*) (Heap 2008; Simarmata et al. 2005) and horseweed (Shrestha et al. 2007) have been reported in California orchards and noncrop areas, respectively.

In recent years, poor control of hairy fleabane with glyphosate has been observed in orchards, vineyards and noncrop areas of California. Since glyphosate-resistant horseweed has been documented in similar California locations (Shrestha et al. 2007), and glyphosate-resistant hairy fleabane has been reported in perennial crops in Spain (Urbano et al. 2007), we suspected glyphosate resistance in hairy fleabane after observing weeds that were not killed by labeled rates of glyphosate (escapes) at several sites. The objective of our study was to test for glyphosate resistance in hairy fleabane

It is very likely that glyphosate-resistant hairy fleabane is present in cropped areas, particularly in orchards and vineyards of the Central Valley.

plants grown from seeds collected in perennial crop and noncrop locations around central California.

Greenhouse studies

Seeds of hairy fleabane were collected in 2006 from a suspected glyphosate-resistant roadside population in Reedley (36°29′15 N; 119°24′10 W). Seeds of suspected glyphosate-susceptible populations were collected from a vineyard in western Fresno (36°47′58 N; 119°57′16 W) and a noncrop area near Esparto (38°40′09 N; 122°01′11 W), where effective control is usually obtained with a labeled rate (22 fluid ounces per acre [fl oz/ac], i.e., 0.78 pounds acid equivalent per acre [lb ae/ac]) of glyphosate formulated as Roundup Weathermax.

Seeds were stored in a refrigerator in the laboratory at 40°F over the winter, planted in plastic germination trays in the laboratory in spring, and moved to a greenhouse following emergence. The day and night temperatures in the greenhouse were set at 75°F to 80°F and 60°F to 65°F, respectively. No supplemental lighting was used. When the seedlings developed two to three leaves, they were transplanted into plastic pots (6 inches deep, 4 inches wide) containing a commercial potting mix.

Experiments comparing the Esparto and Reedley populations and Fresno and Reedley populations were conducted separately and repeated. All the experiments were conducted between May and August. The experimental design was a completely randomized design with five replications. Each pot with a seedling from each location was an experimental unit. The plants were watered regularly and fertilized twice during the growing season with a commercial fertilizer (MiracleGro).

The seedlings were treated with glyphosate (formulated as Roundup Weathermax) at rates of 0 (untreated), 0.19, 0.39, 0.78, 1.55, 3.1, 6.2 and 12.4 lb ae/ac. These rates correspond to 0, 5.5, 11, 22, 44, 88, 176 and 352 fl oz/ac of Roundup Weathermax. Treatments were applied with a moving-nozzle cabinet sprayer calibrated to deliver 17.7 gallons per acre through a single 8002 flat fan nozzle positioned 22 inches above the target plants.

Growth stage (leaf numbers) of the treated plants differed between experiments due to the duration of growth before treatment and conditions in the greenhouse. In the experiments comparing plants from Esparto and Reedley, the plants were treated with glyphosate at the 8-to-11-leaf stage and 18-to-22-leaf stage in the first and second runs of the experiment, respectively. In the experiments comparing the Fresno and Reedley plants, the plants were treated at the 12-to-15-leaf stage and 17-to-23-leaf stage in the first and second runs of the experiment, respectively.

Mortality and aboveground dry weight of the treated plants were recorded 2 weeks after glyphosate application. The plants were designated as "dead" when the aboveground plant parts showed no traces of green tissue (necrosis). All the plants, including the ones that died, were clipped at the surface of the soil, placed in separate paper bags, dried to constant weight in a forced-air oven at 140°F, and their dry weights were recorded. Some extra plants in each treatment were maintained up to a month after glyphosate application for visual assessments of damage and regrowth. Dry weights of the plants were expressed as percentage of control. Mortality data were subjected to analysis of variance using GLM procedures in SAS with an alpha level of 0.05. Dry weight data (% of control) were regressed against glyphosate dose, and a four-parameter logistic curve was fit using SigmaPlot with the following equation:

$$Y = \text{min} + \frac{\text{max} - \text{min}}{1 + 10^{(GR_{50} - x)}}$$

where Y is plant dry weight (% of control), *min* is the minimum response limit, *max* is the maximum response limit, GR_{50} is the glyphosate dose required to reduce dry weight by 50% and x is the concentration of glyphosate.

Seedlings of, *top*, hairy fleabane and, *bottom*, horseweed. Populations of both weeds have now been shown to be resistant to glyphosate, a commonly used herbicide.

There were no interactions ($P >$ 0.05) between the glyphosate rate and experimental run for plant mortality. However, in the biomass data, interactions ($P < 0.05$) occurred between glyphosate rate and experimental run. Therefore, data for plant mortality were combined for experimental rounds, whereas data for plant dry weight were analyzed separately for each run.

Plant mortality and dry weight

Plant mortality. In both experiments, all the seedlings from Fresno and Esparto were killed with a glyphosate rate of 1.55 lb ae/ac (figs. 1A, 1B). However, this was higher than the labeled rate (0.78 lb ae/ac) for hairy fleabane control. In both experiments, about 50% of the hairy fleabane plants from the suspected glyphosate-susceptible populations of Esparto and Fresno were able to survive the

In this study, glyphosate-resistant hairy fleabane recovered from injury 4 weeks after glyphosate was applied at 16 times the recommended rate.

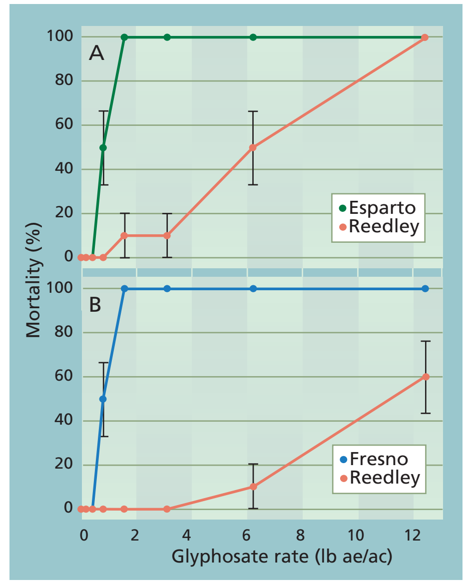

Fig. 1. Average percent mortality (± SE) of hairy fleabane plants sprayed with different glyphosate rates from (A) Esparto and Reedley at the 8-to-11-leaf stage and 18-to-23-leaf stage and (B) Fresno and Reedley at the 12-to-15-leaf stage and 15-to-18-leaf stage.

labeled rate. This indicates that high chances of hairy fleabane escapes are present with the labeled rate even when they are sprayed as early as the 8-to-11-leaf stage. Depending on the growth stage, plants from Reedley required glyphosate rates of 6.2 lb ae/ac or higher to kill 50% of the plants. In the experiment comparing Fresno and Reedley plants (fig. 1B), about 40% of the plants from Reedley survived a glyphosate rate of 12.4 lb ae/ac, which was 16 times the recommended rate.

These results showed that the plants from Reedley were glyphosate-resistant. Although the effect of growth stage on the level of resistance was not evaluated in this study, we suspect that the level of resistance could vary with growth stage. Interactions between glyphosate rate and plant growth stage have been reported in horseweed (Shrestha et al. 2007). The study also showed that although the hairy fleabane populations of Fresno and Esparto were generally susceptible to glyphosate, some plants escaped the labeled rate, and a glyphosate application at 1.55 lb ae/ac was required to kill these plants.

Plant shoot dry weight. Plant shoot dry weight expressed as percentage of untreated control varied between experiments (figs. 2 and 3). This may have been due to differences in the growth stages (leaf numbers) between the experiments. Urbano et al. (2007) have also reported that the glyphosate response of resistant and susceptible hairy fleabane plants was dependant on phenological stage. The GR_{50} of the glyphosate-susceptible and glyphosate-resistant plants increased with growth stage in their study. In our study, the GR_{50} of the Esparto and Reedley plants ranged from 0.28 to 0.30 and 0.92 to 2.88 lb ae/ac, respectively (fig. 2). Similarly, the GR_{50} of the Fresno and Reedley plants ranged from 0.26 to 0.61 and 1.62 to 1.79 lb ae/ac, respectively (fig. 3).

Based on these GR_{50} values, the hairy fleabane plants from Reedley showed at least a 3-fold level of resistance compared to the susceptible populations. However, the level of resistance ranged up to 10-fold depending on the growth stage of the plants at application. This result is consistent with the findings of Urbano et al. (2007), who also reported a 10-fold level of resistance. A phenomenon noticed in the plants that survived the highest rates of glyphosate was the appearance of new leaves from the center of the plant. Similar symptoms were also noticed in glyphosate-resistant horseweed.

Managing hairy fleabane

This study confirmed the presence of glyphosate-resistant hairy fleabane in noncrop areas of the Central Valley. It is very likely that glyphosate-resistant hairy fleabane is also present in cropped areas, particularly in orchards and vineyards of the Central Valley, because the windborne seeds of hairy fleabane can travel considerable distances with wind currents. Our results also indicated that the current labeled rate of glyphosate may not be sufficient to consistently control glyphosate-susceptible hairy fleabane populations at the early rosette stages. The chances of glyphosate escapes will be greater if applications are made after the plants have developed more than 10 leaves.

Because hairy fleabane can emerge in multiple flushes in late fall, late winter,

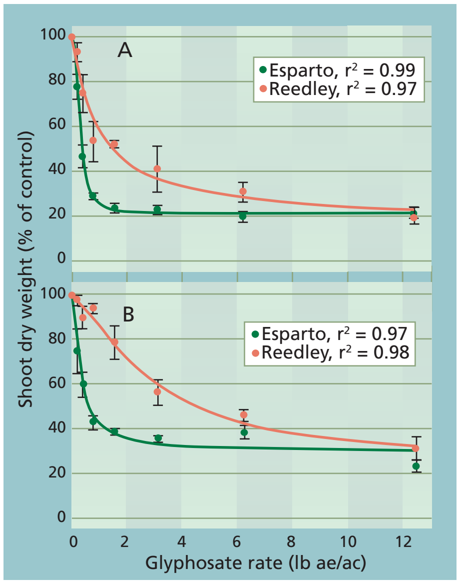

Fig. 2. Average shoot dry weights (± SE) of Esparto and Reedley hairy fleabane plants (expressed as percentage of untreated control) under different glyphosate rates in the (A) first (8-to-11-leaf stage) and (B) second (18-to-22-leaf stage) experimental run.

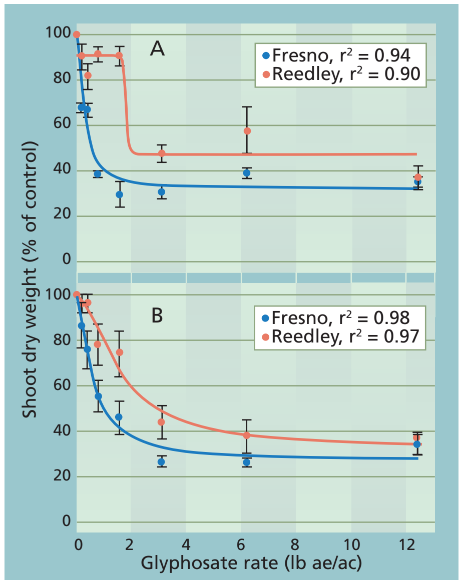

Fig. 3. Average shoot dry weight (± SE) of Fresno and Reedley hairy fleabane plants (expressed as percentage of untreated control) under different glyphosate rates in the (A) first (12-to-15-leaf stage) and (B) second (17-to-23-leaf stage) experimental run.

References

Baylis AD. 2000. Why glyphosate is a global herbicide: Strengths, weaknesses and prospects. Pest Manag Sci 56:299–308.

Christoffers MJ. 1999. Genetic aspects of herbicide-resistant weed management. Weed Technol 13:647–52.

Heap I. 2008. International survey of herbicide resistant weeds. www.weedscience.org.

Holt JS. 1992. History of identification of herbicide-resistant weeds. Weed Technol 6:615–20.

Noyes RD. 2000. Biogeographical and evolutionary insights on *Erigeron* and allies (Asteraceae) from ITS sequence data. Plant System Evolu 220:93–114.

Shrestha A, Hembree KJ, Va N. 2007. Growth stage influences level of resistance in glyphosate-resistant horseweed. Cal Ag 61(2):67–70.

Simarmata M, Bughrara S, Penner D. 2005. Inheritance of glyphosate resistance in rigid ryegrass (*Lolium rigidum*) from California. Weed Sci 53:615–9.

Urbano JM, Borrego A, Torres V, et al. 2007. Glyphosate-resistant hairy fleabane (*Conyza bonariensis*) in Spain. Weed Technol 21:396–401.

Woodburn A. 2000. Glyphosate production, pricing and use worldwide. Pest Manag Sci 56:309–12.

early spring and spring, several applications of the herbicide may be needed if a glyphosate-alone weed management strategy is used. This will decrease the cost-effectiveness of the weed management strategy and will further increase the selection of glyphosate-resistant weeds. Therefore, we recommend that multiple tactics, including applying pre-emergent herbicides and combining glyphosate with other postemergent herbicides, be used to manage hairy fleabane in the Central Valley.

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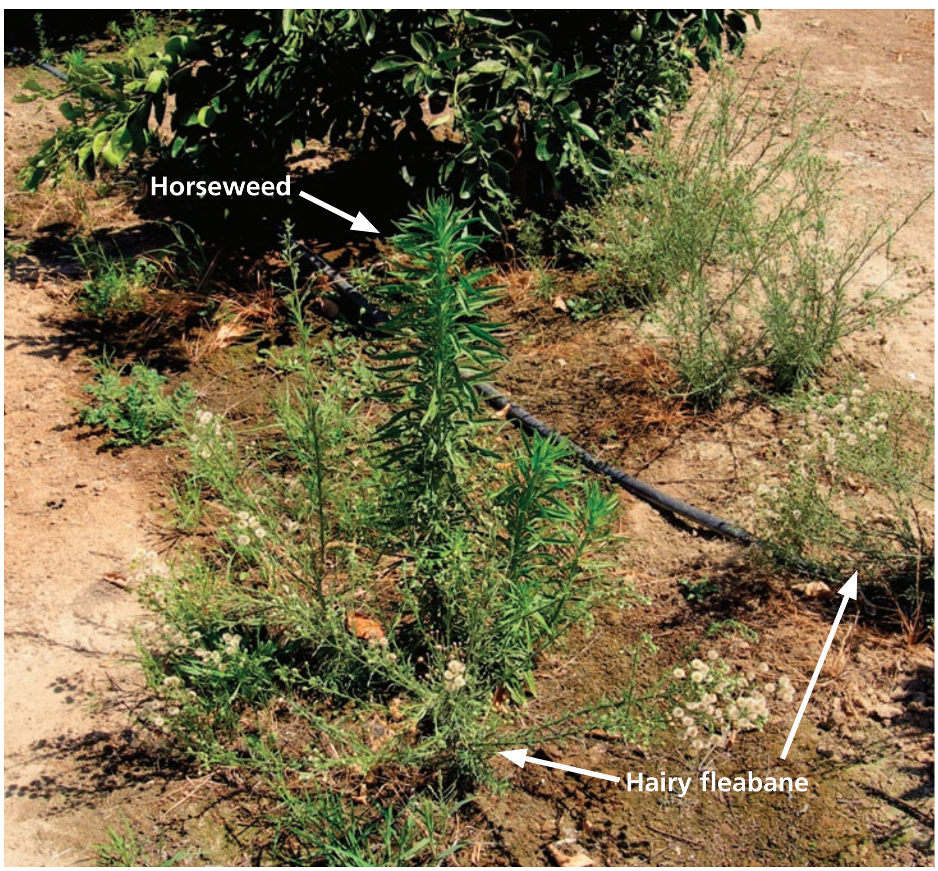

Horseweed and hairy fleabane grow side-by-side in a Fresno County citrus orchard. The use of multiple tactics can prevent further development of herbicide resistance in these weeds.

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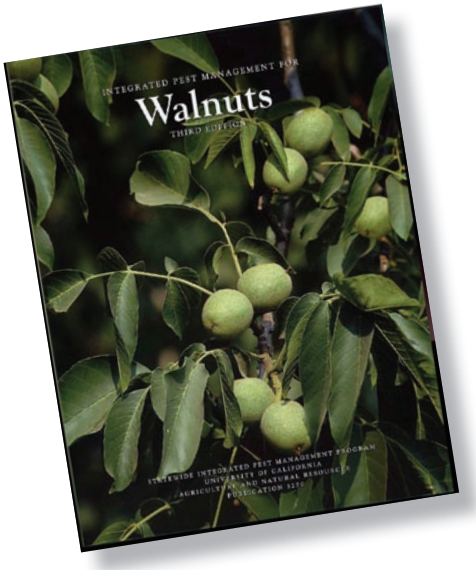

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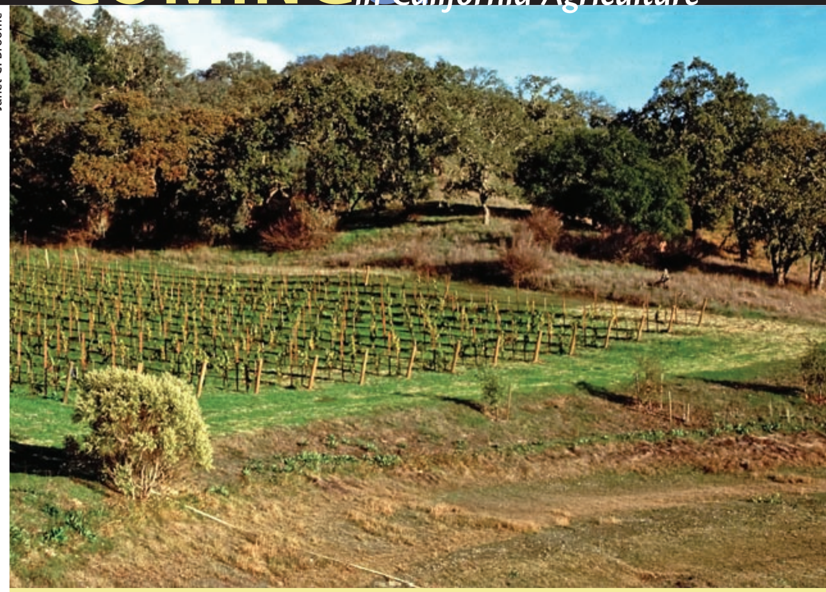

Janet C. Broome

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