JANUARY–MARCH 2010 • VOLUME 64 NUMBER 1

California Agriculture

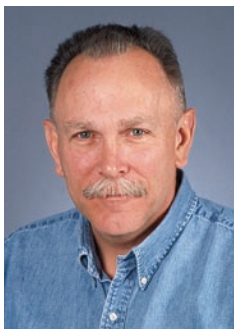
Improving health on the farm

Also: Sugar pine, Verticillium wilt, light brown apple moth

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

What can we do for UC today?

Don Klingborg
Assoc. Dean, Extension, Veterinary Medicine
Director, Strategic Advocacy and UCCE Partnerships



Robert Sams
Director, Communication Services and Information Technology

AS we write this, UC students are protesting fee increases exceeding 30% next year. Each UC campus is implementing a plan to adjust to unprecedented funding cuts and rising, mandated expenses. UC Agriculture and Natural Resources (UC ANR) is restructuring business and program-support administrative offices and taking other actions to adjust to the loss of 20% of its permanent funding. To cap it all off, projections for California's budget next year show even larger deficits and threaten yet further reductions.

The ANR colleges at UC Davis (College of Agricultural and Envirionmental Sciences), UC Berkeley (College of Natural Resources) and UC Riverside (College of Natural and Agricultural Sciences), where many of the authors in this issue of *California Agriculture* are housed, all face equally difficult adjustments and reductions.

Closer to home, print production funding for *California Agriculture* will be reduced. To respond, the editorial staff has already begun expanding the role of *California Agriculture* Online (http://californiaagriculture.ucanr.org). The recently launched Web site, which includes the entire archive of more than 6,000 articles published since 1946 in searchable form (indexed by numerous databases), will serve as a model for other UC ANR publications and electronic information resources. Yet even as we adjust to these realities and diminished resources, the implicit value of the work of UC ANR scientists and educators grows, especially as we look to the future.

In April 2009, UC ANR released the "Strategic Vision 2025." This document culminated months of planning, consultation and feedback. That vision, and the implementation planning that followed, builds on our tradition. To focus our efforts and identify new resources, five strategic initiatives were defined as the first to be pursued from the larger list of initiatives. These include (1) Sustainable Food Systems, (2) Endemic and Invasive Pests and Diseases, (3) Sustainable Natural Ecosystems, (4) Healthy Families and Communities and (5) Water Quality, Quantity and Security. The contents of *California Agriculture* illustrate the integrated and useful research that will contribute to these five initiatives.

For example, UC scientists analyze New Zealand's biological control of the invasive light brown apple moth (page 6), and consider the potential for such a system in California. Linking research and outreach, other scientists evaluate the incidence of type 2 diabetes in farmworkers, describing how healthy lifestyle and ongoing medical care can improve the prognosis in high-risk individuals (page 12). Scientists have also studied the potential health effects of airborne particulates on farmworkers (page 17). Air quality is a primary concern for many San Joaquin Valley residents, and these findings have implications for all. Other articles report on mental-health needs of low-income women (page 22), nursery industry practices that limit impacts of runoff (page 26), steps to reduce disease in pine trees (page 31), breeding *Verticillium* resistance in strawberries (page 37) and wine-grape trends (page 42).

At the same time, UC ANR research and extension do not stand alone. They are inseparable from and dependent on higher education and the state funding that supports it. UC President Mark Yudof and UC ANR Vice President Dan Dooley are asking advocates to contact decision-makers and to support funding for higher education and ANR research and extension. We have all benefited from previous investments in research and education. Those of us working at UC have the privilege of contributing to and earning a living from the returns on that investment.

A few weeks ago, a very upset UC student confronted a senior UC administrator with the words, "What have you, personally, done today to support state funding for UC?" We are unable to get that student's question, and the financial challenges he faces, out of our minds. We can not help but ask, "What have we done today?" If you value the research published in *California Agriculture* journal and the difference that UC ANR makes, we hope you will become part of this effort, called "UC for California" (http://www.ucforcalifornia.org).

For those of us who work at UC, we face a difficult transition — from a time when the state's citizens and our political representatives valued higher education as an investment in the future, and provided access by augmenting the budget with state dollars — to a new political reality where higher education is expected to be much more self-supporting. No longer can we assume that the voters or politicians recognize the value to the state, and to them as individuals, from investing in higher education. Today, and into the foreseeable future, an essential component of each of our tasks is to make visible the bounty of benefits that accrue from UC ANR activities. Those of us who work at UC must count on each other to remove any mystery about what we do, and demonstrate the value provided through ANR and UC in every conversation, presentation and activity. If we do not tell the story it will not be heard. Strategic advocacy as an organized component of our jobs will play a larger role in our future and we must all become involved.

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COVER: California has about 1 million farmworkers and farm family members, who face unique health and safety risks. Air particulate levels in the Central Valley are among the nation's highest (see page 12), and California Latinos may be at increased risk of diabetes (see page 17). For more info, go to http://californiaagriculture.ucanr.org. *Photo of farmworkers harvesting lettuce in Five Points, Calif., by Andy Sacks.*

Research and review articles

News departments

To keep receiving *California Agriculture* journal, see important notice on page 5.

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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.

Indexing. The journal is indexed by AGRICOLA; Current Contents (Thomson ISI's Agriculture, Biology and Environmental Sciences, and the SCIE databases); the Commonwealth Agricultural Bureau (CAB) databases; EBSCO (Academic Search Complete); Gale, including Lexis-Nexis; Google Scholar; Proquest; and others including open-access journal databases. It has high visibility in Google searches. Peer-reviewed articles are posted at the California Digital Library's eScholarship Repository.

Authors. Authors are primarily but not exclusively from UC ANR; in 2007 and 2008, 22% and 15% (respectively) were based at other UC campuses, or other universities and research institutions.

Reviewers. In 2007 and 2008, 19% and 14% (respectively) of reviewers came from universities and research institutions or agencies outside ANR.

Rejection rate. Our rejection rate ranged between 20% and 25% in the last two years, and in the year ending May 31, 2008, associate editors sent back 24% of manuscripts for major revision prior to peer review.

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

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

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

Letters. The editorial staff 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 and address. Letters may be edited for space and clarity.

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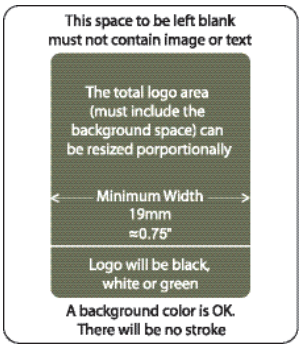

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Fighting 150 million years of cell-wall evolution

Good articles on biofuels (October–December 2009) — and timely. To what extent is the research on how to break down plant cell walls fighting at least 150 million years of plant evolution that protects plants from decaying fungi and bacteria? If we were to produce a plant with a cell wall that was easy for humans to break down, would this plant not be vulnerable to attack? This plant might be difficult to grow, a fact of particular importance to tree farmers like myself. (I have managed my family's tree farm in Comptche since 1977.) It could be that humans are the neophytes here in the effort to find ways to easily grow and rot wood.

Oct.–Dec. 2009

George Hollister
Comptche, CA

Author Laura Bartley, UC Davis postdoctoral plant pathologist, replies:
You make an excellent and sobering point. Cell walls function as a barrier to, and present specific biochemical defenses against, pests and pathogens. In light of this, cell-wall researchers routinely subject plants with modified walls to inoculation with pathogens and at times find increased susceptibility. Modified energy crops will need to be field-tested for hardiness under diverse conditions before large-scale use. This said, we remain optimistic. Plant evolution has been limited to acting on lineage-limited combinations of genetic material. We hope that a semirational approach that combines multiple changes, such as new wall compositions along with wall-independent means for disease resistance, will allow us to both "grow and rot wood." Other approaches may avoid this challenge. For example, one idea is to make plants that produce cell-wall degrading enzymes at the end of their life cycle.

Cal Ag subscriber goes electronic

I'm the head of a small software company, but I have a longstanding interest in agriculture. I think the farmers of California do an incredible job in producing so much food. My wife and I have been going to farmer's markets for more than 20 years. However, there's still a big gap between the knowledge and experience of most city dwellers and most farmers. I'm trying to educate myself.

I've been a print subscriber to *California Agriculture* for several years but I would like to switch to an electronic subscription. I've added your RSS feed so I can keep up. You might want to provide an easy way for other subscribers to switch.

Bravo, for digitizing current and all the previous issues. Too many journals, especially the more specialized ones, have not done that. You've made all that material available to everyone all over the world, including the younger generation that believes if it's not in Google it doesn't exist!

Anthony Meadow
Oakland

Editor's note: Thank you, and others, for this suggestion. We have retooled the Web site to allow readers to easily (1) renew, if they wish to continue receiving the print journal, (2) go electronic or (3) request print subscriptions. Go to the Subscribe button (top bar) — and be sure you have your subscriber number (above your name on the address label).

RSVP

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 and address. Letters may be edited for space and clarity.

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To our valued readers:

As California and UC face unprecedented financial crises, we must ask you to resubscribe online. This will enable us to remove any readers from our list who have no current interest, and gives you the opportunity to update and correct your subscriber information.

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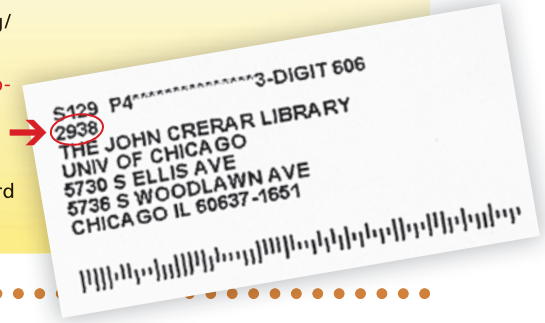
Questions?

E-mail calag@ucdavis.edu or call (510) 642-2431, x33. — *Editor*



Corrections:

The October–December 2009 issue contained the following errors, which were corrected online:

- Typographical errors were corrected in figure 5 (page 175) of the review article by Bryan Jenkins et al.; the correct words are "coal" (not "goal") and "grease" (not "grass"). For corrected figure, go to: http://ucce.ucdavis.edu/files/repository/calag/fig6304p175.jpg.
- Page 164 included a picture of wild rice, which is not under consideration as a biofuel. The photograph was replaced with the Japonica species predominant in California rice production. Go to: http://ucce.ucdavis.edu/files/repository/calag/img6304p164.jpg.
- The title of a review article by Charles E. Wyman and Bin Yang was changed to "Cellulosic biomass could help meet California's transportation fuel needs" (addition of the word "help"; page 185).

New Zealand lessons may aid efforts to control light brown apple moth in California

by Lucia G. Varela, James T.S. Walker, Peter L. Lo *and* David J. Rogers

New Zealand's major fruit industries are dependent upon producing high-quality crops for export with a very low incidence of pest damage. Light brown apple moth was an economically important pest within the fruit sector in the 1960s through the 1980s, and it developed resistance to broad-spectrum insecticides. The increase in its pest status focused research on biological control, and existing native natural enemies were augmented with new introductions from Australia in the late 1960s. By the early 1990s, this effort resulted in substantially reduced leafroller populations and fruit damage. The implementation of integrated pest management (IPM) programs in the New Zealand fruit sector in the mid- to late 1990s practically eliminated the use of broad-spectrum organophosphate insecticides, further enhancing natural control. Today light brown apple moth is successfully managed in IPM and organic programs through a combination of biological control and threshold-based applications of selective insecticides.

The recent discovery of light brown apple moth, a leafroller, in California may affect the management of fruit crops, and because it is a quarantine pest in some markets, the discovery has already had implications for domestic and export trade in produce and nursery stock.

In New Zealand, light brown apple moth, *Epiphyas postvittana* (Walker) (Lepidoptera: Tortricidae), was first reported in 1891 (Hudson 1928). It became a major pest, primarily of pome fruit (apples and pears) and berry fruit, and a minor pest of grapes, citrus, stone fruit and kiwi fruit. The number of acres planted to pome and berry fruit — the crops most affected by light brown apple moth — is similar in New Zealand and California (table 1).

Jack Kelly Clark

In New Zealand, light brown apple moth is controlled by parasitoids and selective insecticides.

New Zealand went through a phase from the 1960s to 1980s when light brown apple moth caused major fruit damage; in apple crops this averaged from 8% to 26% and as high as 48% (Collyer and van Geldermalsen 1975). Control programs were based on frequent applications of broad-spectrum insecticides. This led to the development of resistance to organochlorines in the early 1960s (Collyer and van Geldermalsen 1975) and organophosphates by the early 1980s (Suckling et al. 1984; Suckling and Khoo 1990).

Over the last two decades, the pest status of light brown apple moth in New Zealand apples has shifted significantly. Damage has decreased to typically less than 2% in unsprayed trees (fig. 1). The decline in fruit damage is associated with lower leafroller density, which in turn is attributed to two key factors: (1) the introduction in the 1960s and subsequent spread of parasitoids attacking pupal and late larval stages of light brown apple moth and (2) the change in fruit production programs from frequent applications of broad-spectrum insecticides to less-intensive spraying with selective products.

By using a combination of natural control and selective insecticides, New Zealand growers are able to control light brown apple moth and meet the export standards of more than 60 countries that import a variety of fruit crops. In the 1980s, organophosphate insecticides were sprayed in six to nine applications each season on pome fruit crops for a variety of pests. Over the last decade, use of organophosphate insecticides has declined by 97%, while the frequency of insecticide applications has declined by approximately 50% (Manktelow et al. 2005). The insecticides now used are selective. The incidence of light brown apple moth fruit damage has declined, as has the larval incidence in crops.

In recent U.S. Department of Agriculture preclearance inspections of New Zealand apples grown using the Integrated Fruit Production program, the rejection rate of export consignments for the presence of light brown apple moth was typically less than 1%. A consignment is rejected if one or more larva is detected in 20,000 individually inspected fruit.

Biology and damage

The light brown apple moth's biology was previously described in *California Agriculture* (Varela et al. 2008). In New Zealand, this insect reportedly feeds on 265 different host plant species

TABLE 1. Planted area of light brown apple moth fruit-crop hosts

Crop	New Zealand*	California†
	····· *acres (hectares)* ·····	
Pome fruit	23,539 (9,526)	36,500 (14,771)
Berry fruit	5,913 (2,393)	7,400 (2,994)
Strawberries	420 (170)	35,500 (14,366)
Grapes	72,518 (29,347)	789,000 (319,297)
Citrus	4,532 (1,834)	251,500 (101,778)
Stone fruit	5,669 (2,294)	243,800 (98,662)
Kiwi fruit	30,112 (12,186)	4,000 (1,619)

* Plant & Food Research Fresh Facts 2008.
† USDA NASS 2008.

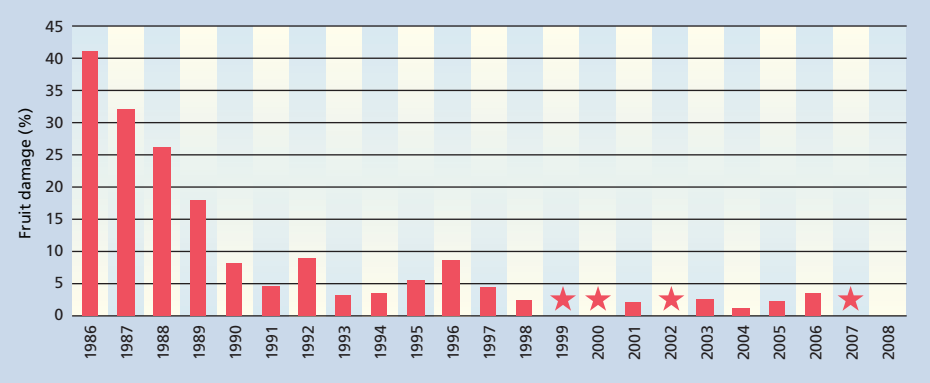


Fig. 1. Leafroller fruit damage on unsprayed apple trees in Hawke's Bay, New Zealand, 1986 to 2008. ★ = no records kept.

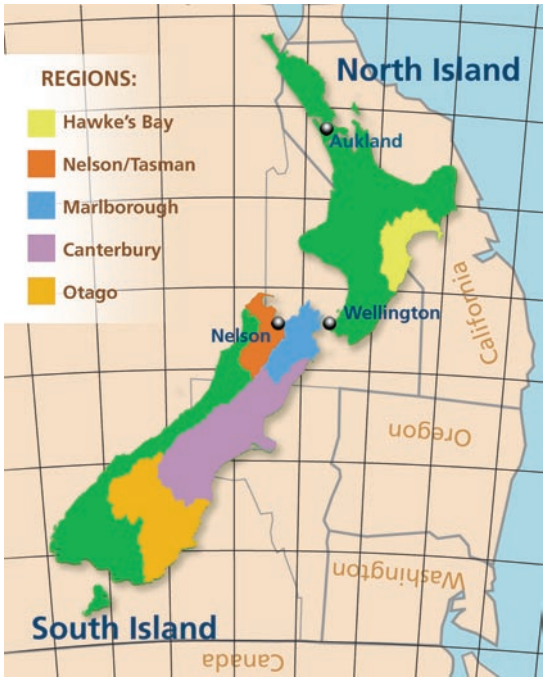


Fig. 2. Major agricultural growing regions of New Zealand, and scale comparison with the U.S. West Coast (inverted to show corresponding latitudes).

(Thomas 1965), including fruit crops, ornamental plants, windbreak trees and broadleaf weeds.

This leafroller is predominantly a foliage feeder (Lo et al. 2000). The newly hatched larva spins a protective, silken, tubular shelter on the lower surface of leaves or ties together young leaves at shoot tips. Second and later stages may web leaves together or attach them to fruit. Fruit feeding is incidental and fruit damage is superficial; the penetration of fruit by larvae is uncommon. Fruit damage may increase during the season because of the larger fruit surface area in contact with leaves or other fruit (Lo et al. 2000).

New Zealand extends from 34° to 47° latitude (a geographic range similar to the lower 48 U.S. states) but has a maritime climate that is mild and relatively humid, similar to that of coastal California (fig. 2). The two major growing regions for New Zealand apples are Hawke's Bay and Nelson (Tasman). The climate of these two regions approximates that of California's Central Coast and North Coast, except that in New Zealand rainfall is year-round while in California precipitation is concentrated in fall and winter.

Light brown apple moth has four generations per year in northern North Island, three generations in the southern North Island and northern South Island, two to three generations in Canterbury and two generations in Central Otago (Wearing et al. 1991). The second- and third-generation larvae cause the most fruit damage (Collyer and van Geldermalsen 1975; Lo et al. 2000).

Historical biological control

A biological control program has evolved in New Zealand that suppresses light brown apple moth populations. The effectiveness of this program relies on a complex of native and introduced natural enemies that attack all life stages (table 2) both in intensively managed fruit crops and the natural landscape. The reduction of broad-spectrum insecticide use since the late 1990s has enhanced natural control. The present state of biological control came about by (1) accidental introductions of parasitoids and predators, (2) the switching of hosts by some native natural enemies and (3) the deliberate introduction from 1967 to 1972 of parasitoids that attack the later stages of light brown apple moth.

An insect parasitoid completes its larval development on or inside a host. Most beneficial insect parasitoids are wasps or flies, the adult of which deposits one or more eggs on or inside a particular life stage (egg, larva or pupa) of its host. When the egg hatches, the parasitoid larva feeds on the host's tissue, ultimately killing the host as it matures and becomes free living as an adult. Endoparasitoids (endo) develop inside of the prey while ectoparasitoids (ecto) develop outside of the host body. In some species, only one parasitoid will develop in or on each host (solitary); in others, several to hundreds of young larvae may develop from a single prey (gregarious).

L.J. Dumbleton (1932, 1935) was the first to report on natural enemies of the light brown apple moth in New Zealand. He listed *Dolichogenidea tasmanica* (Cameron) (Braconidae) as the most frequent parasitoid, found in 20% to 50% of the larvae reared. *D. tasmanica* attacks small leafroller larvae, depositing its eggs inside first- or second-instar larvae. The parasitoid larva develops inside its host and emerges from the third and fourth leafroller stage to form

TABLE 2. Major parasitoids attacking light brown apple moth (LBAM) stages in New Zealand

				LBAM life stage/instar	
Species	**Family**	**Parasitoid type**	**Origin**	**Attack**	**Emerge from**
Dolichogenidea tasmanica	Braconidae	Solitary, endo*	Accidentally introduced	First and second	Fourth
Glyptapanteles demeter	Braconidae	Gregarious†, endo	Endemic	Third and fourth	Late larval
Goniozus jacintae	Bethylidae	Gregarious, ecto‡	Australia	Second to fourth	Late larval
Trigonospila brevifacies	Tachinidae	Solitary, endo	Australia	Third to fifth	Mid- to late larval or pupal
Pales funesta	Tachinidae	Solitary, endo	Endemic	Fourth to fifth	Late larval
Xanthopimpla rhopaloceros	Ichneumonidae	Solitary, endo	Australia	Pupal	Pupal
Glabridorsum stokesii	Ichneumonidae	Solitary, ecto/endo	Australia	Pupal	Pupal

* Parasitoid develops within its host.
† More than one parasitoid develops per host.
‡ Parasitoid develops outside its host.

With a strategic commitment to biological control within an IPM context, California may ultimately achieve the same levels of light brown apple moth control as obtained in New Zealand.

a cocoon inside the webbed nest next to the consumed leafroller larva (Paull and Austin 2006). *D. tasmanica* was accidentally introduced to New Zealand, probably with light brown apple moth from Australia (Dumbleton 1935).

Dumbleton (1936) reported only one early parasitoid importation from Australia in 1922; it was later identified as *Goniozus jacintae* Farrugia (Bethylidae) (Berry 1998). This parasitoid lays one or more eggs externally in the folds between segments of third- to sixth-stage caterpillars (Danthanarayana 1980). The parasitoid larvae feed externally and later form cocoons inside the nest formed by the leafroller. The rest of the species Dumbleton described attacking light brown apple larvae either had arrived with light brown apple moth or were native to New Zealand. Two native parasitoids identified by Dumbleton are still frequently encountered: the gregarious endoparasitoid *Glyptapanteles demeter* (Wilkinson) (Braconidae), which attacks third- and fourth-stage leafroller larvae, and the tachinid fly *Pales funesta* (Hutton), which attacks fourth and fifth larval stages.

G. demeter is the most frequently cited native parasitoid attacking light brown apple moth. In a study conducted in organic apple orchards, *Dolichogenidea* spp. was the most abundant parasitoid attacking leafrollers found in the apple foliage; *G. demeter* was the dominant parasitoid reared from leafrollers collected from broadleaf weeds in the apple orchard understory (Rogers et al. 2003).

Thomas (1989) reported 19 species of parasitoids reared from light brown apple moth eggs, larvae and pupae collected in New Zealand prior to 1967. *D. tasmanica* was the most abundant, and few parasitoids attacked the later larval and pupal stages. Trichogrammatid parasitoids, including *Trichogramma funiculatum* and *Trichogrammatoidea bactrae*, parasitized the eggs of light brown apple moth with wide variation in parasitism levels, rarely rising above 10% (Thomas 1989; Stevens 1995).

In 1967 and 1969, Thomas collected parasitoids in the eastern temperate areas of Australia, from Sydney in New South Wales to Hobart in Tasmania. Of the specimens collected, six species that attack late leafroller stages were released between 1967 and 1972. Five species successfully established themselves, but only three that attack light brown apple moth became relatively widespread. These three species are the tachinid fly *Trigonospila brevifacies* (Hardy), which attacks late larval stages, and the pupal ichneumonid parasitoids *Xanthopimpla rhopaloceros* Krieger and *Glabridorsum stokesii* (Cameron). All three species had been released at several locations in the North Island, and in the Nelson area and Canterbury in the South Island. In 1999, *T. brevifacies* was rereleased in the Nelson area, using specimens collected in Hawke's Bay (Shaw et al. 2001).

In surveys conducted in 1996 and 1997 (Munro 1998), *X. rhopaloceros* and *T. brevifacies* were found throughout the North Island and the north end of the South Island. Both species failed to establish in Canterbury. *X. rhopaloceros* had a faster rate of spread than *T. brevifacies*; *X. rhopaloceros* was first reported established in the north end of the North Island in 1973. Published reports in 1975 and 1976 indicate that this species appeared in Auckland in numbers large enough that the public made inquiries to the authorities (Munro 1998). By the late 1970s and early 1980s it was recorded in the south of the North Island, becoming widespread in Hawke's Bay by 1985 and in Nelson by 1992.

T. brevifacies was first reported as established in the northern tip of the North Island in 1972. Archival records show that it was found in the northern part of the island in the 1980s, moving through the western side and reaching Wellington (in southern North Island) in 1998. Recorded finds from the eastern North Island began in the early 1990s with reports from Hawke's Bay in 1995. In the South Island the first reports were from Nelson in 1997.

Although the impacts of *T. brevifacies* and *X. rhopaloceros* have not been quantified, there is indirect evidence that they have contributed to significant declines in larval fruit-feeding damage by light brown apple moth, and consequently to reduced insecticide use. These generalist parasitoids, in particular *T. brevifacies*, also have had an impact on endemic leafroller species and are likely to compete with native parasitoids in the natural environment (Munro and Henderson 2002), but since no prerelease data on the relative abundance of lepidopteran species was gathered, it is difficult to determine the exact impact. Before any proposed introduction of the natural enemies, possible impacts on both native hosts and natural enemies should be considered.

Photos: New Zealand Institute for Plant & Food Research Limited

Parasitoids are insects that complete their development inside a host. A number of them are known to attack light brown apple moth, including, *top, Xanthopimpla rhopaloceros, center, Glabridorsum stokesii* and, *bottom, Dolichogenidea tasmanica*.

Current biocontrol strategies

Leafroller larvae and pupae (predominantly light brown apple moth) and parasitoid cocoons were collected from orchards and vineyards in Hawke's Bay between 1993 and 2009 (Lo, unpublished data). These specimens were reared to determine which species of leafroller or parasitoid emerged. *D. tasmanica* remains the most abundant leafroller parasitoid, comprising 66% to 97% of the parasitoids reared from apple and stone fruit trees, berry fruit and grapevines. The next most abundant parasitoids were *T. brevifacies* (1% to 27%), *G. demeter* (2% to 16%) and *Goniozus jacintae* (2% to 12%). *D. tasmanica* comprised 90% of the parasitoids reared from the first four larval instars, reducing light brown apple moth larvae by 85% on average. A high proportion of neonate light brown apple moth larvae fail to settle and establish successful leafrolls, and die before reaching the second instar. Later larval stages are then subjected to high levels of parasitism that potentially further reduced light brown

National Research Council reviews pest status of light brown apple moth

by Rhonda J. Smith

IN 2007, the light brown apple moth was classified by the U.S. Department of Agriculture's Animal Plant Health and Inspection Service (APHIS) as an actionable, quarantine-significant pest, meaning that its presence has potentially significant economic importance. Its presence in California resulted in a federal order restricting the interstate movement of specific agricultural commodities and their byproducts from affected counties. To meet the federal order, the moth is subject to quarantine and eradication efforts by both APHIS and the California Department of Food and Agriculture (CDFA).

In 2009, more than 3,500 square miles of California were in the quarantine area. Growers and others who move regulated articles off-site are required to have compliance agreements with the county agricultural commissioner's office. In Sonoma County, for example, affected commodities include wine grapes, apples, cane berries, strawberries, nursery stock, cut flowers and most vegetables and herbs, as well as green waste. Compliance agreements are also required of the entity that receives product, such as wineries, processing and packing plants. Wine-grape haulers are required to have compliance agreements if they transport grapes from a quarantine area.

In September 2008 and February 2009, APHIS received one petition from four citizens, and another from the Pesticide Action Network of North America plus other organizations, requesting that light brown apple moth be reclassified from an actionable to a nonactionable pest. In addition, the petitioners argued against eradication as a feasible regulatory action. In June 2009, APHIS wrote a draft response to the petitions and requested that it be reviewed by the National Research Council (NRC).

The NRC's September 2009 "Letter Report" addressed whether the federal government had the regulatory authority to classify light brown apple moth as an actionable, quarantine-significant pest, and evaluated both the scientific basis for this regulatory decision and the quality of the evidence presented.

The 31-page report had two take-home messages. First, APHIS did have the authority to classify light brown apple moth as an actionable pest and thus could take regulatory action. Second, the evidence used as the basis for the classification decision was insufficient and unclear, and in some instances the evidence was not clearly supported by the data provided.

Finding 1: Only qualitative, rather than quantitative, criteria on economic/environmental damage are required for the Secretary of Agriculture to determine a regulatory response to a pest. APHIS met the minimal standard by providing evidence of the moth's potential invasive nature and economic and environmental impacts, but the agency's justification is not scientifically rigorous.

Finding 2: The data used to predict the potential geographic distribution of light brown apple moth in the United States and the subsequent economic impact analyses are not based on "sound, rigorous science."

Finding 3: The evidence presented to make estimates of the potential economic damage to agricultural production and trade, as well as environmental damage to native and endangered plant species, is not evaluated consistently and has limitations that are not clearly acknowledged or explained.

Finding 4: The credibility of the response is undermined by factors such as inadequately documented statements and scientifically imprecise terminology.

Finding 5: APHIS has not published a proposed or final rule of the federal order in the Federal Register for comment under the Administrative Procedure Act and missed the opportunity to justify its actions to the public.

Finding 6: APHIS chose to limit the scope of its response by not addressing the use of eradication as the current control strategy, and thus "may have exacerbated public concerns about the eradication effort."

The NRC scientists could only address what was contained in the APHIS response; however, they emphasized that APHIS did not include a rationale for choosing eradication, which is one of several possible approaches to control a regulated pest. Instead, APHIS restricted its response to the issue of the light brown apple moth's classification status and missed an opportunity to explain its decisions to the general public.

It is important to read the full NRC Letter Report, which recommends that APHIS refocus on the question of why this pest is so important to the United States and base their response on a detailed economic analysis.

Go to: http://www.nap.edu/catalog.php?record_id=12762. For information on CDFA's Light Brown Apple Moth Project, go to: http://www.cdfa.ca.gov/phpps/PDEP/lbam/lbam_main.html.

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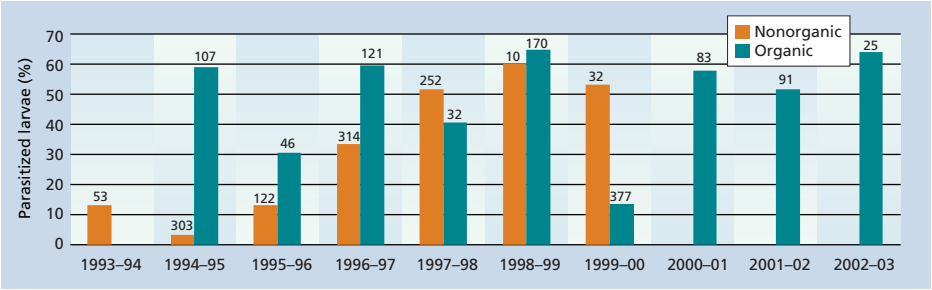

Fig. 3. Parasitized leafroller larvae from apple orchards in Hawke's Bay, New Zealand. Yearly sample size is at the top of each column.

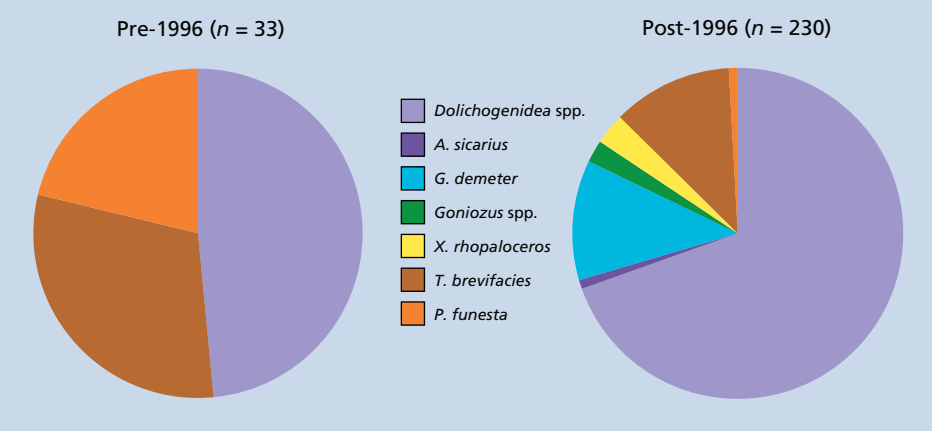

Fig. 4. Parasitoid species reared from leafrollers collected in nonorganic apple orchards in Hawke's Bay, New Zealand, 1993–1995 and 1996–2000.

apple moth populations by an estimated 95% (Lo, unpublished data).

It is difficult to compare the relative importance of each natural enemy without a comprehensive life-table study. Nevertheless, the significance of *D. tasmanica* is evident in the relatively high percentage of parasitism of young larvae (about 50% of instar stages two to four) compared with later immature stages (about 20%). Although the later parasitoids are less abundant than *D. tasmanica*, their importance should not be underestimated. They are removing leafrollers that are more likely to breed and contribute to the growth of subsequent populations.

Perhaps the large increase in parasitism in New Zealand apple orchards during the 1990s also reflected the coincidental change from broad-spectrum to selective insecticides such as insect growth regulators. Many broad-spectrum insecticides are nerve poisons and consequently are toxic to both pests and beneficial species. In contrast, selective insecticides act on metabolic pathways of pests but not those of natural enemies, and therefore have substantially lower toxicity to the latter, in particular parasitoids. In 1996, the New Zealand apple industry began implementing the Integrated Fruit Production Program (Walker et al. 1997), and within 5 years the industry had substantially eliminated broad-spectrum organophosphates from their spray schedules (Manktelow et al. 2005).

To address changing European Union market demands for fruit produced using environmentally sustainable production systems, a pilot Integrated Fruit Production Program was initiated in pome fruit throughout New Zealand in 1996. In this program, insect control relied on the increased use of biological control, monitoring and threshold-based applications of reduced-risk insecticides — those compatible with integrated pest management (IPM) (Walker et al. 1997). Light brown apple moth control is based on one recommended application of an insecticide at petal fall (early November). Any subsequent insecticide use after Dec. 15 is based on a cumulative threshold of 30 male moths caught in pheromone traps.

The program was progressively adopted by growers and became the minimum export standard by 2001. Total organophosphate insecticide use decreased from an average of 9 applications per season in 1996 to 0.3 applications in 2003 (Manktelow et al. 2005). After 2001, just one or two reduced-risk insecticide applications may be required for light brown apple moth control when fruit are grown for domestic consumption. For export apples, pest management is largely driven by codling moth control. This, together with the increased levels of biological control, provides a very high level of management of light brown apple moth.

The impact of the replacement of organophosphate insecticides on biological control was demonstrated in Hawke's Bay apple orchards. The proportion of parasitized leafroller larvae and pupae from nonorganic apple orchards increased significantly between 1993 and 1994, and between 1999 and 2000 (fig. 3) (Lo, unpublished data). Of 478 leafrollers collected from 23 orchards between 1993 and 1995, 7% were parasitized. In contrast, from 1996 to 2000, 604 leafrollers were collected from 19 orchards, and 42% were parasitized. In 1998, after implementation of the Integrated Fruit Production Program, it became increasingly difficult to find leafroller infestations in nonorganic apple orchards. By 2000, the whole sector had adopted Integrated Fruit Production practices, and larval collections ended because of the scarcity of leafroller fruit damage. In organic apple orchards where there was no major change in spray programs between 1993 and 2003, parasitism was high throughout this period, albeit with some annual fluctuations.

In addition to an increase in parasitism after the change to selective insecticides, there is also a greater diversity in the parasitoid fauna attacking leafrollers in New Zealand. In nonorganic apple orchards, three parasitoid species were reared from pre-1996 collections compared with seven species in later years (fig. 4). In studies conducted in berry fruit in 1985 and 1986 in Hawke's Bay (Charles et al. 1996), 14% to 70% of larvae collected and reared were parasitized. More than 90% of the parasitoids reared were the solitary species *D. tasmanica*. The remaining were the gregarious larval parasitoids *G. demeter* and *Goniozus* spp. Parasitism of larvae and pupae collected from berries was 62% from 1996 to 1999, and 79% from 2008 to 2009 (Lo, unpublished data). *D. tasmanica* was less dominant than in the Charles et al. (1996)

study, because *T. brevifacies* and *Meteorus pulchricornis* were found in addition to *G. demeter* and *Goniozus* spp.

Current insecticide use

The selective insecticides used in pome fruit today in New Zealand primarily target codling moth, but they are also effective against light brown apple moth and provide high levels of control. They include tebufenozide (Confirm), methoxyfenozide (Intrepid), indoxacarb (Avaunt), chlorantraniliprole (Altacor) and emamectin benzoate (Proclaim). All are effective and provide long residual control with low to moderate impacts on beneficial natural enemies. About 8% of the New Zealand apple crop is grown organically; the insecticides used in these orchards include spinosad (Entrust) and *Bacillus thuringiensis* (Bt). Significant proportions of organic growers successfully produce export apple crops using mating disruption for codling moth control without any use of these insecticides, and they suffer only negligible fruit damage from light brown apple moth.

Some of the new insecticides are significantly less disruptive to natural enemies than the broad-spectrum organophosphates used in the past. Residual bioassays measuring the effects of field application rates of insecticides to *D. tasmanica* showed that tebufenozide and emamectin benzoate were harmless (less than 21% mortality) to adults 7 days after treatment. Indoxacarb and lime-sulfur residues caused 80% to 99% mortality, while carbaryl (Sevin), diazinon and spinosad (Success) were very harmful (more than 99% mortality) (Newman et al. 2004). These toxicity categories followed the standard criteria for laboratory studies defined by the International Organization for Biological and Integrated Control of Noxious Animals and Plants (Hassan 1985).

By early 2000, all of New Zealand's major fruit industries had implemented programs based on the concepts embodied within Integrated Fruit Production: use of thresholds for pesticide inputs, with an emphasis on selective control options (Manktelow et al. 2005). Wine-grape industry records show that, for leafroller control, national insecticide use has shifted from an average of one organophosphate application in 1997 to less than 0.4 insect growth regulator applications by 2008. The two insect growth regulator insecticides used in wine grapes for leafroller control are tebufenozide and methoxyfenozide. The need for an application is determined by damage observed during the previous harvest. When treatment is needed, a single prebloom spray is applied.

Considerations for California

With a strategic commitment to biological control within an IPM context, California may ultimately achieve the

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References

Berry JA. 1998. The bethyline species (Hymenoptera: Bethylidae: Bethylinae) imported into New Zealand for biological control of pest leafrollers. NZ J Zool 25:329–33.

Charles JG, Walker JTS, White V. 1996. Leafroller phenology and parasitism in Hawkes Bay, New Zealand, canefruit gardens. NZ J Crop Hort Sci 24:123–31.

Collyer E, van Geldermalsen M. 1975. Integrated control of apple pests in New Zealand. 1. Outline of experiment and general results. NZ J Zool 2:101–34.

Danthanarayana W. 1980. Parasitism of the light brown apple moth *Epiphyas postvittana* (Walker), by its larval ectoparasite, *Goniozus jacintae* Farrugia (Hymenoptera: Bethylidae), in natural populations in Victoria. Aust J Zool 28:685–92.

Dumbleton LJ. 1932. The apple leaf-roller (*Tortrix postvittana* Walker). NZ J Sci Tech 14:83–92.

Dumbleton LJ. 1935. *Apanteles tasmanica* Cam., a braconid parasite of leafroller larvae. NZ J Sci Tech 17:572–6.

Dumbleton LJ. 1936. The biological control of fruit pests in New Zealand. NZ J Sci Tech 18:588–92.

Hassan SA. 1985. Standard methods to test the side-effects of pesticides on natural enemies of insects and mites developed by the IOBC/WPRS Working Group Pesticides and Beneficial Organisms. Bull OEPP/EPPO 15:214–55.

Hudson GV. 1928. *The Butterflies and Moths of New Zealand.* Wellington, New Zealand: Ferguson Osborn. 386 p.

Lo PL, Suckling DM, Bradley SJ, et al. 2000. Factors affecting feeding site preferences of lightbrown apple moth, *Epiphyas postvittana* (Lepidoptera: Tortricidae), on apple trees in New Zealand. NZ J Crop Hort Sci 28:235–43.

Manktelow D, Stevens P, Walker JTS, et al. 2005. Trends in Pesticide Use in New Zealand: 2004. Report to the Ministry of Environment, Project SMF4193. 73 p.

Munro VMW. 1998. A record of the releases and recoveries of the Australian parasitoids *Xanthopimpla rhopaloceros* Krieger (Hymenoptera: Ichneumonidae) and *Trigonospila brevifacies* Hardy (Diptera: Tachinidae) introduced into New Zealand for leafroller control. NZ Entomol 21:81–91.

Munro VMW, Henderson IM. 2002. Nontarget effect of entomophagous biocontrol: Shared parasitism between native lepidopteran parasitoids and the biocontrol agent *Trigonospila brevifacies* (Diptera: Tachinidae) in forest habitats. Env Entomol 31:388–96.

Newman IC, Walker JTS, Rogers DJ. 2004. Mortality of the leafroller parasitoid *Dolichogenidea tasmanica* (Hym: Braconidae) exposed to orchard pesticide residues. NZ Plant Protect 57:8–12.

Paull C, Austin AD. 2006. The hymenopteran parasitoids of light brown apple moth, *Epiphyas postvittana* (Walker) (Lepidoptera: Tortricidea) in Australia. Aust J Entomol 45:142–56.

Plant & Food Research. 2008. Fresh Facts: New Zealand Horticulture 2008. http://www.hortresearch.co.nz/files/aboutus/factsandfigs/ff2008.pdf. 36 p.

Rogers DJ, Walker JTS, Moen IC, et al. 2003. Understory influence on leafroller populations in Hawke's Bay organic apple orchards. NZ Plant Protect 56:168–73.

Shaw PW, Lo P, Wallis DR. 2001. Recent introduction and establishment of the leafroller parasitoid *Trigonospila brevifacies* (Hardy) (Diptera: Tachinidae) in Nelson. NZ Plant Protect 54:33–6.

Stevens PS. 1995. Host preferences of *Trichogrammatoidea bactrae fumata* (Hym.: Trichogrammatidae) an egg parasitoid of leafrollers (Lep.: Tortricidae). Entomophaga 40:379–85.

Suckling DM, Chapman RB, Penman DR. 1984. Insecticide resistance in the lightbrown apple moth *Epiphyas postvittana* (Walker): Larval responses to azinphosmethyl. J Econ Entomol 77:579–83.

Suckling DM, Khoo JGI. 1990. Cross-resistance in the lightbrown apple moth *Epiphyas postvittana* (Lepidoptera: Tortricidae). NZ J Crop Host Sci 18:173–80.

Thomas WP. 1965. Studies on *Epiphyas postvittana* (Walker) (Lepidoptera, Tortricidae) and its parasitoid complex. M.Sc. thesis, University of Canterbury. 130 p.

Thomas WP. 1989. *Epiphyas postvittana* (Walker), lightbrown apple moth (Lepidoptera: Tortricidae). In: Cameron PJ, Hill RL, Bain J, Thomas WP (eds.). *A Review of Biological Control of Invertebrate Pests and Weeds in New Zealand, 1874 to 1987*. Wallingford, UK: CAB Int. p 187–95.

[USDA NASS] US Department of Agriculture National Agricultural Statistics Service. 2008. California Agricultural Statistics, Agricultural Overview 2007. http://www.nass.usda.gov/Statistics_by_State/California/Publications/California_Ag_Statistics. 10 p.

Varela LG, Johnson MW, Strand L, et al. 2008. Light brown apple moth's arrival in California worries commodity groups. Cal Ag 62:57–61.

Walker JTS, Hodson AJ, Wearing CH, et al. 1997. Integrated fruit production for New Zealand pipfruit: Evaluation of pest management in a pilot programme. Proc 50th NZ Plant Protect Conf. p 258–63.

Wearing CH, Thomas WP, Dugdale JS, Danthanarayana W. 1991. Tortricid pests of pome and stone fruits, Australian and New Zealand species. In: *Tortricid Pests: Their Biology, Natural Enemies and Control*; *World Crop Pests, Vol. 5.* Amsterdam: Elsevier. p 453–72.

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same levels of light brown apple moth control as obtained in New Zealand. Many fruit crops in California already receive control measures for native and introduced leafrollers, and these tactics may prove to be effective for light brown apple moth without a great deal of modification.

If the New Zealand experience is any indication, adequate control of this leafroller can be achieved more effectively through a vigorous program of biological control and the use of selective insecticides for other pest species. That approach identified a need to introduce natural enemies to attack light brown apple moth through all stages of development. The focus on introductions to address parasitism gaps, especially those targeting the late larval and pupal stages, proved to be highly effective. Further exploration of natural enemies in New Zealand may yield guidance for possible parasitoid importations to North America.

As New Zealand has already found, it is unlikely that any one parasitoid will be so specific that it attacks only light brown apple moth. Therefore, any introduction of natural enemies into California must be preceded by a careful cost-benefit analysis. Light brown apple moth is a polyphagous insect, feeding on many plant species, and some native leafrollers may occupy the same niche. The benefit of suppressing populations of light brown apple moth and allowing reduced use of insecticide must outweigh possible adverse impacts on populations of endemic moths and natural enemies. This is an issue that must be carefully considered in the development of a strategic plan for the long-term management of this pest in California.

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References (see page 11)

RESEARCH ARTICLE

Airborne particles in the San Joaquin Valley may affect human health

by Mai A. Ngo, Kent E. Pinkerton, Sandra Freeland, Michael Geller, Walter Ham, Steven Cliff, Laurie E. Hopkins, Michael J. Kleeman, Urmila P. Kodavanti, Emily Meharg, Laurel Plummer, Julian J. Recendez, Marc B. Schenker, Constantinos Sioutas, Suzette Smiley-Jewell, Christine Haas, Joyce Gutstein *and* Anthony S. Wexler

Air quality is a primary concern for many San Joaquin Valley residents. In addition to rapid population growth, a widening interface between urban and agricultural communities, and increasing traffic along the I-5 and Hwy. 99 corridors, farming practices in the San Joaquin Valley subject agricultural workers to high concentrations of airborne particulate matter potentially associated with adverse health effects. We created a research team and mobile field unit equipped with a special inhalation system, particle monitoring and characterization abilities, and housing for the transport and care of animals to examine the effects of particulate matter throughout the San Joaquin Valley. With this system, a variety of biological endpoints can be examined to determine respiratory, systemic and neurological responses to short-term particle exposure. Field research of this nature coupled with biological assays and location-specific inhalation studies can help researchers and regulators to better understand potential health effects due to environmental and occupational airborne-particle exposures faced by workers and residents in the San Joaquin Valley.

Agriculture is a major industry in California, generating $36 billion in 2007 (CDFA 2009). The state claims nine of the 10 most productive counties in the nation. The majority are in the San Joaquin Valley, which extends approximately 250 miles from San Joaquin County in the north to Kern County in the south. San Joaquin Valley agriculture encompasses more than 400 plant and animal commodities — with Fresno and Tulare counties leading in agricultural value for the production of grapes, almonds, milk, oranges and cattle. Approximately 4 million people live in the San Joaquin Valley (State of California 2007) and the number of farmworkers is estimated to be between 175,000 to 500,000.

While the San Joaquin Valley is one of the world's most productive agricultural regions, it is also frequently in violation of U.S. ambient air-quality concentration standards, particularly those for atmospheric particulate matter (PM) (Velasco 2005), which is defined as liquid or solid material such as soil dust or smoke suspended in the air. Particulate levels for the South Coast Air Basin and the Central Valley in California are the highest recorded in the country, exceeding the national ambient air-quality standards for each season of the year. Workers and residents of the San Joaquin Valley are exposed to airborne particulate matter from a broad range of sources including farming practices such as the tilling of dry soil, agricultural burning, crop harvesting and diesel-powered water pumping. Particle emissions include inorganic compounds from soil lofted by, for example, dairy operations and off-road vehicles, or organic matter from animal feed and disturbed, dried manure.

The three parameters — size, composition and distribution — for each classification of particles are sufficiently different that each can produce unique health outcomes following inhalation. Epidemiological studies have shown a strong correlation between the exposure of human populations to particulate matter and acute and chronic health effects, including increased deaths due to cardiovascular illness and emergency room visits related to the severity of asthma symptoms (Sheppard

Workers and residents of the San Joaquin Valley are exposed to a wide range of airborne particulate matter.

et al. 1999; Peters et al. 2000; Pope and Dockery 2006; Pope 2007). Farm and dairy workers and residents of the San Joaquin Valley may be at increased risk for unfavorable health consequences that have been linked to airborne particle exposure.

Health effects of particles

Particulate matter can be classified by size: coarse, PM_{10} (< 10 microns); fine, $PM_{2.5}$ (< 2.5 microns); or ultrafine, $PM_{0.1}$ (< 0.1 micron). One micron (μm) equals 4 one-hundred-thousandths (0.00004) of an inch. Fine and ultrafine particles, between 0.1 and 2.5 microns, are capable of penetrating deeply into the respiratory tract. Evidence increasingly suggests that these are the more harmful particle sizes because they are associated with increased mortality and respiratory illnesses (Samet et al. 2000; Peters et al. 1997; Englert 2004; Ostro et al. 2006; Pope and Dockery 2006).

Coarse particles, between 2.5 and 10 microns, are also associated with adverse health effects, especially in the elderly, with increased morbidity and mortality due to cardiopulmonary complications (Ostro et al. 2006). Although agricultural activity is generally believed to produce coarse particle emissions ($PM_{2.5}$ to PM_{10}), it also contributes fine ($PM_{2.5}$) and ultrafine ($PM_{0.1}$) particles to the air. For example, diesel emissions from agricultural operations and the burning of agricultural crop waste actively produce $PM_{2.5}$ and its subset, $PM_{0.1}$. Moreover, ammonia emitted from fertilizer and livestock can combine with vehicle exhaust to form ammonium nitrate particles in the $PM_{2.5}/PM_{0.1}$ range.

PM_{10}, $PM_{2.5}$ and $PM_{0.1}$ particles consist of hundreds of compounds in liquid and solid form created by sources ranging from agricultural activities to diesel engines to vegetative burning (Davidson et al. 2005; Herner et al. 2005). Organic hydrocarbons found in airborne particulate matter such as polycyclic aromatic hydrocarbons and quinones, and transition metals such as chromium and iron, may be responsible for producing reactive oxygen molecules, which induce oxidative stress and subsequent inflammation that can lead to disease (Ghio et al. 1999). Inflammation of the airways following exposure to particulate matter can exacerbate asthma, chronic bronchitis and airway obstruction. Oxidative stress, inflammation or alterations in autonomic (neural control) perturbations from particulate matter exposure may also exacerbate adverse cardiovascular conditions, especially in individuals with pre-existing heart and vascular disease (Ostro et al. 2006; Pope 2007).

PM field studies

Ambient atmospheric measurements indicate that particulate-matter concentrations in the San Joaquin Valley fluctuate over the course of a day and can vary seasonally and from year to year; variations in weather and emissions are the primary causes of these ambient concentration changes (Chow et al. 1993, 1999; Velasco 2005).

To account for seasonal fluctuations, our initial studies evaluated the health effects of exposure to San Joaquin Valley particulate matter for 2 consecutive weeks in June 2006 (representing summer) and November 2006 (representing winter). The studies utilized a customized, climate-controlled mobile trailer designed specifically for housing laboratory animals and conducting ambient particulate-matter exposure studies.

Young adult rats (10 to 12 weeks of age) were housed and acclimatized for 1 week prior to exposure in our trailer, located at the UC Kearney Agricultural Research Center in the small farming community of Parlier, Calif., approximately 15 miles southeast of Fresno. Animals were housed in standard polycarbonate cages. During exposure periods, the animals were transferred to cages specifically modified for use as exposure chambers with special sealed tops (Smith et al. 2003). To determine the effects of short-term exposure to particulate matter, the animals were divided into three groups: (1) filtered air (control), (2) fine/ultrafine particles and (3) coarse particles. Animals were exposed 6 hours per day for 3 consecutive days. Ambient air was drawn from the rooftop of the trailer and filtered through HEPA filters for the control animals or concentrated to approximately 20 times ambient levels of fine/ultrafine ($PM_{2.5}$/ $PM_{0.1}$) or coarse (PM_{10}) particles with two different portable Versatile Aerosol Concentrator Enhancement Systems (VACES) (Kim et al. 2001; Smith et al. 2003). All animals were handled according to the U.S. Animal Welfare Act and all procedures

Agricultural workers and residents of the San Joaquin Valley are exposed to airborne pollutants from a broad range of sources. *Above*, a worker sprays a field during the 2007 railroad bridge fire north of Sacramento.

Community engagement and outreach

A critical component of our field studies is translating research to practice, along with community engagement at all levels. Therefore, we participated in a community health fair held in Parlier, titled "Empowering Parlier Community Members to Make Positive Lifestyle Changes – Eat Better and Move More." Sponsored by UC Cooperative Extension in Fresno County, the health fair was attended by more than 200 farmworkers and their families. Participants took full advantage of more than 30 health-awareness booths, which included information about cancer, nutrition and diabetes; free screenings; and hands-on workshops. Through the participation of the Western Center for Agricultural Health and Safety (WCAHS), we sponsored an air-quality booth with bilingual handouts, interactive materials and graphics for nonreaders, created for the event. The San Joaquin Valley Unified Air Pollution Control District, the California Air Resources Board and the Fresno-Madera Medical Society also provided air-quality brochures.

Keynote speaker California Assembly Member Juan Arambula (31st district) and Parlier City Manager Lou Martinez acknowledged the contributions of the health fair to their communities and noted that the collaboration of health care workers, researchers, government agencies and volunteers is making significant progress in raising health awareness and facilitating realistic approaches that promote positive lifestyle changes.

At a health fair in Parlier, Assemblyman Juan Arambula (left) discusses air quality with Kent Pinkerton and graduate student Emily Meharg of the Western Center for Agricultural Health and Safety at UC Davis.

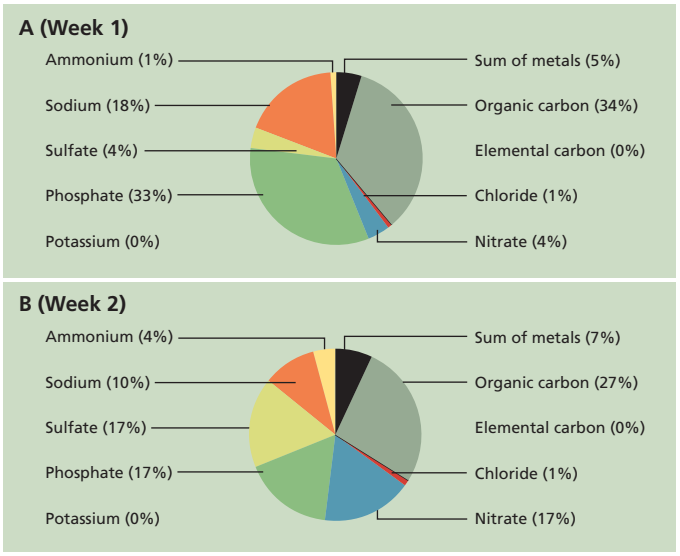


Fig. 1. Chemical composition of fine/ultrafine particles measured during 3-day particle exposure in the San Joaquin Valley, June 2006.

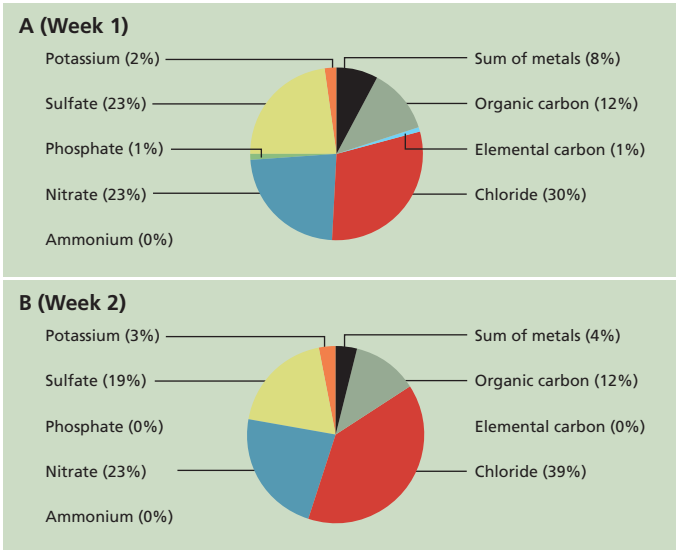


Fig. 2. Chemical composition of coarse particles measured during 3-day particle exposure in the San Joaquin Valley, June 2006.

were performed under the supervision of the University Animal Care and Use Committee at UC Davis.

To determine ambient particle-mass concentrations for ultrafine, fine and coarse particles, as well as their chemical and biological composition, two Micro Orifice Uniform Deposit Impactors (MOUDI) collected size-fractionated ambient particulate-matter samples onto Teflon and quartz filters. Particle-mass concentrations were also obtained from the coarse and fine/ultrafine concentrator filters to verify particle concentration efficiency.

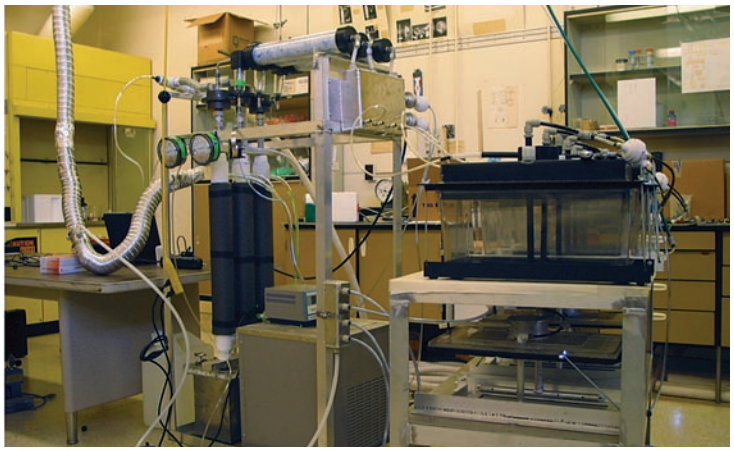
TABLE 1. Particle exposure conditions, 6 hrs/day for 3 days in rats 10–12 weeks old

	June 2006		November 2006	
Concentration	Week 1	Week 2	Week 1	Week 2
	..... mg/m^3 air			
Fine/ultrafine	392	268	320	131
Coarse	268	214	298	292

Observations following exposure

The average concentrations of ambient particles were measured for each inhalation study by week and season (table 1). Although the total mass concentration of particles in the air changed little from week 1 to week 2, during the summer season the chemical composition of the fine/ultrafine ($PM_{2.5}/PM_{0.1}$) and coarse (PM_{10}) particles varied widely (figs. 1 and 2). Most notable was the variability in nitrate, sulfate, organic material, phosphate and metal content of the particles. Although cations are clearly present in the mixture of ambient particulate matter, they were not measured because the study did not focus on particle acidity. We only measured nitrates and sulfates based on the assumption that they are likely to be in the form of their fully neutralized ammonium salts. Previous

A mobile trailer was used to conduct field air-quality studies at the Kearney Agricultural Research Center in Parlier.



Rats were exposed to airborne particulate matter via an aerosol concentrator (VACES) in inhalation chambers.

studies have verified that ammonia is present in excess amounts within the San Joaquin Valley and that ammonium ion is the dominant cation in the $PM_{2.5}$ size range (Herner et al. 2005, 2006).

Following 3 days of exposure to concentrated ambient particles (6 hours per day), the animals were examined for evidence of changes in the lungs, systemic circulation and central nervous system. Assays were designed to measure cell injury, inflammation or mediators involved in inflammation and altered metabolic function. These assays included the examination of immune cells, tissue pathology and gene expression. Bronchoalveolar lavage (a method of sterile saline instillation) was used to recover cells from the lungs. For experiments to date, no statistically significant increases in the number of lung cells recovered from the rats have been noted, suggesting that there is no active recruitment of immune cells from the blood to the lungs due to inhaled particles.

However, in one experiment where cells were recovered from the lungs by lavage, a significant increase in the proportion of cells with increased permeability or cell membrane leakage (reflecting irreversible cell injury) was observed following exposure to fine/ultrafine particles, but not to coarse particles (fig. 3). In contrast, some experiments demonstrated a slight, but statistically significant, increase in the total number of neutrophils (white blood cells involved in inflammation and immune responses of the body) recovered by bronchoalveolar lavage after exposure to coarse particles (data not shown). Also, the results of one experiment showed a significant increase in the amount of interleukin 1ß (IL-1ß), a proinflammatory cytokine, in the lungs of rats exposed to fine/ultrafine particles compared with rats exposed to coarse particles or in the control. Together, these findings suggest that short-term exposure to concentrated ambient particles can be associated with occasional subtle, but significant, particle effects.

The examination of blood samples from each experimental group of animals failed to demonstrate significant changes in markers of oxidative stress, metabolic alteration or proinflammatory cytokines. However, one experiment resulted in a particularly intriguing finding: a significant increase in gene expression for interleukin-6 (IL-6), a proinflammatory cytokine, in the brains of animals exposed to fine/ultrafine particles compared to animals exposed to coarse particles (fig. 4). This observation suggests that inhaled particles may have an effect on nonrespiratory organ systems such as the central nervous system, and we plan to study this area further.

Future research

We have observed seasonal variability in particle mass and composition along with small, significant changes in some markers of inflammation and cell viability. This type of field study, which characterizes ambient particulate-matter mixtures found in agricultural regions and determines health outcomes in animal inhalation models, helps provide new insights into how particulate matter affects agricultural workers and residents living in the San Joaquin Valley. This was a relatively short study (3-day exposure), and in the future we

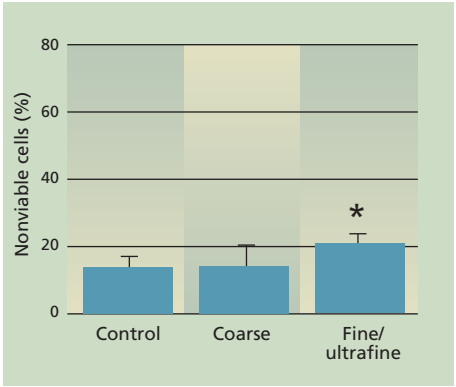


Fig. 3. Proportion of nonviable cells recovered from rat lungs following exposure to concentrated ambient particles in the San Joaquin Valley. Asterisk notes significant change from filtered air control ($P < 0.05$).

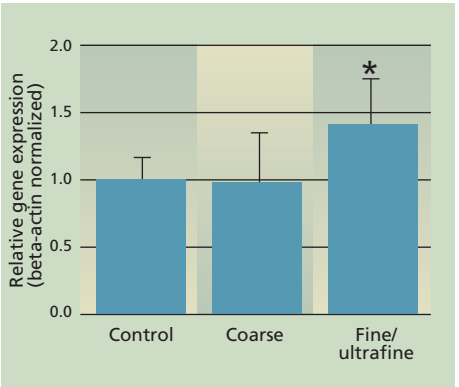


Fig. 4. IL-6 mRNA expression in the rat central nervous system following short-term repeated exposure to concentrated ambient particles. Asterisk notes significant change from control ($P < 0.05$).

plan to conduct longer exposures to more closely mimic the long-term particulate-matter concentrations to which agricultural workers and residents are exposed. We will continue to focus on seasonal differences in fine and coarse particle composition and whether there are particular physical and chemical properties of particulate matter (such as size or composition) that are especially relevant to adverse health effects. The ultimate goal of these inhalation studies is to provide information to improve the health of people working and living in the San Joaquin Valley.

Jack Kelly Clark

Particulate matter has been linked to adverse health effects including cardiovascular illness and asthma. Agricultural operations, such as wheat harvesting in Yolo County, *above*, can generate dust.

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References

[CDFA] California Department of Food and Agriculture. 2009. An overview of California agricultural production statistics. Sacramento, CA. http://www.cdfa.ca.gov/statistics.

Chow JC, Watson JG, Lowenthal DH, et al. 1993. PM_{10} and $PM_{2.5}$ compositions in California San Joaquin Valley. Aerosol Sci Technol 18(2):105–28.

Chow JC, Watson JG, Lowenthal DH, et al. 1999. Temporal variations of $PM_{2.5}$, PM_{10}, and gaseous precursors during the 1995 integrated monitoring study in central California. J Air Waste Manag Assoc 49:16–24.

Davidson C, Phalen R, Solomon P. 2005. Airborne particulate matter and human health: A review. Aerosol Sci Technol 38(8):737–49.

Englert N. 2004. Fine particles and human health — a review of epidemiological studies. Toxicol Lett 149(1–3):235–42.

Ghio AJ, Stonehuerner J, Dailey LA, et al. 1999. Metals associated with both the water-soluble and insoluble fractions of an ambient air pollution particle catalyze an oxidative stress. Inhal Toxicol 11(1):37–49.

Herner JD, Aw J, Gao O, et al. 2005. Size and composition distribution of airborne particulate matter in northern California: I — particulate mass, carbon, and water-soluble ions. J Air Waste Manag Assoc 55(1):30–51.

Herner JD, Aw J, Gao O, et al. 2006. Dominant mechanisms that shape the airborne particle size and composition distribution in central California. Aerosol Sci Technol 40:827–44.

Kim S, Jaques PA, Chang M, et al. 2001. Versatile aerosol concentration enrichment system (VACES) for simultaneous in vivo and in vitro evaluation of toxic effects of ultrafine, fine and coarse ambient particles — Part I: Development and laboratory characterization. J Aerosol Sci 32(11):1281–97.

Ostro B, Broadwin R, Green S, et al. 2006. Fine particulate air pollution and mortality in nine California counties: Results from CALFINE. Env Health Perspect 114(1):29–33.

Peters A, Wichmann HE, Tuch T, et al. 1997. Respiratory effects are associated with the number of ultrafine particles. Am J Respir Crit Care Med 155(4):1376–83.

Pope 3rd CA. 2007. Mortality effects of longer term exposures to fine particulate air pollution: Review of recent epidemiological evidence. Inhal Toxicol 19 Suppl 1:33–8.

Pope 3rd CA, Dockery DW. 2006. Health effects of fine particulate air pollution: Lines that connect. J Air Waste Manag Assoc 56(6):709–42.

Samet JM, Dominici F, Curriero FC, et al. 2000. Fine particulate air pollution and mortality in 20 U.S. cities, 1987–1994. N Engl J Med 343(24):1742–9.

Sheppard L, Levy D, Norris G, et al. 1999. Effects of ambient air pollution on nonelderly asthma hospital admissions in Seattle, Washington, 1987–1994. Epidemiology 10(1):23–30.

Smith KR, Kim S, Recendez JJ, et al. 2003. Airborne particles of the California Central Valley alter the lungs of healthy adult rats. Env Health Perspect 111(7):902–8; discussion A408–9.

State of California. 2007. Population Projections for California and Its Counties, 2000–2050. Department of Finance. http://www.dof.ca.gov/html/DEMOGRAP/ReportsPapers/Projections/P1/P1.php.

Velasco P. 2005. Characterization of Ambient PM_{10} and $PM_{2.5}$ in California. California Environmental Protection Agency Air Resources Board. Sacramento, CA.

Research and outreach can lessen the overall burden of diabetes in farmworkers

by Lucia L. Kaiser, Anna C. Martin
and Francene M. Steinberg

Type 2 diabetes is increasing rapidly in the United States and Latin America and contributes significantly to the rise in health care spending. Diabetes increases the risk of cardiovascular disease, renal failure and blindness, and leads to other complications. Type 2 diabetes and its complications can be delayed in high-risk individuals through a healthy lifestyle and ongoing medical care. Some research suggests a relationship between diabetes and other underlying metabolic conditions, either as predisposing factors or as adverse outcomes of occupational exposures in farmworkers. UC Cooperative Extension can have a greater impact on the health and safety of California's workforce by filling in research gaps and strengthening collaborations.

Phil Schermeister

Type 2 diabetes is being diagnosed more frequently in Latinos, in whom serious complications such as amputation are more common than in non-Latino white patients.

IN the United States, diabetes affects an estimated 23.6 million people, most of whom do not achieve optimal control of their blood glucose levels (Valitutto 2008). Fueled by the obesity epidemic, this disease is expected to affect 48.3 million people by 2050 (Narayan et al. 2006). Globally, the number of people with diabetes is projected to double over the next 30 years, with much of the increase expected to occur in developing countries (Chaturvedi 2007). We review trends in type 2 diabetes and provide a perspective on the implications for occupational health and safety programs targeting farmworker populations. We also discuss ways that outreach and research programs of the University of California and UC Cooperative Extension can help to reduce the burden of diabetes.

Epidemiologic trends in diabetes

United States. The prevalence of type 2 diabetes is increasing rapidly in the United States and contibutes significantly to the rise in health care spending (Koopman et al. 2005; Thorpe 2006). Although type 2 diabetes is still more common in seniors over age 60 than in adults under age 40, the average age at diagnosis dropped from 52 years in 1988 to 1994, to 46 years in 1999 to 2000 (Koopman et al. 2005). In fact, diabetes and other chronic health problems related to obesity are now appearing in young people at such increased frequency that today's youth may be the first generation in modern history to have a life expectancy shorter than that of their parents (Daniels 2006).

Latin America. Type 2 diabetes has also emerged as a serious health concern in Mexico and other parts of Latin America. Diabetes is the third major cause of mortality for the general population in Mexico and the primary cause in adults 55 years and older (Barquera et al. 2003). The dramatic rise in diabetes, hypertension and coronary heart disease in Mexico from 1980 to 1998 has paralleled an increase in obesity and may be in part related to increased intake of fat and refined carbohydrate (including soda) in that country (Rivera et al. 2002). Over the next 10 years, the number of diabetes cases in Latin America is expected to increase more than two-fold and to exceed the number of cases in the United States, Canada and Europe by 2025 (Aschner 2002). Factors driving this trend include aging of the population, urbanization, and lifestyle and dietary changes. Diagnosis often occurs late in the disease, result-

Phil Schermeister

Nutrition therapy, exercise and medication can help to manage type 2 diabetes, and ongoing medical attention is critical.

Jack Kelly Clark

While limited research has examined occupational factors that contribute to the risk of diabetes, there is evidence of an association with environmental exposure to pesticides. ***Above***, protective gear helps to protect a farmworker from pesticide exposure in a San Diego County nursery.

ing in 10% to 40% of uncontrolled diabetes cases already having developed complications by the time of diagnosis.

Complications. U.S. adults with diabetes die from heart disease at rates that are two to four times higher than those in adults without diabetes (CDC 2007). Diabetes is the leading cause of blindness in adults 20 to 74 years old, and results in 12,000 to 24,000 new cases of blindness each year. Diabetes is also the main cause of kidney failure. In 2005, 178,689 people with end-stage renal disease due to diabetes were treated with dialysis or received a transplant. About 60% to 70% of adults with diabetes have mild to severe forms of nerve damage, including impaired sensation or pain in the hands and feet, slowed digestion of food and other nerve problems. Severe nerve damage is a major contributor to lower-extremity amputations and resulted in 71,000 amputations in 2004. Other health problems related to diabetes include periodontal disease, miscarriage, birth defects and excessively large birth weight (macrosomia) in babies born to women with diabetes.

Risks in agriculture

Relatively little research has examined diabetes and other metabolic conditions in farmworkers as either (1) predisposing factors to injury or (2) adverse outcomes from occupational exposures. Since type 2 diabetes can go undiagnosed or develop slowly over years, self-reported diabetes status as a variable in epidemiological studies may lead to underestimates of risk. Many people are unaware that they have diabetes. In addition to traditional, population-based epidemiologic research, a "disease-first" approach is being taken in environmental health research (Wilson and Schwartz 2006). This paradigm emphasizes linking the understanding of molecular mechanisms of disease pathogenesis to information from traditional environmental-exposure assessments. The combination of new science tools and knowledge of early disease processes can facilitate rapid advances in knowledge of causality and individual susceptibility to environmental stressors. An example of this approach is the hypothesis that lifetime cumulative exposure to pesticides is associated with an increased risk of diabetes.

There is evidence of an association between pesticide exposure and diabetes. In a sample of 1,300 Mexican Americans who participated in the Hispanic Health and Nutrition Examination Survey, conducted from 1982 to 1984, higher levels of organochlorine compounds, which are found in pesticides, were observed in the blood of adults with self-reported diabetes compared to those without diabetes (Cox et al. 2007). However, due to the cross-sectional design of the study, it is not clear whether there is a causal relationship between pesticide exposure and diabetes, or what the nature of that relationship may be.

Metabolic conditions like diabetes that alter blood cholesterol levels may also increase the solubility of organochlorines, resulting in increased blood levels of these compounds. In a national sample of adults without diabetes, higher blood levels of organochlorine and nondioxin-like polychlorinated biphenyl compounds were associated with insulin resistance, which frequently precedes the development of type 2 diabetes (Lee et al. 2007). In the same data set, a strong dose-response relationship was observed between diabetes prevalence and the blood concentrations of six such compounds (Lee et al. 2006).

In the Agricultural Health Study, women who reported agricultural pesticide exposure (by mixing or applying pesticides to crops or repairing pesticide application equipment) were twice as likely to develop gestational diabetes (odds ratio = 2.2 [95% confidence interval = 1.5 – 3.3]) (Saldana et al. 2007). The most recent findings from this prospective study of nearly 32,000 individuals showed that lifetime cumulative exposure to seven specific chlorinated pesticides increased the likelihood of diabetes (Montgomery et al. 2008). It is recognized that the disease is multifactorial with a complex interplay between biology, the environment, lifestyles and health

outcomes. Overall, the results suggest that environmental exposure to pesticides may be a contributing factor for the risk of diabetes, and the hypothesis warrants further investigation.

Occupational hazards

The primary occupational hazards in agriculture include sun exposure, injuries, pesticide exposure and poor field sanitation. Exposure to extreme temperatures is challenging for individuals with diabetes. Sweat production in response to warm temperatures and exercise may be impaired in adults with diabetes (Petrofsky et al. 2005). Impaired response to temperature may partly explain why the majority of hospital admissions due to heat stroke, dehydration and heat exhaustion during heat waves occur in people with underlying metabolic conditions including diabetes, cardiovascular disease and renal problems (Semenza et al. 1999).

Agricultural workers have one of the highest rates of injury resulting in amputation (Boyle et al. 2000). The extent to which agriculture-related injuries in farmworkers are exacerbated by underlying diabetes and other metabolic diseases is not known. We do know that Latino patients with vascular disease experience higher rates of amputation than non-Latino white patients (Morrissey et al. 2007). High rates of this particular diabetes-related complication among Latinos may be due to relatively poor control of blood glucose levels and inadequate access to preventive care (Kirk et al. 2008; Oladele and Barnett 2006). Carpal tunnel syndrome occurs with increased frequency in workers with diabetes (Falkiner and Myers 2002; Werner et al. 2005). Since high levels of glucose in the blood can result in nerve damage, repetitive motions at work may exacerbate the problem.

People with type 2 diabetes need to understand that insulin may eventually be required to control blood glucose levels and that it is important not to delay insulin therapy.

Prevention and management

To prevent type 2 diabetes, the American Diabetes Association recommends lifestyle changes (ADA 2008a). Key elements include moderate weight loss, physical activity and a diet with reduced calories and total fat — especially saturated fat — and high in fiber. The extent to which these recommendations are effective in preventing diabetes in youth remains to be determined. Evidence is insufficient to recommend alcohol in moderation or foods with a low glycemic index as diabetes prevention strategies.

Management of diabetes typically involves a combination of individualized medical nutrition therapy, physical activity and medication (pills with or without insulin). Since type 2 diabetes is a progressive disease that results in the loss of pancreatic beta-cell function over time, patients need ongoing medical attention to monitor their health status and adjust medications appropriately. We have observed a cultural belief in some Mexican populations that insulin causes blindness or thins the blood. People with type 2 diabetes need to understand that insulin may eventually be required to control blood glucose levels and that it is important not to delay insulin therapy (Valitutto 2008). Knowledge about the perceptions of farmworkers regarding their risks for diabetes and how to manage the chronic disease is crucial when designing interventions (Heuer and Lausch 2006).

In 2008, the National Heart, Lung, and Blood Institute halted a large, randomized, controlled trial because very tight control of diabetes in older patients appeared to increase their risk of mortality. In that study, the intensive treatment was aimed at achieving a hemoglobin A1C (a measurement commonly used to monitor longer-term control of blood glucose in diabetes patients) value of less than 6%, compared to a standard goal of 7% to 7.9%. The public should not interpret this announcement to mean that the control of blood glucose in diabetes no longer matters. The American Diabetes Association's response to this news reiterated that (1) the importance of glucose control is firmly established, (2) treatment should be tailored to the individual and (3) for some older patients, intensive, tight control may not be warranted.

Major types of diabetes

Type 1 (5% to 10%): The body makes little or no insulin as a result of autoimmune attack on pancreatic cells. Therapy coordinates insulin injections with the individual's diet and activity patterns.

Type 2 (90% to 95%): Cells do not respond normally to insulin and/or the body cannot deliver enough insulin to control blood sugar. Blood glucose control involves a healthy lifestyle and diet, and physical activity. Oral medications and/or insulin may also be prescribed.

Gestational (GDM): Onset occurs during pregnancy, and ends after delivery, but 20% to 50% of women with GDM will develop type 2 diabetes later in life. GDM is often managed with diet, but may also require insulin injections to control blood sugar.

Other: Diabetes is related to genetic abnormalities, medications or pancreatic disease.

Source: CDC 2007.

Current recommendations for primary prevention of diabetes in high-risk adult populations

- Moderate weight loss (about 7% of body weight).
- Physical activity (at least 150 minutes of moderate exercise per week).
- A diet that is low in fat and calories and high in fiber (14 grams per 1,000 calories).

Source: ADA 2008a.

Benefits of effective management

Effective diabetes management decreases risk and costs. The body of evidence from randomized, controlled trials is strong that type 2 diabetes can be prevented, or at least delayed, in high-risk individuals through the adoption of a healthy lifestyle (CDC 2004). In fact, lifestyle changes can reduce the incidence of new cases by 58% and are clearly more cost-effective than providing medication to prevent diabetes in middle-aged adults (Herman et al. 2005). Compared to the standard course of treatment, intensive

Diabetes education with culturally appropriate messages can help to prevent and control the disease. "Take Care of Yourself! (¡Cuidad bien!)" is a bilingual diabetes-awareness curriculum that targets adult Latinos (ANR Pub 3415; http://anrcatalog.ucdavis.edu).

Using Hispanic radio as effective outreach to farmworkers

- There were 730 Spanish-language stations in 2002, up 37% from 1998.
- Hispanic radio attracts listeners in every demographic group.
- The time spent listening is particularly on the rise in older adults (65 years and over).
- More listening is done away from home, during the morning and lunchtime hours.
- Mexican Regional, the most popular format, reaches 7.6 million listeners per week.

Source: Arbitron 2007.

therapy for type 2 diabetes lowered the risk of cardiovascular disease and other complications (Gaede et al. 2003). To achieve those results, the intensive therapy involved individual consultations with health professionals, lifestyle changes (such as a diet low in total and saturated fat, moderate exercise and smoking cessation) and progressive changes in medication (Gaede et al. 2003). An economic analysis of 17 different diabetes interventions concluded that eye care and preconception care were clearly cost-saving, most of the other interventions were at least cost effective, and more studies are required (Klonoff and Schwartz 2000). There is an urgent need to translate the intensive diabetes therapies utilized in research studies into effective strategies for community-based health care and education.

How can we make a difference?

Farmworker access to health care is often limited, due not only to lack of insurance coverage, but also to language and cultural barriers, work schedules and lack of transportation. Lay health educators from the same communities (known in Spanish as *promotoras*) can help farmworkers and their families bridge the gaps in care. The role of a *promotora* varies from a support person or patient advocate to a teacher who can deliver basic health education in group settings or home visits. A randomized, controlled intervention among 150 Mexican-American adults with diabetes living along the U.S.-Mexico border found that *promotora*-taught classes were effective in improving glycemic control (hemoglobin A1C) 6 months postintervention compared to a control group that received standard clinic care only (Lujan et al. 2007). A demonstration project in a similar population reported greater improvement in glycemic control among those patients who participated more frequently in *promotora*-led support groups (Ingram et al. 2007).

In a report of programs funded under their Agricultural Worker Health Initiative, the California Endowment identified practices that are promising for health promotion and other key areas related to health services provided to agricultural workers (Glasnapp 2003). These practices include providing mobile clinics and child-care programs with services designed for migrant families, using the radio to reach large numbers of workers (see box above), scheduling events during the "low season" for workers and using child-focused experiences and/or popular recreational activities such as soccer to attract parents and other family members. Farmworkers and their families are excellent resources to involve in the educational process through advisory boards, outreach worker programs and *promotora* health programs.

UC Cooperative Extension specialists and advisors are uniquely positioned to implement many of these practices through their county connections and collaborations. Specialists and advisors have established strong networks that foster the cooperation of agricultural leaders, growers, migrant-clinic operators and community health leaders. Cooperative Extension's health promotion programs, focused on motivating participants to practice healthy eating and lifestyle behavior modifications, provide opportunities to extend the key messages so critical to diabetes prevention and awareness — eat smart, be physically active and be proactive about your health. Cooperative Extension can also play an important role in training *promotoras* and other extenders who work directly with farmworkers.

Implications for the future

The current trends in diabetes are projected to have staggering economic

and social costs (Aschner 2002; Daniels 2006; Narayan et al. 2006). A conservative estimate of the direct medical and indirect expenditures attributable to diabetes was $174 billion in 2007 (CDC 2007). That figure is projected to reach $192 billion by 2020. The Latino population has a high prevalence of diabetes, and farmworkers often experience disparities in health care access, but there is great potential to mitigate diabetes-related costs through culturally appropriate education aimed at primary disease prevention.

We have the capability within UC and Cooperative Extension to have a greater impact on the health and safety of the current workforce, but there are gaps to fill and collaborations that need strengthening. As a first step, the agenda should include interdisciplinary research to capitalize on growing collaborations between nutrition, toxicology and public-health scientists to increase understanding of the molecular mechanisms of disease pathogenesis and the associations among diet, lifestyle and environmental exposures in farmworkers and other high-risk populations. Second, more dialogue and coordination are needed between those involved in occupational health and safety programs, and health promotion and obesity/disease prevention programs. Research should examine the costs and benefits of emphasizing nutrition in general — as well as diabetes awareness and prevention — in worksite wellness programs, with the goal of improving health outcomes. Finally, to confront the obesity and diabetes epidemics occurring in the United States and worldwide, a multidimensional approach involving both public education and environmental change is urgently needed. Such an approach will require strengthening collaboration across disciplines and programs.

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References

[ADA] American Diabetes Association. 2008. Nutrition recommendations and interventions for diabetes: A position statement of the American Diabetes Association. Diabetes Care 31(suppl 1):S61–78.

Arbitron. 2007. Hispanic Radio Today. How America Listens to Radio. http://www.arbitron.com/downloads/hispanicradiotoday07.pdf.

Aschner P. 2002. Diabetes trends in Latin America. Diabetes Metab Res Rev 18(suppl 3):S27–31.

Barquera S, Tovar-Guzman V, Campos-Nonato I. 2003. Geography of diabetes mellitus mortality in Mexico: An epidemiologic transition analysis. Arch Med Res 34(5):407–14.

Boyle D, Parker D, Larson C, Pessoa-Brandao L. 2000. Nature, incidence, and cause of work-related amputations in Minnesota. Am J Ind Med 37(5):542–50.

[CDC] Centers for Disease Control and Prevention. 2004. Primary prevention of type 2 diabetes mellitus by lifestyle intervention: Implications for health policy. Primary Prevention Working Group. Ann Intern Med 140:951–7.

CDC. 2007. National diabetes fact sheet: General information and national estimates on diabetes in the United States, 2007. http://www.cdc.gov/diabetes/pubs/pdf/ndfs_2007.pdf.

Chaturvedi N. 2007. The burden of diabetes and its complications: Trends and implications for intervention. Diabetes Res Clin Pract 76(suppl 1):S3–12.

Cox S, Niskar AS, Narayan KM, Marcus M. 2007. Prevalence of self-reported diabetes and exposure to organochlorine pesticides among Mexican Americans: Hispanic Health and Nutrition Examination Survey, 1982–1984. Env Health Perspectiv 115(12):1747–52.

Daniels SR. 2006. The consequences of childhood overweight and obesity. Future Child 16(1):47–67.

Falkiner S, Myers S. 2002. When exactly can carpal tunnel syndrome be considered work-related? ANZ J Surg 72(3):204–9.

Gaede P, Vedel P, Larsen N, et al. 2003. Multifactorial intervention and cardiovascular disease in patients with type 2 diabetes. N Engl J Med 348(5):383–93.

Glasnapp JD. 2003. Identified promising practices and multicultural health models: A look at the California Endowment's Agricultural Worker Health Program. http://www.calendow.org/uploadedFiles/identified_promising_practices.pdf.

Herman WH, Hoerger TJ, Brandle M, et al. 2005. The cost-effectiveness of lifestyle modification or metformin in preventing type 2 diabetes in adults with impaired glucose tolerance. Ann Intern Med 142(5):323–32.

Heuer L, Lausch C. 2006. Living with diabetes: Perceptions of Hispanic migrant farmworkers . J Comm Health Nurs 23(1):49–64.

Ingram M, Torres E, Redondo F, et al. 2007. The impact of promotoras on social support and glycemic control among members of a farmworker community on the U.S.-Mexico border. Diabetes Educ 33(suppl 6):172–8S.

Kirk JK, Passmore LV, Bell RA, et al. 2008. Disparities in A1C levels between Hispanic and non-Hispanic white adults with diabetes: A meta-analysis. Diabetes Care 31(2):240–6.

Klonoff DC, Schwartz DM. 2000. An economic analysis of interventions for diabetes. Diabetes Care 23(3):390–404.

Koopman RJ, Mainous AG, Diaz VA, Geesey ME. 2005. Changes in age at diagnosis of type 2 diabetes mellitus in the United States, 1988 to 2000. Ann Fam Med 3(1):60–3.

Lee DH, Lee IK, Jin SH, et al. 2007. Association between serum concentrations of persistent organic pollutants and insulin resistance among nondiabetic adults: Results from the National Health and Nutrition Examination Survey, 1999–2002. Diabetes Care 30(3):622–8.

Lee DH, Lee IK, Song K, et al. 2006. A strong dose-response relation between serum concentrations of persistent organic pollutants and diabetes: Results from the National Health and Examination Survey, 1999–2002. Diabetes Care 29(7):1638–44.

Lujan J, Ostwald SK, Ortiz M. 2007. Promotora diabetes intervention for Mexican Americans. Diabetes Educ 33(4):660–70.

Montgomery MP, Kamel F, Saldana TM, et al. 2008. Incident diabetes and pesticide exposure among licensed pesticide applicators: Agricultural Health Study, 1993–2003. Am J Epidemiol 167:1235–46.

Morrissey NJ, Giacovelli J, Egorova N, et al. 2007. Disparities in the treatment and outcomes of vascular disease in Hispanic patients. J Vasc Surg 46(5):971–8.

Narayan KM, Boyle JP, Geiss LS, et al. 2006. Impact of recent increase in incidence on future diabetes burden: U.S., 2005–2050. Diabetes Care 29(9):2114–6.

Oladele CR, Barnett E. 2006. Racial/ethnic and social class differences in preventive care practices among persons with diabetes. BMC Public Health 6:259.

Petrofsky JS, Lee S, Patterson C, et al. 2005. Sweat production during global heating and during isometric exercise in people with diabetes. Med Sci Monit 11(11):CR515–21.

Rivera JA, Barquera S, Campirano F, et al. 2002. Epidemiological and nutritional transition in Mexico: Rapid increase of non-communicable chronic diseases and obesity. Public Health Nutr 5(1A):113–22.

Saldana TM, Basso O, Hoppin JA, et al. 2007. Pesticide exposure and self-reported gestational diabetes mellitus in the Agricultural Health Study. Diabetes Care 30(3):529–34.

Semenza JC, McCullough JE, Flanders WD, et al. 1999. Excess hospital admissions during the July 1995 heat wave in Chicago. Am J Prev Med 16(4):269–77.

Thorpe KE. 2006. Factors accounting for the rise in health-care spending in the United States: The role of rising disease prevalence and treatment intensity. Public Health 120(11):1002–7.

Valitutto M. 2008. Common crossroads in diabetes management. Osteopath Med Prim Care 2(1):4.

Werner RA, Franzblau A, Gell N, et al. 2005. Incidence of carpal tunnel syndrome among automobile assembly workers and assessment of risk factors. J Occup Environ Med 47(10):1044–50.

Wilson SH, Schwartz DA. 2006. Disease-first: A new paradigm for environmental health science research. Env Health Perspectiv 114(7):A398.

High risk of depression among low-income women raises awareness about treatment options

by Amy Block Joy *and* Mark Hudes

Depression in young women living in poverty has devastating consequences if left untreated. Low-income women are at a higher risk for depression than other income groups, and the majority of these women are untreated. The Center for Epidemiologic Studies Depression Scale was used to assess depression symptoms in women under 45 years old in five California counties. More than 45% were identified as depressed, and the highest level of depressive symptoms was found in Sonoma County. We also found a significant negative association between the number of people in the household and depressive symptom scores, that is, with fewer people in the household depression increased. This result may indicate the need for a support system that is more accessible to individuals in smaller households or it may be an artifact of Hispanics having larger families and lower depression scores. Our results indicate that there is a critical need to provide mental health resources to low-income women, especially those with young children.

Diane L. Metz

Low-income women have a higher risk for depression than women in other income groups. The consequences of depression include fatigue, poor health and low self-esteem. Depression also increases the risk of financial stress and unemployment.

Depression among low-income women remains an unacknowledged and devastating illness. The consequences include low self-esteem, acute and chronic illnesses, relationship conflicts, poor health, financial instability, emotional insecurity and unemployment. Depression affects the whole family, yet it is a treatable condition. Among low-income populations, there is a need for awareness, screening programs and treatment services.

Low-income women are at a higher risk for depression than women in other income groups, and the majority of affected women are untreated (Lennon et al. 2001; Hall 1990; Gadalla 2008). The prevalence of depression in low-income populations has been documented. In one study, the depression rate for women of all income groups (n = 7,000, ages 15 to 46 years) was 20.4% (Chen et al. 2005). A report on the prevalence, treatment and consequences of depression highlighted the high rate in low-income women, with a median of 47% (Lennon et al. 2001). Higher rates of depression have been reported in low-income minority groups, specifically blacks, as well as young mothers and women without a social support network (McBarnette 1996; Chung et al. 2004).

Health care providers who work with low-income families often see a multitude of needs, and food and shelter are usually the first step in treating the effects of poverty. Yet, in battling with daily economic and health concerns, women caught in the cycle of poverty can experience acute stress, despair, loss of self-worth and chronic hopelessness.

The disabling effects of depression are numerous and well known. Symptoms include loss of motivation and interest, mood changes and irritability, fatigue, loss of energy and sleep, changes in appetite, poor concentration and forgetfulness, profound sadness, and loss of self-worth and self-esteem. In addition, many people who suffer from depression are also at risk for anxiety symptoms, including fearfulness, worries, headaches, insomnia, fatigue and multiple physical symptoms (e.g., chest pain, palpitations, sweating and alarm).

However, once identified, there are effective treatments for both anxiety and depression. The purpose of this study was to evaluate depression among low-income women in California, and raise awareness of the

critical need for screening and treatment options.

Women caught in the cycle of poverty can experience acute stress, despair, loss of self-worth and chronic hopelessness.

Assessing depression

A short, easy-to-administer questionnaire — the Center for Epidemiologic Studies Depression Scale (CES-D) — was used to assess depression symptoms in low-income women (Radoff 1977). The National Institute of Mental Health's Center for Epidemiologic Studies developed the self-report instrument to measure the frequency and severity of 20 common depression symptoms. Using a four-point Likert scale, the response for each symptom is scored and the scores (ranging from 0 to 60) calculated. Scores of 16 or greater indicate depression**.** The reliability of the instrument is 0.85 (internal consistency, coefficient alpha, Spearman-Brown).

This instrument has been demonstrated to be reliable and valid for low-income populations (Radoff 1977; Thomas et al. 2001). In a study of 179 low-income women attending primary care clinics (ages 20 to 77), the cutoff score of 16 or higher was validated (sensitivity = 0.95, specificity = 0.70) for diagnosing major depressive disorder (MDD) in low-income populations (Thomas et al. 2001). Research has shown that the scores of clinically depressed individuals are much higher than those of nondepressed individuals. Furthermore, researchers have validated this instrument in other ethnic groups: 65% of low-income mothers, mainly blacks, were identified as being depressed in a study using the CES-D screener (Chung et al. 2004).

The self-report instrument has been widely used in both community and population studies to assess depressive symptoms and to identify the proportion of individuals with major depressive disorders. Radoff (1977) examined the structure of the screener (questionnaire). Her four-factor structure — (1) depressed affect, (2) positive affect, (3) somatic complaints and (4) interpersonal problems — has been replicated and is widely accepted. Another study validated the use of this screener and the four-factor structure for low-income blacks (Nguyen et al. 2004). The general factor structure is also considered adequate for Mexican Americans, blacks and whites (Roberts 1980) but not for Native Americans (Chapleski et al. 1997).

Depression screening

CES-D questionnaires were initially completed by 157 low-income women as part of a nutrition-education study (Cena 2007; Cena et al. 2007; Cena et al. 2008a, 2008b). In all, the researchers studied 14 variables that included demographic factors (geographical location, language spoken, ethnicity, low-income status, household size, age and participation in the federal Special Supplemental Program for Women, Infants and Children [WIC] and Food Stamp Program), folic acid intake (natural-food folic acid, synthetic folic acid [SFA] from fortified foods, synthetic folic acid from supplements, total folic acid from all sources, folate status) and depression. The folic acid variables were added to determine if there was a relationship between folic acid intake and depression. Since folic acid has a role in maintaining serotonin — the major neurotransmitter needed to maintain a feeling of "well-being" — researchers have hypothesized that folic acid may reduce depression. However, studies have found both a positive and inverse relationship between folic acid and depression (Astorg et al. 2008; Coppen and Bolander-Gouaille 2005; Taylor et al. 2004).

Most food sources of folic acid are considered healthy foods and include breakfast cereals (cold cereals, oatmeal, grits, Cream of Wheat), eggs, beans, green vegetables, tortillas and other breads (slices, rolls, bagels, muffins, buns), oranges and orange juice. Some of these foods — breads, orange juice and breakfast cereals — are fortified with synthetic folic acid.

Demographics. The women in the study (n = 157) were low-income clients enrolled in a nutrition-education program for food-stamp-eligible recipients; 52.9% were enrolled in WIC with incomes less than 185% of the poverty level, 39.5% were enrolled in the federal Food Stamp Program with incomes less than 130% of the poverty level, and 73% were receiving either or both WIC and Food Stamp Program benefits.

The sample size per county was Fresno, 39; Sonoma, 41; Shasta/Trinity, 36; and San Diego, 41. The women were 18 to 45 years of age (average = 31.6 years) and had diverse ethnicity (56.7% Hispanic, 35.7% non-Hispanic white, 3.8% Native American/Alaskan Native, 1.3% Asian/Pacific Islander, 2.5% mixed ethnicity).

All participants in Fresno and San Diego counties were self-identified as Hispanic and completed the screener in Spanish (51%), while all the participants in Shasta/Trinity and Sonoma counties identified themselves as a number of ethnicities and completed the screener in English (49%). All subjects signed a consent form, and the Institutional Review Board of UC Davis approved the study.

Statistical analysis. Of the 157 clients enrolled in the study, 121 completed the CES-D survey. Thirty-six participants were not included in the analysis due to incomplete survey responses or incorrectly marked multiple answers for at least one question on the instrument.

Statistical tests were performed using SPSS version 15.0 (SPSS, Chicago, IL, 2006) to examine relationships between depression and 14 variables. Two-sample independent t-tests were employed to evaluate depressive symptoms by each dichotomous variable (language, food stamps, WIC participation). For categorical variables (county, ethnicity, folate intake), one-way analysis-of-variance techniques were used, and, if significant, followed up using Tukey's post-

TABLE 1. Depression scores by county and language

County (n)	Mean score ± SD*	P value† = 0.018
Sonoma (41)	19.8 ± 10.4	
San Diego (41)	12.1 ± 10.4	
Language (n)		**P value = 0.059**
English (49)	17.7 ± 10.5	
Spanish (51)	14.1 ± 10.0	

* Standard deviation.

† Statistical significance was defined to be $P < 0.05$ where P is the likelihood of observing the result by chance alone.

hoc tests for multiple comparisons. We examined the relationship between depression score and continuous variables (e.g., folate intake, household size) utilizing Pearson correlation coefficients. Statistical significance was defined as $P < 0.05$, and results where $0.05 < P < 0.06$ were considered to be approaching statistical significance.

Referrals. Program staff provided the study participants with referrals to free mental-health resources in their local communities. The researchers hypothesized that the CES-D screener might raise awareness in study participants, and this awareness might lead to increased stress. Staff members were trained to listen for questions about depression, and a referral handout was given to participants after they completed the screener. Due to confidentiality, the participants were not asked about their use of referrals, and staff did not identify any mental health issues related directly to depression.

High depression scores

Of the 121 participants who completed the CES-D screener correctly, scores ranged from 0 to 44 with a mean of 16.1 (standard deviation of 10.4). As described in the literature, CES-D scores of 16 or more were classified as "depressed" and scores below 16 were "not depressed," so that 45.5% of the study participants were identified as depressed (Cena et al. 2007).

Language. The results demonstrated some associations between depressive symptoms and the respondent's language (table 1). Of all the sites studied, Sonoma County ($n = 41$) had the highest level of depressive symptoms, and all were English-speaking women. San Diego County ($n = 41$) scores were lower, and all were Spanish speakers (table 1). There was a significant difference in the depressive symptom scores between Sonoma and San Diego counties ($P = 0.018$) and a near-significant difference between English and Spanish language ($P = 0.059$).

TABLE 2. Statistical associations between folate foods and household size and depression measured by CES-D scores in low-income women ($n = 121$)

Variable	Correlation with CES-D score (r)	P value*
Folate from fortified foods (SFA)	0.277	0.002
Number of people in household	–0.174	0.056

* Statistical significance was defined to be $P < 0.05$ where P is the likelihood of observing the result by chance alone.

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Depression is a treatable illness; free counseling services are available through community referrals in every California county.

Household size. The average household size was 4.3 people (± 1.7), with means of 4.9 (± 1.5) people for Hispanic women and 3.3 (± 1.6) for non-Hispanic white women. Household size was significantly different among Hispanic clients compared to non-Hispanic white clients ($P < 0.001$). In addition, there was a negative association between the number of people in the household and depressive symptoms that trended toward statistical significance ($P = 0.056$) (table 2). A possible explanation is that more than half the women were Hispanic, with larger household sizes and lower CES-D scores.

Folic acid intake. When the women were divided into two groups (depressed and nondepressed) and compared for folic acid intake, there were no significant differences between groups. This is consistent with other published studies (Astorg et al. 2008). In a longitudinal study of young women ($n = 5{,}051$, ages 20 to 34 years), low blood folic acid levels were not significantly associated with depression (Kendrick et al. 2008). In a study of pregnant women, depression was not associated with folic acid intake ($n = 1{,}277$ women, with 8.1% classified as depressed) (Cho et al. 2008).

However, we found a significant positive association between depression and foods fortified with synthetic folic acid when CES-D score was treated as a continuous variable ($r = 0.277$, $P = 0.002$) (table 2). Women who reported more synthetic folic acid intake also had higher depression scores. Previous research documents a positive as well as an inverse association between depression and folic acid.

Folic acid is recommended for women of childbearing age to prevent birth defects. The relationship between folic acid and depression is still under debate. Three published studies have found an inverse association between blood levels of folate and depression, that is, depressed individuals have been shown to have low blood folate levels (Coppen and Bolander-Gouaille 2005; Taylor et al. 2004; Morris et al. 2003). Some doctors recommend folic acid supplementation to enhance the treatment of depression by improving the effectiveness of some antidepressant medications (Coppen and Bolander-Gouaille 2005; Taylor et al. 2004).

Depression trends

The National Center for Children in Poverty used the CES-D instrument to study the prevalence of depression in low-income U.S. women, and found that 12.9% had experienced major depressive disorder for the past 12 months (Lennon et al. 2001). For women in this study the percentage was even higher: in the five counties that we studied, 45.5% were identified as depressed using the criteria defined in the CES-D screener.

Of the 14 variables studied, only two showed significant trends. There was a significant negative association between

the number of people in the household and depressive symptom scores; that is, with fewer people in the household, depression increased. This result may indicate the need for a support system that is more accessible to individuals in smaller households. Researchers have documented that Hispanic women with social-support networks, such as those provided by larger families, have reduced depression risk compared to other ethnic groups (Samaan 2000), suggesting that they have better coping strategies due to a variety of factors including social, religious and spiritual roots and extended family support**.** In this study, the household size of 4.9 persons for Hispanic clients was significantly larger than the 3.3-person households of non-Hispanic white clients ($P < 0.001$).

Treating low-income women

Numerous treatment options are available for depression, and successful results in low-income populations have been published. The main options are counseling (individual and group) and medication (a number of antidepressants and antianxiety medications have been tested). In a study on the treatment preferences of 1,893 low-income women, 78% selected counseling, 55% chose group counseling and 32% chose medication (Nadeem et al. 2008). In a sample of 267 low-income minority women who were randomly assigned to antidepressant medications, psychotherapy or community referrals, researchers found that both the medication and therapy treatments significantly reduced depressive symptoms. After a year of treatment, 50.9% of the medication group and 56.9% of the therapy group were no longer clinically depressed. Depression in the community-referral group (control) was not significant (Miranda et al. 2006). Other research has shown similar results in low-income black and Latino populations (Green et al. 2006).

Our results indicate that there is an important need to provide information on mental health programs to low-income women. Further work is needed to determine the feasibility of treating depression by identifying the need through screening programs and providing referrals. Depression is a treatable condition, and linking women and others to free treatment services is essential. In addition, information about depression, its symptoms and treatment options should be provided in public health and antipoverty programs, including for women in low-income agricultural jobs and communities.

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References

Astorg G, Couthouis A, deCourcy GP, et al. 2008. Association of folate intake with the occurrence of depressive episodes in middle-aged French men and women. Brit J Nutr 100(1):183–7.

Cena ER. 2007. Folate intake, food-related behaviors, and nutrition education in low-income women of childbearing age. Ph.D. dissertation, Department of Nutritional Biology, Office of Graduate Studies, UC Davis.

Cena ER, Joy AB, Heneman K, et al. 2008a. Folate intake and food-related behaviors in nonpregnant, low-income women of childbearing age. J Am Diet Assoc 108:1364–8.

Cena ER, Joy AB, Heneman K, et al. 2008b. Learner-centered nutrition education improves folate intake and food-related behaviors in nonpregnant, low-income women of childbearing age. J Am Diet Assoc 108:1627–35.

Cena ER, Joy AB, Heneman K, Zidenberg-Cherr S. 2007. Low-income women in California may be at risk of inadequate folate intake. Cal Ag 61:85–9.

Chapleski EE, Lamphere JK, Kaczynski R, et al. 1997. Structure of a depression measure among American Indian elders: Confirmatory factor analysis of the CES-D Scale. Res Aging 19:462–85.

Chen YY, Subramanian SV, Acevedo-Garcia D, Kawachi I. 2005. Women's status and depressive symptoms: A multilevel analysis. Soc Sci Med 60(1):49–60.

Cho YJ, Han Jy, Cho JS, et al. 2008. Prenatal multivitamins containing folic acid do not decrease prevalence of depression among pregnant women. J Obstet Gynaecol 28(5):482–4.

Chung EK, McCollum KF, Elo IT, et al. 2004. Maternal depressive symptoms and infant health practices among low-income women. Pediatrics 113(6):e523–9.

Coppen A, Bolander-Gouaille C. 2005. Treatment of depression: Time to consider folic acid and vitamin B-12. J Psychopharmacol 19(1):59–65.

Gadalla TM. 2008. Comparison of users and non-users of mental health services among depressed women: A national study. Women Health 47:1–19.

Green BL, Krupnick JL, Chung J, et al. 2006. Impact of PTSD comorbidity on one-year outcomes in a depression trail. J Clin Psychol 62(7):815–35.

Hall LA. 1990. Prevalence and correlations of depression symptoms in mothers of young children. Public Health Nurs 7(2):71–9.

Kendrick T, Dunn N, Robinson S, et al. 2008. A longitudinal study of blood folate levels and depression symptoms among young women in the Southampton Women's Survey. J Epidemiol Commun Health 62(11):966–72.

Lennon MC, Blome J, English K. 2001. Depression and low-income women: Challenges for TANF and Welfare-to-Work policies and programs. Research Forum on Children, Families and New Federalism; National Center for Children in Poverty. Columbia University Report.

McBarnette LS. 1996. African American women. In: Bayne-Smith M (ed.). *Race, Gender, and Health*. Newbury Park, CA: Sage Pub. p 43–67.

Miranda J, Green BL, Krupnick JL, et al. 2006. One-year outcomes of a randomized clinical trial treating depression in low-income minority women. J Consult Clin Psychol 74(1):99–111.

Morris MS, Fava M, Jacques PF, et al. 2003. Depressed folate status in the U.S. population. Psychother Psychosom 72(2):80–7.

Nadeem E, Lange JM, Miranda J. 2008. Mental health care preferences among low-income and minority women. Arch Womens Ment Health 11(2):93–102.

Nguyen HT, Kitner-Triolog M, Evans MK, et al. 2004. Factorial invariance of the CES-D in low socioeconomic status African Americans compared with a nationally representative sample. Psychiat Res 126:177–87.

Radoff LS. 1977. The CES-D scale: A self-report depression scale for research in the general population. Appl Psych Meas 1(3):385–401.

Roberts RE. 1980. Reliability of the CES-D scale in different ethnic contexts. Psychiat Res 2(2):125–34.

Samaan RA. 2000. The influence of race, ethnicity, and poverty on the mental health of children. Health Care Underserved 11:100–10.

Taylor MJ, Carney SM, Goodwin GM, et al. 2004. Folate for depressive disorders: Systematic review and meta-analysis of randomized controlled trials. J Psychopharmacol 18(2):251–6.

Thomas JL, Jones GN, Scarinci IC, et al. 2001. The utility of the CES-D as a depression screening measure among low-income women attending primary care clinics. Int J Psychiat Med 31(1):25–40.

Nurseries surveyed in Southern California adopt best practices for water quality

by Salvatore S. Mangiafico, Julie Newman, Maren Mochizuki, Dale Zurawski, Donald J. Merhaut *and* Ben Faber

A variety of good management practices have been recommended to minimize the impact of water runoff from production nurseries. However, studies have not been conducted to gauge which management practices nursery producers are most likely to adopt in response to education and increased government oversight. We surveyed 85 production nurseries in Southern California about their existing practices to limit the impacts of runoff from their facilities. Of these, 65 in Ventura County were resurveyed with the same questionnaire within 2 years. The positive response rate for following good management practices was 65%, compared to 57% in the initial survey. There were significant increases in every category of practices surveyed, and significant changes in the adoption of 38 specific practices. This suggests that nurseries are amenable to adopting management practices within a short time span in areas where there is increased governmental oversight and educational opportunities for growers.

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Nurseries in Southern California employ a variety of methods to produce a broad range of products. Eighty percent of the surveyed production area was uncovered, while the rest was in greenhouses and shadehouses, with numerous irrigation methods.

California's nursery and flower industries each rank among the top 10 agricultural commodities in the state, with a combined $3.8 billion in sales in 2006 (CDFA 2007). California's nursery industry is the largest in the nation, and is concentrated particularly in the central and south-coast counties (CDFA 2007). The intense application of fertilizers, pesticides and irrigation water has made runoff from these facilities an environmental concern. Practices recommended to minimize potential pollution by water outflow from nurseries include proper management of fertilizers, pesticides and irrigation water, as well as technologies such as retention basins to collect runoff for treatment and reuse (Newman 2009). However, few studies have documented the extent to which production nurseries have adopted these management practices.

Some studies have found considerable adoption of selected management practices by nurseries. For example, surveys of U.S. container production nurseries in Alabama and Georgia found that about half or more captured runoff water, and more than half used vegetative filter strips (Fain et al. 2000; Garber et al. 2002). Other practices may be less commonly adopted. A survey of container nurseries in west-central Florida from 1999 to 2002 found that only 35% of respondents using overhead irrigation monitored their system's uniformity (Schoene et al. 2006).

Discovering deficiencies in the adoption of management practices to protect water quality may be valuable to guide future education and research efforts. However, studies have not been conducted to gauge which practices will be adopted by nursery producers in response to grower education and increased government oversight. In an earlier survey of Southern California nurseries, respondents said that environmental and governmental regulations had a lower impact on their businesses relative to economic and resource factors (Merhaut and Pittenger 2005), raising the question of whether such pressure will lead to the adoption of appropriate practices. Our study was conducted to characterize management practices relevant to water-quality protection at 85 Southern California production nurseries, and to determine changes in the adoption of improved practices in a climate of regulatory pressure and available educational resources at 65 production nurseries in Ventura County.

Changes in practices could represent a substantial decrease in the potential contamination of surface water and groundwater from the participating operations.

Self-assessment surveys

We surveyed 65 nurseries in Ventura County and an additional 20 comparison nurseries in Los Angeles, Monterey, Riverside, San Bernardino, San Diego, San Luis Obispo, Santa Barbara and Santa Cruz counties. Surveys from Ventura County represented about 46% of all production nurseries in the county, and were conducted between January 2004 and September 2005. The same nurseries in Ventura County were then resurveyed with the same questionnaire between October 2005 and September 2006. The interval between the initial survey and the resurvey was between 12 and 21 months. For simplicity, the initial survey time period is referred to as "2004" and the resurvey as "2006."

Surveys from other counties were conducted in 2007 and 2008 and were not repeated. The survey was a 142-question self-assessment questionnaire (UCCE VC 2003) developed from an earlier self-assessment tool used in San Diego County (UCCE SDC). Questionnaires were typically completed during personal interviews with Cooperative Extension staff so that any questions could be addressed immediately. Responses were kept confidential to promote honesty and accuracy.

Size and production methods

In the first 10 questions, growers were asked about their production areas and methods. Differences between responses for Ventura County and those from other counties were tested with the Mann-Whitney-Wilcoxon two-sample test. No significant differences ($P \geq 0.05$) were found, suggesting that nurseries in Ventura County are similar to those throughout Southern California in terms of production area, products, irrigation practices and covered facilities.

Surveyed nurseries had production areas ranging from 0.25 to 290 acres (0.10 to 120 hectares), with a median of 15 acres (6.1 hectares). While the majority were relatively small, 11 (13%) had production areas greater than 120 acres (fig. 1). Sixty-nine percent of the total area produced outdoor container nursery stock, and 14% produced cut flowers. A small percentage of area was devoted to plant propagation (6%), bedding plants (7%) and potted plants for indoor use (4%). Most production area was uncovered (80%); the rest was in greenhouses (12%) and shadehouses (9%) (note slight rounding error). Low-volume irrigation was the most common irrigation method (51% of total surveyed production area), overhead irrigation was the second most common (30%) and hand-watering accounted for 18% of production area.

Management practices

The rest of the questions (132) were grouped into nine categories dealing with good management practices, including irrigation, leaching, runoff, field soil, container media, nutrient assessment, fertilizer, pest management and general property management (table 1). For these questions respondents were able to answer "yes," indicating that the practice had been implemented at their operation; "no," indicating that it had not been implemented but the practice was applicable; or "not applicable," indicating that it was not applicable to their operation. For example, collecting irrigation runoff would not be applicable at operations that do not produce irrigation runoff, nor would field soil practices be applicable when the entire crop is grown in containers. Not all recommended practices are desirable, depending on site-specific operations. Therefore, a "no" response did not necessarily indicate a deficiency. In general, though, a "yes" response indicated that a good management practice had been implemented.

Changes in responses from the initial survey to the resurvey for the Ventura County nurseries were assessed two different ways. For calculating changes within categories, "yes" responses were pooled and a repeated-measures analysis of variance (ANOVA) was performed. A significant positive result indicated a significant increase in "yes" responses.

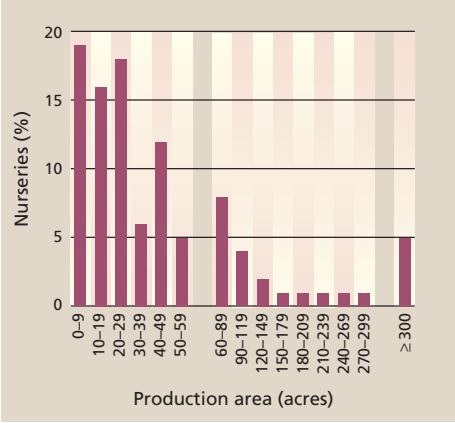

Fig. 1. Distribution by production area of surveyed nurseries in Southern California.

TABLE 1. Summary of responses to self-assessment survey (2004) and resurvey (2006) for Ventura County production nurseries (n = 65)

Management question category	Questions	Yes responses		Significance	Resurvey "not applicable" responses	Questions with significant change
		Initial (2004)	Resurvey (2006)			
	no.	..... %		P *value less than*	%	*no.*
Irrigation	26	58	66	0.0001	18	7
Leaching	4	32	34	0.01	46	3
Runoff	6	10	20	0.01	43	5
Field soil	6	27	32	0.05	56	0
Container media	3	52	66	0.0001	9	2
Nutrient assessment	5	64	73	0.01	5	1
Fertilizer	11	67	71	0.01	21	4
Integrated pest	33	62	70	0.0001	16	7
Property	39	64	71	0.0001	19	9
All	133	57	65	0.0001	21	38

Drip tape, *left*, and microirrigation stakes, *right*, are low-volume irrigation methods. In Southern California, 51% of surveyed production areas employed a low-volume irrigation method. When properly scheduled, such methods are effective in preventing runoff.

TABLE 2. Questions and responses concerning leaching management from self-assessment questionnaire for Ventura County production nurseries (*n* = 65)

Runoff management question	Year	Response			Significance of change
		Yes	No	Not applicable	
		%			P *value* <
36. Are specific factors, such as electrical conductivity (EC) of root media or leachates, used to determine leaching practices (i.e., deliberately overwatering to flush salts) as part of the irrigation schedule?	2004	42	32	26	
	2006	43	18	38*	0.05
37. Are irrigation schedules set to perform leaching at specific irrigation events, rather than every time irrigation is performed?	2004	31	34	35	
	2006	35	15	49	0.01
38. Is leaching performed only with fertilizer injectors turned off?	2004	38	17	45	
	2006	35	12	52	Not significant
39. Has the amount of leaching that occurs been measured?	2004	17	45	38	
	2006	23	34	43	0.05

* Some questions do not add up to 100% due to rounding error.

TABLE 3. Questions and responses concerning runoff management from self-assessment questionnaire for Ventura County production nurseries (*n* = 65)

Leaching management question	Year	Response			Significance of change
		Yes	No	Not applicable	
		%			P *value* <
40. Is irrigation runoff collected from production areas?	2004	11	66	23	
	2006	22	42	37*	0.05
41. Is collected irrigation water recycled?	2004	6	42	52	
	2006	14	29	57	0.001
42. Are collection reservoirs/tanks managed to avoid overflow during both dry and wet weather?	2004	8	25	68	
	2006	23	12	65	Not significant
43. Is runoff water quality regularly monitored, either by growing operation personnel or professionally by a lab?	2004	12	60	28	
	2006	17	40	43	0.01
44. Are runoff water-quality records maintained?	2004	8	55	37	
	2006	17	34	49	0.01
45. Is storm water collected?	2004	15	78	6	
	2006	26	66	8	0.01

* Some questions do not add up to 100% due to rounding error.

One limitation was that "not applicable" responses were not distinguished from "no" responses in the analyses. To calculate changes in responses for individual questions, a repeated measures test for marginal homogeneity was performed for each question. This analysis detects differences in the relative frequencies of "yes," "no" and "not applicable," but a significant result doesn't necessarily indicate an increase in "yes" responses.

Irrigation. The 26 irrigation questions covered practices such as monitoring irrigation water quality, maintaining systems, and the scheduling of timing and amounts. Ventura County nurseries commonly followed good management practices for irrigation management. The percentage of "yes" responses was 66% in 2006, with 18% "not applicable" (table 1). More than 90% maintained their irrigation systems, assigned personnel for irrigation, grouped plants by watering requirements and adjusted watering schedules to meet plant needs (data not shown), with similar results in 2004. Compared with 2004, significantly more respondents performed distribution uniformity evaluations in 2006 (from 29% to 48%), used pot weights or other measurements to determine irrigation schedules (22% to 43%) or adjusted overhead irrigation to prevent overspray (40% to 54%). For pooled responses, the number of "yes" responses significantly increased from 58% to 66% (table 1).

Leaching. The four questions in the leaching management category covered the scheduling and amount of water applied to leach salts from the root zone. The percentage of positive responses was 34% in 2006, a significant 2% increase from 2004 (table 1). This increase was attributable to changes in response to three of the four questions (table 2), including increased use of electrical conductivity measurements to determine leaching practices, increased avoidance of leaching at every irrigation event and an increase in measuring the amount of leachate. There was no significant change ($P \geq 0.5$) in the number of nurseries practicing leaching with fertilizer injectors turned off.

Overhead irrigation was used in 30% of the surveyed production area. If containers are not closely spaced, a significant portion of the applied water falls between containers and is wasted as runoff.

Hand-watering accounted for 18% of the production area in surveyed nurseries. Experienced personnel are necessary to avoid overwatering, and an on/off valve is recommended.

Runoff. The six questions in the runoff management category covered the collection and recycling of irrigation and storm-water runoff. Good management practices were not common, but their adoption increased from the initial survey to the resurvey in 2006. Pooled "yes" responses were only 10% in 2004, but increased significantly to 20% in 2006, with 43% "not applicable" (table 1).

Responses to five out of six questions changed significantly from 2004 to 2006 (table 3). Specifically, the frequency of runoff collection doubled (11% to 22%), the recycling of runoff water doubled (6% to 14%) and runoff water-quality monitoring (12% to 17%) and record keeping (8% to 17%) increased. The adoption of runoff management practices was low compared with surveys in Alabama, Georgia and Florida, which found that 75%, 45% and 50% of nurseries, respectively, collected runoff (Fain et al. 2000; Garber et al. 2002; Schoene et al. 2006).

Field soil. The six questions in the field-soil management category concerned managing soil erosion, applying soil amendments, and using cover crops and mulches. Many container nurseries had no area in field production, leading to 56% "not applicable" compared with 32% "yes" responses (table 1). While the change in responses was not significant for any individual question, the pooled number of "yes" responses increased significantly from 27% to 32% (table 1).

Container media. The three questions in the container-media management category concerned mixing potting media in a sheltered area, measuring media-water holding capacity and the use of wetting agents. Good practices for container-media management were commonly adopted, with 66% "yes" and 9% "not applicable" responses in 2006. The number of positive responses increased significantly from 2004 (table 1). Specific

Amy Storm, UCCE Ventura County

The unlined bottom of this detention basin allows captured runoff to percolate slowly into the ground. Soils and vegetation remove some contaminants from the water as it percolates or is taken up by plants.

A retention basin allows runoff to be treated and recycled for use as irrigation water. Ventura County nurseries that recycle irrigation runoff significantly increased from 6% in 2004 to 14% in 2006.

management practices that improved were testing media for water-holding capacity (51% to 71%) and considering the use of wetting agents (38% to 57%) (data not shown).

Nutrients, fertilizers, pest management and property management. Questions in the nutrient, fertilizer and pest management categories covered practices including soil and plant tissue testing, the application of fertilizer at proper rates, monitoring to assess disease and pest populations, and the proper application of pesticides. Questions in the property management category covered practices that included preventing water pollution by fuels, trash and sewage. The adoption of good management practices in these categories was common, with the frequency of "yes" responses in each category significantly increasing from greater than 60% in 2004 to greater than 70% in 2006 (table 1). More respondents accounted for nutrients in irrigation water or composts (from 57% to 77%) (data not shown), tested nutrient levels in fertigation water (63% to 68%) and used impermeable surfaces for fertilizer storage (58% to 72%) and mixing (57% to 69%). In the integrated pest management category, practices with significant changes included the use of diagnostic labs (66% to 78%), the calibration of spraying equipment (74% to 85%) and the use of plant quarantines (26% to 48%). In the property management category, more respondents managed nonproduction areas to prevent erosion and runoff (68% to 86%) and made spill kits available (60% to 72%).

Comparison of nurseries

Within good management question categories, no significant ($P \geq 0.05$) differences were found between Ventura County nurseries and the other Southern California counties (data not shown). Similarly, no significant differences were found when all management practice questions were pooled. This suggests that surveyed nurseries in Ventura County were similar to nurseries elsewhere in the region in terms of the extent to which they adopted good management practices. If it is the case that nurseries are similar among counties, education programs could be developed for regionwide application instead of for specific counties.

There were significant increases in positive responses in every good management category for Ventura County nurseries between surveying in 2004 and resurveying in 2006, as well as significant changes in responses for 38 out of 132 good management practices. This indicates that nurseries can become amenable to the adoption of such practices within a relatively short time frame.

Best management practices

These changes in practices could represent a substantial decrease in the potential contamination of surface water and groundwater from participating operations. We did not determine the causes for the increased adoption of good management practices. However, during the interval between the survey and resurvey, at least 54 of the 85 growers (63%) attended UC Cooperative Extension education programs in either English or Spanish, attended tours of nurseries implementing good management practices or interacted with Cooperative Extension staff during site visits.

Furthermore, completing the survey itself served as an educational tool for growers to evaluate their operations and learn about practices that help protect water resources. Participation in educational programs may be a factor in increasing growers' adoption of such practices. Increased governmental regulation of runoff from nurseries and other agriculture in this region may also have prompted growers to change. State and regional water-quality control boards and county agricultural commissioners implemented new regulatory requirements, which varied by county. Question categories in which respondents did not report a high rate of adoption — such as leaching and runoff management — merit increased educational efforts to further the adoption of good management practices in the nursery and flower industries.

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References

[CDFA] California Department of Food and Agriculture. 2007. California Agricultural Resource Directory. Agricultural Statistical Review. http://www.cdfa.ca.gov/files/pdf/card/ResDir07_Overview.pdf.

Fain GB, Gilliam CH, Tilt KM, et al. 2000. Survey of best management practices in container production nurseries. J Env Hortic 18:142–4.

Garber MP, Ruter JM, Midcap JT, Bondari K. 2002. Survey of container nursery irrigation practices in Georgia. HortTechnology 12:727–31.

Merhaut DJ, Pittenger D. 2005. Marketing trends and business management practices for the wholesale nursery industry in California. HortTechnology 15:381–5.

Newman JP (ed.). 2009. *Greenhouse and Nursery Management Practices to Protect Water Quality.* UC ANR Pub 3508. Oakland, CA. 160 p.

Schoene G, Yeager T, Haman D. 2006. Survey of container nursery irrigation practices in west-central Florida: An educational opportunity. HortTechnology 16:682–5.

[UCCE SDC] UC Cooperative Extension, San Diego County. (No date.) Runoff & Nonpoint Source Pollution Self-assessment: Greenhouses & Container Nurseries. http://cesandiego.ucdavis.edu/files/8455.pdf.

[UCCE VC] UC Cooperative Extension, Ventura County. 2003. Checklist for assessing and mitigating runoff in greenhouses and nurseries. http://ceVentura.ucdavis.edu/files/54712.pdf.

Pruning reduces blister rust in sugar pine with minimal effects on tree growth

by Kevin L. O'Hara, Lauren A. Grand
and Amy A. Whitcomb

Sugar pine trees from nine stands in two California study areas were assessed to determine the effects of pruning on the incidence and growth of white pine blister rust. Lower limbs up to 8 feet high were removed on alternate trees. Six years following treatment, the number of infections in pruned trees was reduced compared to unpruned trees at one study area, but no blister rust was found at the other area. The results suggest that artificial pruning of sugar pine may be part of an effective, integrated strategy to maintain this species in mixed-conifer California forests.

Pruning treatments were tested for their effectiveness against white pine blister rust.

Sugar pine is an iconic species in the mixed-conifer forests of the Sierra Nevada and Cascade Range. Due to their massive size, individuals stand with a stately and elegant presence among and above their associates. In 1894, John Muir described sugar pines (*Pinus lambertiana* Dougl.) as "the priests of pines" and said they "seem ever to be addressing the surrounding forests" (Muir 1894). The species is also fast growing and produces valuable wood and other ecosystem amenities such as food for small mammals.

Sugar pine is a "white" or five-needle pine and part of a subgenus of the pine group that is susceptible to white pine blister rust (*Cronartium ribicola* J.C. Fisch). Blister rust was introduced to western North America in British Columbia in 1910 and has spread southward into the sugar pine range. This invasive pathogen has sharply reduced populations of susceptible trees across North America, including sugar pine in California and Oregon.

Treatments to limit white pine blister rust have included the physical removal of understory species in the genus *Ribes*, which is an alternate host for the pathogen (Maloy 1997); chemical spraying of *Ribes* species; and breeding of resistant sugar pine (Samman and Kitzmiller 1996). The tree-breeding efforts, which have been the most successful strategy to date, offer some promise of trees for reforestation that have an estimated 60% level of resistance to the pathogen.

However, the pathogen is also evolving, and a more virulent strain was recognized in California in 1976 (Kinloch and Comstock 1981). There are several mechanisms that allow some sugar pine to be resistant to the pathogen (Kinloch and Davis 1996). Because there is natural resistance in native populations of sugar pine and the pathogen is evolving, an integrated resistance strategy should maximize resistance in natural populations as a future safeguard (Millar et al. 1996; Samman et al. 2003).

Infection process

Trees are infected through a viable spore landing on a water droplet on a live needle fascicle or group of pine needles. The spore then germinates and infects the tree by growing through the fascicle into the inner bark of the branch or stem. Once in the stem or branch, the pathogen causes canker formation and eventually girdles the branch or stem, killing anything above the point of infection (Edmonds et al. 2000). A successful pathogen attack requires a viable spore and a living needle fascicle with moisture on it.

Viable spores typically originate from *Ribes* species such as currants and gooseberries and occur in highest concentrations near the ground where humidity is usually highest. Infections are therefore most common near the ground. For example, 85% of branch cankers in young sugar pine stands in Oregon were found within 12 feet of the ground and 97% within 20 feet (Hays and Stein 1957). Byler and Parmeter (1979) and Smith (1996) reported similar findings in California. However, working in environments with greater fog in the southern Sierra Nevada, Kinloch and Dulitz (1990) reported greater proportions of cankers higher in trees.

Artificial pruning is an accepted means of enhancing wood quality in forest trees.

TABLE 1. Stand descriptions for sugar pine pruning treatments

Study site/ stand*	Age in 2000	Regeneration harvest method	Postregeneration treatments (year)
	years		
BFRS-141	10	Clear-cut	Herbicide (1995)
BFRS-190	11	Group selection	Herbicide (1997), PCT† (1998), mastication (2005)
BFRS-280	20	Shelterwood	PCT (1995), herbicide (1984, 1989)
BFRS-330	9	Clear-cut	PCT (1998), herbicide (1999), mastication (2003)
BFRS-480	9	Clear-cut	PCT (1998), herbicide (1999), mastication (2003)
BFRS-501	13	Clear-cut	PCT (1998), herbicide (1991)
BFRS-400	12	Group selection	PCT (1998), herbicide (1992, 1997)
LA-75	25	Clear-cut	None
LA-86	14	Clear-cut	None

* BFRS = Blodgett Forest Research Station; LA = Lake Almanor.
† PCT = precommercial thinning.

TABLE 2. Sample sizes and numbers of infected trees by stand, 2006

Study site/ stand*	Pruned trees		Unpruned trees	
	Total	Infected	Total	Infected
BFRS-141	27	6	26	7
BFRS-190	12	2	12	6
BFRS-280	7	0	8	2
BFRS-330	12	8	13	10
BFRS-480	23	7	27	9
BFRS-501	15	6	15	12
BFRS-400	12	1	13	5
Blodgett totals	108	30	114	51
LA-75	38	0	38	0
LA-86	40	0	39	0
Lake Almanor totals	78	0	77	0

* BFRS = Blodgett Forest Research Station; LA = Lake Almanor.

Artificial pruning

Artificial pruning is a potentially effective means of enhancing sugar pine survival because it removes the lowermost branches where infections are most likely to occur. Previous research with eastern white pine (*Pinus strobus* L.) and western white pine (*Pinus monticola* Dougl. ex D. Don) indicated that pruning to only an 8-foot height could significantly reduce white pine blister rust infections (Weber 1964; Lehrer 1982; Hungerford et al. 1982; Hagle and Grasham 1988; O'Hara, Parent, et al. 1995; Hunt 1998). Although foresters have had some success in other white pines, and artificial pruning has been included in integrated management programs for white pine blister rust in western white pine (Hagle et al. 1989), no systematic pruning trials have been undertaken in sugar pine, and previous pruning experiments have only briefly referred to this species (Kinloch and Dulitz 1990; Kliejunas and Adams 2003).

Artificial pruning is also an accepted means of enhancing wood quality in forest trees. A typical pruning operation involves removing the lowermost live and dead branches from fast-growing trees that have straight, high-quality boles with minimal taper. After severing lower branches, trees occlude wounds, and subsequent wood formation is free of knots. This "clearwood" is therefore of higher value than wood formed without pruning. Pruning younger trees is generally most desirable as these trees can produce clearwood over a smaller defect core than older trees (O'Hara 2007). However, pruning live branches reduces a tree's photosynthetic capacity and can adversely affect tree vigor. Developing a pruning regime for sugar pine involves tradeoffs between reducing tree growth and vigor, and increasing the resistance of pruned trees to blister rust.

This study explored artificial pruning as a potentially effective means of reducing the incidence of white pine blister rust in sugar pine. The specific objectives were to: (1) assess the effectiveness of pruning on white pine blister rust incidence in sugar pine and (2) determine the consequences of pruning on sugar pine tree growth.

Sierra and Cascades study sites

Site selection. Two areas were selected because each had relatively young sugar pines in sufficient numbers to develop a study. One site was at Blodgett Forest Research Station in the central Sierra Nevada (38°52′ N, 120°40′ W), and the other was near Lake Almanor in the southern Cascades (40°19′ N, 121°07 30′ W) on land owned by Roseburg Forest Products and sold to Sierra Pacific Industries during the study period.

Sites were selected and all pruning was completed early in the 2000 growing season. Sample trees were limited to 8 to 20 feet in height so that they could receive a relatively substantial pruning that might be typical of an operational pruning regime in a young stand. Seven stands, or management compartments, were selected at Blodgett forest. All had been planted in harvested openings with a mixture of conifers including both blister rust–resistant and nonresistant sugar pine; some natural regeneration had also occurred. These stands had been harvested previously with a range of regeneration methods including group selection, clear-cut and shelterwood, which leaves variable amounts of overstory cover (table 1). A combination of herbicide spraying and mechanical treatments were applied at Blodgett to control competing vegetation and reduce intertree competition. Two stands were located near Lake Almanor; both was pure sugar pine plantations planted after clear-cut harvest.

Study trees and pruning. At both sites, study trees were selected that were free of any external symptoms of white pine blister rust or any stem defects that might have been caused by animals, the formation of multiple branch leaders or

The large canker on this sugar pine at Blodgett Forest Research Station was caused by white pine blister rust, an invasive pathogen that has reduced sugar pine populations in California and Oregon.

other disturbances. Both sites had active blister rust infections on nonstudy sugar pine trees in 2000 within the sampled stands. All of the study trees were tagged, and every other tree was pruned to a height equal to approximately a 50% live-crown ratio — defined as the ratio of the distance from the treetop to the lowest live branch to total tree height — or no greater than 8 feet.

All needle fascicles on the stem were removed up to the pruned height to eliminate potential infection sites along the pruned stem. Branches were removed with loppers, and cuts were made as close to the stem as possible (O'Hara 2007). Pruned branches were left on the ground where they fell. Because sugar pine branches occur in whorls that can be several feet apart, pruning to a 50% live-crown ratio resulted in pruning immediately above or below a branch whorl in some cases. For these trees, the residual live-crown ratio may have been considerably more or less than 50%. Control trees were the alternating unpruned trees. Both pruned and unpruned trees were selected systematically with a random start among those trees acceptable for pruning.

Measurements. After pruning, all trees were measured for total height, pruning height, diameter at breast height (dbh), and breast-height age by counting branch whorls from the treetop. Breast height was marked on all trees. Any blister rust infections that were not seen before pruning were also noted. Trees were assessed for white pine blister rust in 2003 and again after the 2006 growing season. Trees were examined for the presence of cankers on the stem or branches, and dead or flagged branches. All trees were remeasured for height and dbh after the 2006 growing season. The 2000-to-2006 study period included nearly seven full growing seasons.

Statistical analysis. A chi-square test was used to assess the effect of pruning on blister rust infection for all trees. Nonparametric tests were used to assess the effectiveness of pruning because the main response is a binary variable (either presence or absence of blister rust). Logistic regression was used to assess variables such as compartment, tree size, percent live crown after pruning, and a binary variable indicating whether a tree was pruned or not.

At Lake Almanor, a sugar pine, *left*, before pruning and, *center*, after being pruned to about 8 feet. *Right*, small branches remain above the whorl of pruned branches; these potential infection sites for white pine blister rust should be removed as part of the pruning operation.

Tree volume increment is a measurement that integrates both tree diameter and height and provides a representation of tree growth and vigor. Volumes were estimated by assuming that tree sections formed geometric solids: a cylinder below breast height, and a paraboloid from breast height to treetop. These sections were summed to total tree stem volume. Stem volume increment over the 7-year study period was the difference between volume early in the 2000 growing season and following the 2006 growing season. Tree volume was compared between pruned and unpruned trees with and without infections using analysis of variance.

Effectiveness of pruning

Mortality. Average live-crown ratio after pruning was 50.3% at Blodgett and ranged from 32.8% to 67.1%. At Lake Almanor, live-crown ratio averaged 50.6% after pruning and ranged from 38.7% to 67.6%. Tree mortality was noted during both the 2003 and 2006 measurements. Eleven trees died during the study period, all of which were from stands at Blodgett, and 10 of which were pruned. Blister rust was confirmed on only one of these trees. One tree was killed in a mastication operation, and another was badly damaged by a bear. The others were possibly attacked by bark beetles or stressed by the pruning. In addition, three control trees were pruned in 2003 in a separate pruning operation. All of these trees were excluded from the volume-growth analysis.

There was no mortality in either of the Lake Almanor stands. However, 16 pruned trees in one stand were apparently attacked by bark beetles or a pitch moth shortly after pruning. These trees experienced the death of some cambium on the north side below the pruning height. None of these trees died during the study period, and all showed callus development by 2003. Four trees were not found at the Lake Almanor sites in 2006.

Blister rust infections. Blister rust–infected trees were found in all seven stands at Blodgett, but disease incidence was variable among stands (table 2). Infections were located almost exclusively on branches. Stands 330 and 501 had the greatest proportion of infected trees and stand 280, the lowest. In 2006, 46% of unpruned trees were infected with blister rust at Blodgett compared to only 26% of pruned trees. A chi-square test comparing the numbers of infected trees in the pruned and unpruned groups indicated a significantly higher frequency of infections in the unpruned trees ($P < 0.0019$). During the study period, there were no visible white pine blister rust infections in either of the Lake Almanor stands.

At Blodgett, the logistic regression model to predict presence or absence of rust indicated that the percent live crown in 2000 was a significant variable ($P < 0.0001$) but neither tree size (dbh) nor pruning height was significant. The model included both pruned and unpruned trees, and suggested a high

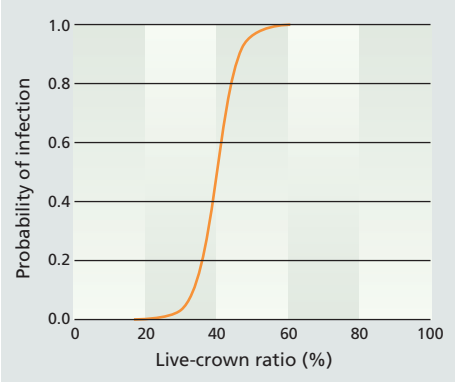

Fig. 1. Probability of infection from white pine blister rust as a function of percent live-crown ratio, based on logistic regression. The model, based on 234 observations, was significant in 2000 at $P < 0.0001$.

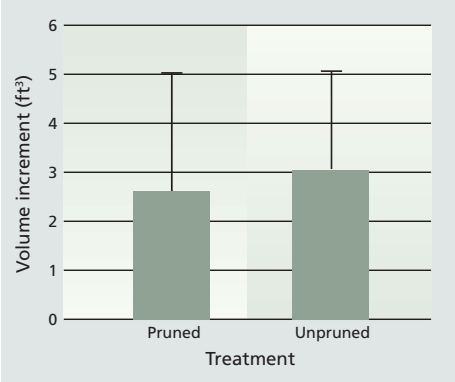

Fig. 2. Volume increment of pruned ($n = 107$) and unpruned ($n = 114$) sugar pine trees at Blodgett Forest Research Station. Differences were not significant ($P < 0.1741$). Error bars show one standard deviation.

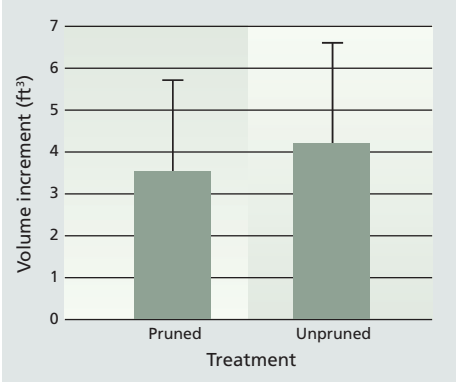

Fig. 3. Volume increment of pruned ($n = 77$) and unpruned ($n = 75$) sugar pine trees at Lake Almanor study site. Differences were not significant ($P < 0.0788$). Error bars show one standard deviation.

level of significance among unpruned trees for the proximity of live branches to the ground in affecting the probability of infection (fig. 1). The resulting model was of the form:

$$P_i = e^{zi}/(1 + e^{zi})$$

where P_i is the probability of infection, e is the exponent and $z^i = -13.697 + 0.343 \times$ (percent live crown)

The absence of blister rust at the Lake Almanor sites precluded a similar analysis.

Tree volume. The volume increment of individual trees averaged 2.9 square feet (ranging from 0.4 to 17.0 square feet) over the 7-year study period at Blodgett. At Lake Almanor, where trees were generally older, the average was 3.9 square feet (ranging from 0.7 to 13.6 square feet). The volume increment of pruned trees was slightly less than that of unpruned trees, but these differences were not significant in either study area (figs. 2 and 3). When trees with and without rust were compared within either pruned or unpruned groups, differences were also not significant (fig. 4). No significant patterns between relative growth rate and either posttreatment crown length or initial volume were evident for pruned trees.

Managing to protect sugar pine

The history of managing white pines such as sugar pine in the presence of white pine blister rust includes a variety of approaches to limit the damage from this exotic pathogen. Massive efforts to locally eradicate species in the *Ribes* genus, the primary alternate hosts for the pathogen, were undertaken for decades in affected regions in the western United States including California (Maloy 1997). These costly efforts were unsuccessful at controlling damage. There have also been efforts to excise stem cankers by severing the cambium around the canker, but this was considered impractical (Hagle and Grasham 1988). Efforts to breed resistant trees have shown more potential but have revealed the pathogen's ability to evolve and overcome resistance in sugar pine (Kinloch and Comstock 1981). A variety of resistance mechanisms has also been noted, reinforcing the need for a genetically diverse population of sugar pine (Kinloch and Davis 1996; Millar et al. 1996; Samman et al. 2003).

Infection rates varied significantly by stand at Blodgett (table 2). This was expected given the variety of regeneration methods used historically. This study was not designed to compare the combination of regeneration methods and pruning on infection rates, and there was insufficient data to provide meaningful comparisons. These stand differences suggest that future study of regeneration methods and microclimate effects on spore movement or production, or on *Ribes* frequency or vigor, may be warranted.

For example, the shelterwood treatment (stand 280) had the lowest infection rate, but the overstory trees were removed before initiation of this study. During the study period, the primary difference in stand structures between the Blodgett compartments was their size, with the group-selection unit having smaller openings than the others. Ironically, notes on stand 280 from the study installation in 2000 indicate that approximately 60% of the trees had lethal infections. This may be more indicative of wavelike patterns in the temporal spread of blister rust when some years have favorable environmental conditions, rather than differences attributable to stand structure.

Wave patterns of spread have been documented in the sugar pine range since 1927 (Smith 1996). The absence of rust in the Lake Almanor sites may be explained by our study period falling between wave years. It does not indicate that the pruning at Lake Almanor was unsuccessful — these trees received both the benefit of greater resistance to blister rust that may happen at any time, and the benefit of greater clearwood production.

The small but insignificant effects of pruning on tree volume increment are a logical result of reducing the photosynthetic potential of a tree. Small reductions in tree increment with low-severity pruning have been observed in a variety of conifers including Ponderosa pine (*Pinus ponderosa* P. & C. Lawson) (Barrett 1968), coast Douglas fir (*Pseudotsuga menziesii* [Mirb.] Franco var *menziesii*) (O'Hara 1991) and western white pine (*Pinus monticola* Dougl. ex D. Don) (Helmers 1946). The height growth that occurs after pruning increases live-crown length and rebuilds the photosynthetic potential of the tree. The growth reductions following pruning are therefore greatest immediately after pruning and become smaller with time. In seven

growing seasons following pruning, this study observed no significant growth effects. A shorter study period may have revealed significant differences. However, over longer periods such as several decades or over their lifetimes, the effect of pruning on the growth of these trees will probably be negligible.

Including artificial pruning in an integrated approach to managing sugar pine can contribute to maintaining a broad genetic base, given the success of pruning in this study and in other white pines (Lehrer 1982; O'Hara, Parent, et al. 1995; Hunt 1998). Hagle et al. (1989) included pruning as a central piece of their strategy to enhance the survival of western white pine in the northern Rocky Mountains. Artificial pruning is far from completely effective, but by increasing the probability of individual trees surviving to reproductive age or beyond, it promotes genetic diversity in surviving populations of sugar pine.

The trees in this study were pruned to no greater than 8 feet, which is probably less than optimal to increase the survival of trees. A higher pruning lift would remove additional branches that are prone to infection because of their proximity to the ground. At Blodgett, the study trees received an additional pruning lift up to 50% of the live crown, or no greater than 18 feet, during 2007. Pruning recommendations for western white pine also suggest that pruning lifts to 18 feet will provide further increases in survival (Hagle and Grasham 1988).

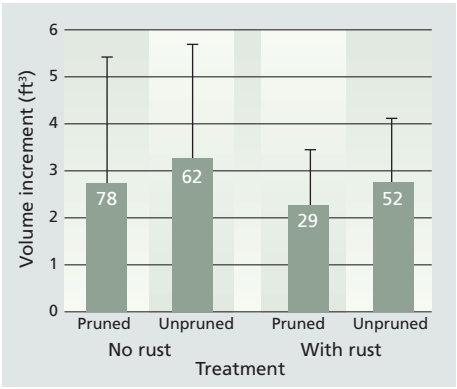

Fig. 4. Volume increment of pruned and unpruned sugar pine within groups of trees without white pine blister rust (no rust) and trees infected with rust (with rust) at Blodgett Forest Research Station. Differences were not significant within any grouping ($P < 0.2430$). Error bars show one standard deviation and numbers on bars show sample sizes.

***Left*, at Blodgett Forest Research Station, co-author Lauren Grand prepares to prune a sugar pine. *Right*, field assistant Zak Thomas uses loppers and a ladder to remove a whorl of branches to a height of approximately 12 feet. A higher pruning, or pruning to the second lift, may increase an infected sugar pine's chances of survival.**

Pruning sugar pine to prevent blister rust

Our management recommendations include the following:

- In production forests, pruning should focus on well-spaced trees with good form and a high likelihood of long-term survival.
- In nonproduction forests, such as on public lands, the criteria of trees with good form may be less important than selecting trees with good prospects for long-term survival.
- Eight feet represents a reasonable target pruning height for both operational reasons and blister rust control.
- Pruning should not reduce crown length by more than approximately 50% of height to maintain rapid growth rates.
- All live branches to the prescribed pruning height should be removed, including those near the ground.
- Dead branch removal is also important for meeting wood-quality objectives.
- Needle fascicles on the stem below the pruning height are potential infection sites and should be removed during the pruning operation.
- Branches with blister rust cankers greater than 4 inches from the main stem can probably be removed to prevent stem infection (DeNitto 1996).
- There is no blister rust prevention value in pruning trees with stem cankers present.

However, a shorter pruning lift offers the opportunity to prune a tree earlier in its development, thereby providing earlier removal of potential infection sites. An appropriate pruning regime for timber production and enhancing sugar pine tree survival may therefore involve multiple pruning lifts and making the first lift as early as possible in the life of a tree. Pruning to approximately 8 feet costs about $1 per tree for sugar pine. Pruning to 18 feet may push these costs to more than $3 per tree, as costs increase exponentially when pruning height exceeds the height of the operator (O'Hara, Larvik, et al. 1995). A pruning regime directed toward only enhancing sugar pine survival might include pruning more trees to a shorter height, since most infections occur near the ground (Hays and Stein 1957; Hunt 1982) and the per-height-unit costs of pruning higher increase exponentially above 8 feet.

Integrated strategies

Our recommendations are to include pruning as part of integrated strategies to maintain sugar pine in ecosystems affected by white pine blister rust. Although our results are limited to several silvicultural systems on a series of similar sites in the Sierra Nevada, the success of pruning on these sites along with success in other white pine ecosystems (Weber 1964; Lehrer 1982; Hagle and Grasham 1988; Hunt 1998) suggests that pruning can be an effective tool in similar situations. Pruning in these systems will not assure the survival of any given tree, but will increase the chances of that tree reaching a reproductive age or a merchantable size (see box, page 35).

Artificial pruning of young sugar pine trees appears to be an effective integrated management tool to sustain this important species. Pruning reduced blister rust incidence in trials of three different regeneration methods at Blodgett Forest. In conjunction with the planting of genetically resistant seedlings, thinning to favor both natural and planted sugar pine, and other activities, pruning can apparently assist with sustaining sugar pine in ecosystems affected by blister rust. Additionally, artificial pruning has a negligible effect on tree growth over the first 7 years following pruning, and future effects are likely to be inconsequential.

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References

Barrett JW. 1968. Pruning of Ponderosa Pine: Effect on Growth. USDA For Serv Res Pap PNW-68. 9 p.

Byler JW, Parmeter JR. 1979. An Evaluation of White Pine Blister Rust in the Sierra Nevada. USDA For Serv Pac Southwest Region. FPM Report 79-3. 19 p.

DeNitto GA. 1996. Silvicultural methods of limiting blister rust in sugar pine. In: Kinloch Jr BB, Morosy M, Huddleson M (eds.). *Sugar Pine: Status, Values, and Roles in Ecosystems*. UC ANR Pub 3362. p 179–84.

Edmonds RL, Agee JK, Gara RI. 2000. *Forest Health and Protection*. Long Grove, IL: Waveland Pr. 630 p.

Hagle SK, Grasham J. 1988. Biological and Economic Feasibility of Pruning and Excising Western White Pines for Blister Rust Control. USDA For Serv Northern Region Pest Management, Missoula, MT. Report 88-6. 14 p.

Hagle SK, McDonald GI, Norby EA. 1989. White Pine Blister Rust in Northern Idaho and Western Montana: Alternatives for Integrated Management. USDA For Serv GTR-INT-261. 35 p.

Hays GL, Stein WI. 1957. Eliminating Blister Rust Cankers From Sugar Pine by Pruning. USDA For Serv Pac Northwest Res Stat. Res Note 151. 8 p.

Helmers AE. 1946. Effect of pruning on growth of western white pine. J For 44(9):673–6.

Hungerford RD, Williams RE, Marsden, MA. 1982. Thinning and Pruning Western White Pine: A Potential for Reducing Mortality Due to Blister Rust. USDA For Serv Res Note INT-322. 7 p.

Hunt RS. 1982. White pine blister rust in British Columbia. I. The possibilities of control by branch removal. For Chron 59:136–8.

Hunt RS. 1998. Pruning western white pine in British Columbia to reduce white pine blister rust losses: 10-year results. West J Appl For 13(2):60–3.

Kinloch Jr BB, Comstock M. 1981. Race of *Cronartium ribicola* virulent to major gene resistance in sugar pine. Plant Dis 65:604–5.

Kinloch Jr BB, Davis D. 1996. Mechanisms and inheritance of resistance to blister rust in sugar pine. In: Kinloch Jr BB, Morosy M, Huddleson M (eds.). *Sugar Pine: Status, Values, and Roles in Ecosystems*. UC ANR Pub 3362. p 125–32.

Kinloch Jr BB, Dulitz D. 1990. White Pine Blister Rust at Mountain Home Demonstration State Forest: A Case Study of the Epidemic and Prospects for Genetic Control. USDA For Serv Res Pap PSW-204. 7 p.

Kliejunas J, Adams D. 2003. White Pine Blister Rust in California. California Dept For Fire Prot. Tree Notes No 27.

Lehrer GF. 1982. Pathological pruning: A useful tool in white pine blister rust control. Plant Dis 66(12):1138–9.

Maloy OC. 1997. White pine blister rust control in North America: A case history. Ann Rev Phytopathol 35:87–109.

Millar CI, Kinloch Jr BB, Westfall RD. 1996. Conservation and biodiversity in sugar pine: Effects of the blister rust epidemic on genetic diversity. In: Kinloch Jr BB, Morosy M, Huddleson M (eds.). *Sugar Pine: Status, Values, and Roles in Ecosystems*. UC ANR Pub 3362. p 190–9.

Muir J. 1894. *The Mountains of California.* New York, NY: Century Co. 381 p.

O'Hara KL. 1991. A biological justification for pruning in coastal Douglas-fir stands. West J Appl For 6(3):59–63.

O'Hara KL. 2007. Pruning wounds and occlusion: A long-standing conundrum in forestry. J For 105(3):131–8.

O'Hara KL, Larvik DA, Valappil NI. 1995. Pruning costs for four northern Rocky Mountain species with three equipment combinations. West J Appl For 10(2):59–65.

O'Hara KL, Parent DR, Hagle SK. 1995. Pruning eastern Cascade and Northern Rocky Mountain species: Biological opportunities. In: Hanley DP, Oliver CD, Maguire DA, et al. (eds.). *Forest Pruning and Wood Quality.* Univ Washington Institute of Forest Resources. Contrib No 77. p. 216–37.

Samman S, Kitzmiller JH. 1996. The sugar pine program for development of resistance to blister rust in the Pacific Southwest region. In: Kinloch Jr BB, Morosy M, Huddleson M (eds.). *Sugar Pine: Status, Values, and Roles in Ecosystems*. UC ANR Pub 3362. p 162–70.

Samman S, Schwandt JW, Wilson JL. 2003. Managing for Healthy White Pine Ecosystems in the United States to Reduce the Impacts of White Pine Blister Rust. USDA For Serv Rep R1-03-118. Missoula, MT. 12 p.

Smith Jr RS. 1996. Spread and intensification of blister rust in the range of sugar pine. In: Kinloch Jr BB, Morosy M, Huddleson M (eds.). *Sugar Pine: Status, Values, and Roles in Ecosystems*. UC ANR Pub 3362. p 112–8.

Weber R. 1964. Early Pruning Reduces Blister Rust Mortality in White Pine Plantations. USDA For Serv Lake States Forest Experiment Station. Res Note LS-38. 2 p.

Strawberry breeding improves genetic resistance to Verticillium wilt

by Douglas V. Shaw, Thomas R. Gordon, Kirk D. Larson, W. Douglas Gubler, John Hansen *and* Sharon C. Kirkpatrick

Since 1994, more than 480 genotypes from the UC strawberry breeding program have been screened for resistance to* Verticillium dahliae *Kleb., an important soil pathogen of strawberry. Genotypes for parents of subsequent generations have been chosen using a multiple-trait strategy that incorporates their* Verticillium *resistance rating. This selection strategy has increased resistance scores for the parents by 60%, and increased the percentage of moderately resistant genotypes from 35.0% in the original germplasm to 78.5% in those used as parents for the most recent crosses. Selection has reduced genetic variation for the resistance score, and genotypic coefficients of variation (GCV) decreased in the breeding population from 34.4% to 11.6% from 1994 to 2008. Inspection of genotypic scores suggests that the GCV change pattern may not be due to a scarcity of variation, but rather to limitations in the detection test. Our results suggest the need for broader testing of the more-resistant types identified in naturally infested soils and improved understanding of resistance mechanisms. Ultimately, this work seeks to provide a* Verticillium*-resistant cultivar to growers if access to effective soil fumigants becomes more limited.

Jack Kelly Clark

***Inset*, Verticillium wilt causes browning and reddening of outer strawberry leaves and eventual plant mortality. Breeding can improve resistance to the pathogen *Verticillium dahliae*. *Above*, a test plot in Watsonville.**

Prior to the widespread use of soil fumigants, *Verticillium dahliae* Kleb. was considered among the most important pathogens affecting commercial strawberry production in California (Thomas 1932). Plantations established in infested soils often suffered 50% or greater mortality (Thomas 1932; Wilhelm and Koch 1956), and wilt from this pathogen continues to be a major concern where strawberries (*Fragaria x ananassa* Duch.) are managed in perennial planting systems (Wilhelm and Paulus 1980; Maas et al. 1989; Paulus 1990). Breeding for resistance has been an important strategy for minimizing damage caused by *V. dahliae* in strawberry for several decades, and genetic variation for resistance to this pathogen has been demonstrated in many breeding populations (Bringhurst et al. 1966, 1968; Maas et al. 1989; Shaw et al. 1996).

The University of California (UC) strawberry breeding program was initiated in 1930, and its goal since initiation has been to release cultivars specifically adapted to California production environments. In part due to concerns about the continued availability of effective soil fumigants, researchers in the UC strawberry breeding program began to develop a field-based resistance screening method in 1992 (Shaw et al. 1996; Shaw et al. 1997; Gordon et al. 2005), and an ongoing resistance evaluation program has been conducted for this disease since 1994.

Preliminary experimental results demonstrated substantial genetic variation for an overall low level of resistance to *V. dahliae* in the UC breeding population (Shaw et al. 1996). Researchers also verified that resistance to the pathogen in this population has polygenic inheritance, is conditioned by both additive and dominance genetic effects, and that genotypes with high resistance were rare in the germplasm at that time. These results suggested that the infusion of non-California germplasm was not needed to obtain genetic progress, but that substantial time and effort would be needed to change the genetic composition of the breeding population and generate *Verticillium*-resistant strawberry cultivars with adequate frequency.

Strategies to improve resistance

Backcrossing. Two broad strategies have been used to improve genetic resistance to soil disease in crop

Even asymptomatic plants suffer some yield loss under conditions of high disease pressure.

plants. One common approach is to first identify resistant germplasm and generate highly resistant lines, then backcross the resistance into elite cultivars. This method works well when the inheritance of resistance is conditioned by one or a few genes and the crop-specific breeding system permits backcrossing and self-fertilization for rapid genetic transfer and stabilization. Intensive selection for resistance within the UC germplasm base has resulted in genotypes that exhibit few symptoms following inoculation with *V. dahliae* (Shaw and Gordon 2003; Gordon et al. 2005; Shaw et al. 2005), and these genotypes have been useful in evaluating selection limits and the mechanisms of resistance within this genetic base (Gordon et al. 2006). However, even asymptomatic plants suffer some yield loss under conditions of high disease pressure (Shaw et al. 2005). Furthermore, due to the intensified focus on resistance in generating these genotypes, they all express substantial deficiencies for horticultural or productivity traits, and as a consequence this strategy has not been successful in generating cultivars that meet the commercial standards required of modern strawberry cultivars in California.

Population improvement. An alternative breeding strategy is to obtain incremental increases in resistance through population improvement, by inclusion of *V. dahliae*–screening results in a multiple-trait selection system to choose the parents of elite breeding populations. This strategy is generally a superior alternative for developing resistance in cross-fertilized crops such as strawberry. This system is especially useful when inheritance of the resistance is polygenic, or determined by many genes, and backcrossing systems are consequently less effective. Furthermore, with multiple-trait selection, *Verticillium* resistance is considered as one among the many characteristics required to render a cultivar useful to strawberry growers in commercial production. This selection system permits flexibility in the relative weighting of selection intensity for resistance and horticultural traits, and can result in cultivars of balanced commercial utility. Backcrossing methods for resistance can be combined with multiple-trait selection for horticultural traits, but this strategy is generally most effective for inbred crops.

UC has conducted strawberry breeding continuously since 1930 (Bringhurst and Voth 1960), and the improvement of traits important for commercial productivity has been substantial (Shaw and Larson 2008). The choice of parents for the population-improvement component of this program has depended in part on resistance to important pathogens, and the longest continuous screening effort has been dedicated to *Verticillium dahliae* Kleb. resistance. This study reports on progress in developing resistance to *V. dahliae* within the UC strawberry breeding program obtained through parent selection and population improvement since 1994.

Evaluating resistance

Between 1994 and 2008, 481 genotypes from the UC strawberry breeding program were screened for resistance to *V. dahliae*. This sample included 461 advanced selections, genotypes identified with superior characteristics and which might either serve as parents for future generations or eventually be released to growers as cultivars. These selections were obtained from controlled crosses conducted over 18 years (1988 to 2005), with 11 to 49 genotypes from each cross year. Twenty genotypes were tested from the original germplasm base present prior to 1988. Strawberry breeding proceeds with overlapping generations, but the yearly changes in resistance for the genotypes used as parents from 1988 to 2005 provided a reliable empirical index of genetic progress for this population.

The advanced selections tested for resistance in each trial year included those genotypes considered most promising based on their performance in fruiting trials conducted at either the UC South Coast Research and Extension Center near Irvine, Calif. (33°41′ N, 117°43′ W), or the Watsonville Strawberry Research Facility (36°54′ N, 121°48′ W). The genotypes included from any cross year had not been evaluated for resistance prior to their selection for horticultural and productivity traits, and they provide a representative sample of the variation for resistance in that cohort. Changes in resistance parameters over time reflect the outcome of including resistance in the multitrait selection strategy for prior parent choice.

Selection intensity. The selection intensities — which reflect the relative importance of the selected trait — applied to the improvement of Verticillium wilt resistance during the study period are impossible to quantify with precision, but the genetic progress reported

Since 1994, the UC strawberry breeding program has screened more than 480 genotypes for *V. dahliae* resistance. *Left*, a resistant cultivar; *right*, a susceptible breed.

here results from two sources. First, the most susceptible genotypes (those with resistance scores less than 2.0) usually were eliminated entirely, and the participation of moderately susceptible genotypes (those with scores between 2.0 and 3.0) as parents was limited to a few crosses. Moderately susceptible genotypes were included if they expressed outstanding horticultural characteristics, but they usually served as parents in crosses for just one year. Second, individual genotypic selections were made with knowledge of parental resistance scores, and fewer genotypes were retained from crosses expected to contain high frequencies of susceptible individuals.

Resistance evaluations. All *Verticillium*-resistance evaluations were conducted following root-dip inoculations (Shaw et al. 1996). Runner plants from each tested genotype were immersed in an aqueous suspension of 1.0×10^6 *V. dahliae* spores per milliliter. All evaluations were conducted at the Wolfskill Experimental Orchard near Winters, Calif. (38°30′ N, 121°59′ W). The inoculum included spores from one to three isolates originally obtained from symptomatic plants found in commercial production fields in California (Gordon et al. 2006). Each genotype was represented by two plots of five inoculated runner plants per trial year; two noninoculated plants of the test genotype were placed adjacent to each plot, and disease ratings were made relative to these control plants. Plots were distributed between two replicates, and each year's trial comprised a randomized complete block design. Inoculated plants and controls were established in the field from Oct. 5 to 18 each year. Many of the individual genotypes, 204 of the 481, were tested in more than one year, and the average number of test years per genotype was 1.7. In general, genotypes under consideration for release as commercial cultivars were tested with greater replication over years, and these superior genotypes were also heavily represented in crosses conducted to facilitate population improvement.

Genotypes were evaluated in the spring following inoculation, by rating plants for symptoms of Verticillium wilt on a scale of 1 to 5, where 1 = severely diseased and 5 = no symptoms of disease (comparable in appearance to corresponding noninoculated controls). Individual plots were evaluated four to seven times in each trial year at approximately 3-week intervals beginning with the first symptoms on susceptible genotypes (Feb. 28 to May 5), and a combined score was obtained as the arithmetic mean of scores for all dates (Shaw et al. 1996). An average resistance score was calculated for each genotype and year combination as the mean for the two replicates.

Soil fumigants are effective in preventing Verticillium wilt and other strawberry diseases, but their availability is waning due to regulatory concerns.

Resistance scores. Variation in resistance scores over trial years due to environmental factors — such as differences in ambient temperature, isolate source or inoculum quality — was confounded with genetic differences generated due to selection over years. Several of the genotypes were tested in most of the evaluation years, and the examination of these samples demonstrated relatively small yearly fluctuations in genotypic score. For example, on a resistance scale of 1 to 5, the relatively susceptible cultivar Camarosa had an average score of 2.52 and a standard deviation of 0.46 over all years, and the moderately resistant cultivar Camino Real had an average score of 4.25 and a standard deviation of 0.41 for trials conducted in 11 of the 15 years. This suggests that more than two-thirds of the samples will vary by no more than about 0.435 scoring units from year to year. The effect of trial year was not considered further, but is reflected as part of the error variation in our analyses.

Changes in the *Verticillium* resistance scores due to selection were evaluated by first calculating a composite genotypic score as the average for each genotype over all trial years in which it was tested, then plotting and regressing these composite scores by cross year. The 20 genotypes from the original germplasm sample were considered representative of a base population present in 1987, and are included as such in plots and regression analyses. The average resistance scores were further resolved by calculating the percentage of genotypes in each cross-year population with a composite score greater than 3.0, and thus exhibiting at least moderate resistance. The percentages calculated for each cross year were plotted and treated by regression analysis as described for the resistance scores.

Genetic variation. Successful directional selection for any polygenic trait can lead to a reduction of genetic diversity, as favorable genetic combinations are fixed in the breeding population. Genetic variation was evaluated in our experiment by obtaining estimates of genotypic variance components using the restricted maximum likelihood option of the SAS procedure VARCOMP (SAS 1999). To monitor changes in genetic variation for resistance due to selection, the component of variance due to genotypes was first estimated for each cross year, then transformed to a genotypic coefficient of variance (GCV) to correct for scale effects (Falconer and Mackay 1996) as:

$$GCV = 100 * (\sigma^2_g)^{1/2} / \overline{X}$$

where σ^2_g is the genotypic variance estimate for the *Verticillium* resistance score and $\overline{X}$ is the mean resistance score in any cross year.

Coefficients of variation are recommended to avoid scale effects for comparing variation among populations that

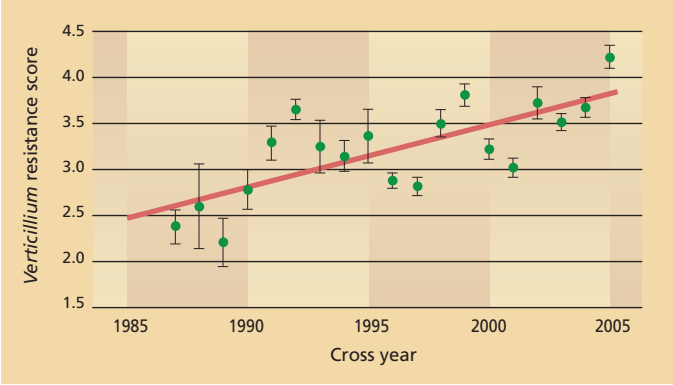

Fig. 1. Changes in the mean *Verticillium* resistance score (1 = severely diseased, and 5 = no symptoms of disease) in genotypes from cross years 1987 (original germplasm) to 2005, ± standard error.

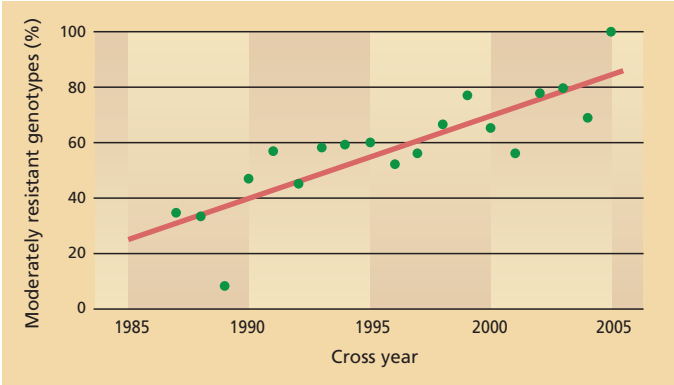

Fig. 2. Changes in percentage of genotypes with at least moderate resistance to *Verticillium dahliae* Kleb. (resistance score > 3.0) from cross years 1987 (original germplasm) to 2005.

differ in mean (Snedecor and Cochran 1980), as might be expected for a trait in a population under recurrent selection. Trends throughout the experimental period were analyzed by plotting and regressing each estimated GCV by cross year. Trial year was ignored in this analysis, and replicates were considered as completely random; this strategy was adopted to avoid confounding variance due to trial year with that due to differences among genotypes.

Analysis of resistance trends

The absence of reliable estimates for selection intensities and the presence of overlapping generations precludes precise determinations of the genetic response; however, the general trends for inclusion of *Verticillium* resistance in the population improvement program are evident from the steady increase in resistance scores over cross years (fig. 1). Regression of resistance scores for the 481 genotypes on their cross year demonstrated a highly significant increase over time, with $b = 0.061 \pm 0.007$ ($F_{1,479} = 73.1$**; ** = statistically significant at the 1% probability level). The predicted change in resistance score from this regression analysis over 18 cross years affected by selection is 1.10 resistance-score units, or a 46.3% improvement over the average resistance score for the original germplasm ($\overline{X} = 2.37 \pm 0.19$). The observed average resistance score for genotypes from cross years 2003 to 2005, for example those that would serve as parents in the most recent controlled crosses, was $\overline{X} = 3.79 \pm 0.06$, giving a realized difference of 1.42 resistance-score units between the current and original germplasm bases, or a 59.9% increase over the 18 selection years.

Selection has had a somewhat larger effect on the fraction of genotypes in the population with at least moderate resistance, defined as a resistance score greater than 3.0 (fig. 2). Regression of the percentage of genotypes with scores above 3.0 on cross year resulted in a highly significant result with $b = 2.99 \pm 0.47$ ($F_{1,17} = 41.1$**). Based on this regression result, the predicted change in the percentage of moderately resistant genotypes over 18 years of selection is 53.8%; the observed percentage for cross years 2003 to 2005 ($\overline{X} = 78.5\%$) was more than double that for genotypes from the original germplasm ($\overline{X} = 35.0\%$), suggesting that selection had been somewhat more effective at eliminating highly susceptible genotypes than predicted by linear analysis.

The selection response since 1994 has had a substantial effect on the variation for resistance remaining in the breeding population (fig. 3). GCV for resistance score decreased in the breeding population from 34.4% in the original germplasm to 11.6% for genotypes in the 2005 cross year. Regression of the estimated GCV on cross year demonstrated a highly significant decrease in genetic variation over time, with $b = -0.011 \pm 0.003$ ($F_{1,17} = 17.6$**), indicating a reduction in just over 1% of the original GCV per cross year. This reduction might be due to the depletion of genetic variation, and might indicate limits to the development of improved resistance due to further selection. However, the inspection of genotypic scores also demonstrated a concentration of genotypes in recent years with scores near the highest ratings discernible by current testing methods. The pattern of change in GCV may be due to limits in discernment among the more resistant genotypes imposed by the test itself, rather than an absence of variation available for further progress.

Creating superior cultivars

Ultimately, the impact of this genetic improvement will be realized when superior resistance is packaged and utilized commercially in the form of a cultivar that possesses superior horticultural characteristics as well. The response to selection for horticultural traits has been well documented in the UC program. For example, Shaw and Larson (2008) demonstrated improvement of 47% to 140% for yield, fruit size, fruit appearance

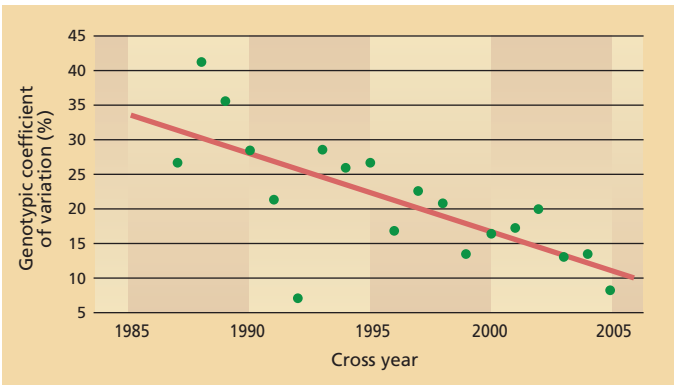

Fig. 3. Changes in the genotypic coefficient of variation (GCV) for populations of genotypes from cross years 1987 (original germplasm) to 2005.

and fruit firmness in cultivars released over a 47-year period. Similar analysis of these traits in the breeding population from 1992 to 2005, roughly the period of genetic improvement for Verticillium wilt resistance evaluated here, indicates response rates for the same traits 1.7 to 2.6 times the historical rates.

Clearly, the progress for resistance obtained with this selection strategy has not excessively limited the opportunity for horticultural trait improvement. For comparison, the 17 cultivars released from the UC program prior to 1994 had an average resistance score of $\overline{X} = 2.53 \pm 0.18$, whereas the seven cultivars released after 2001 had scores of $\overline{X} = 3.53 \pm 0.17$. These mean differences reflect responses similar to those obtained in the germplasm as a whole, and indicate that the typical cultivar prior to this program was moderately susceptible, whereas the most recently released cultivars are moderately resistant to Verticillium wilt. Multiple-trait selection strategies could have weighted resistance traits more heavily and horticultural traits less so, with corresponding tradeoffs in selection response.

Screening improvements

Our results, especially the last comparison, suggest two areas requiring further research. First, broader testing is needed of the more resistant types identified in this program in naturally infested soils to determine whether resistance outside the range presently observed will be required for adequate performance of cultivars in commercial conditions where *V. dahliae* is an expected limiting factor. To date, opportunities for such tests have been limited by the common practice of preplant soil fumigation. Soil fumigation maintains soil populations of *V. dahliae* below levels that are damaging even to susceptible genotypes, and opportunities for widespread testing in naturally infested soil simply do not exist at present. In the immediate future, it is likely that high soil-inoculum levels will continue to be a rarity as long as growers utilize the most effective available fumigants to suppress *V. dahliae*.

Genotypes with resistance capacity exceeding that already realized may not be required to meet commercial needs in the near future, but they may become essential if and when efficacious fumigants are no longer available. It is not known whether the levels of resistance achieved to date will be sufficient to sustain production in the worst-case scenario. Also, one limitation of the multiple-trait and population-improvement strategy is that it tends to fix the alleles favorable for resistance only after many generations. Continued selection within the breeding population is still needed to eliminate the moderately susceptible genotypes that do emerge through segregation, regardless of potential changes in fumigation practices.

Second, if resistance outside the range of that detectible by present screening methods is needed, then a better understanding of the mechanism of resistance may facilitate the development of screening procedures that will expand the range of discrimination beyond that currently available. Genetic variation required for developing such genotypes may or may not exist within the currently available germplasm, but there is no reason to suspect its absence until more sensitive tests are developed.

Breeding for resistance to *V. dahliae* over 18 cross years has yet to resolve the problem completely, but our results suggest that the multiple-trait selection strategy employed to date has generated substantial improvement without compromising gains for the myriad other characteristics of importance in a commercial strawberry cultivar.

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References

Bringhurst RS, Hansche PE, Voth V. 1968. Inheritance of Verticillium wilt resistance and the correlation of resistance with performance traits. Proc Amer Soc Hort Sci 92:369–75.

Bringhurst RS, Voth V. 1960. The strawberry breeding program of the University of California, historical. California Strawberry Advisory Board Strawberry News Bulletin, Vol VI, Bulletin 11. March 16, 1960.

Bringhurst RS, Wilhelm S, Voth V. 1966. Verticillium wilt resistance in natural populations of *Fragaria chiloensis* in California. Phytopathol 56:219–22.

Falconer DS, Mackay TFC. 1996. *Introduction to Quantitative Genetics* (4th ed.). Chap 17. London: Longman Gr. p 290–6.

Gordon TR, Kirkpatrick SK, Hansen J, Shaw DV. 2006. The response of strawberry genotypes to inoculation with isolates of *Verticillium dahliae* differing in host origin. Phytopathol 55:766–9.

Gordon TR, Shaw DV, Larson KD. 2005. Comparative response of strawberries to conidial root dip inoculations and infection by soilborne microsclerotia of *Verticillium dahliae* Kleb. HortScience 40:1398–400.

Maas JL, Galletta GJ, Draper AD. 1989. Resistance in strawberry to races of *Phytophthora fragariae* and to isolates of *Verticillium* from North America. Acta Hortic 265:521–6.

Paulus AL. 1990. Fungal diseases of strawberry. HortScience 25:885–9.

[SAS] SAS Institute. 1999. *SAS/STAT Users Guide, Version 8*. Cary, NC: SAS Institute Inc.

Shaw DV, Gordon TR. 2003. Genetic reaction for resistance to Verticillium wilt (*Verticillium dahliae* Kleb.) in strawberry (*Fragaria x ananassa* Duch.) with two-stage family and genotypic selection. HortScience 38:432–4.

Shaw DV, Gubler WD, Hansen J. 1997. Field resistance of California strawberries to *Verticillium dahliae* at three conidial inoculum concentrations. HortScience 32:711–3.

Shaw DV, Gubler WD, Larson KD, Hansen J. 1996. Genetic variation for field resistance to *Verticillium dahliae* evaluated using genotypes and segregating progenies of California strawberries. J Amer Soc Hort Sci 121:625–8.

Shaw DV, Gubler WD, Larson KD, Kirkpatrick SC. 2005. The effect of *Verticillium* infection in runner plant propagation nurseries on resistant and susceptible strawberry genotypes. J Amer Soc Hort Sci 130:707–10.

Shaw DV, Larson KD. 2008. Performance of early-generation and modern strawberry cultivars from the University of California breeding programme in growing systems simulating traditional and modern horticulture. J Hort Sci Biotech 83:648–52.

Snedecor GW, Cochran WG. 1980. *Statistical Methods* (7th ed.). Chap 3. Ames, IA: Iowa State Univ Pr. 507 p.

Thomas HE. 1932. Verticillium wilt of strawberries. UC Ag Exper Station, Bull 530.

Wilhelm S, Koch EC. 1956. Verticillium wilt controlled. Cal Ag 10(6):3–14.

Wilhelm S, Paulus AO. 1980. How soil fumigation benefits the California strawberry industry. Plant Dis 64:264–70.

Wine-grape production trends reflect evolving consumer demand over 30 years

by Richard James Volpe III, Richard Green, Dale Heien *and* Richard Howitt

The California wine industry has been in the midst of a prolonged boom for more than 30 years. In 1975, California was home to approximately 330 wineries; by 2006 there were nearly 2,500. There has been a dramatic shift in demand toward higher priced and higher quality table wines, as reflected in the total revenues and crush shares of the state's four major growing regions. We examine the major trends in the California wine-grape industry over the last 30 years, specifically differences that are arising between the coastal and inland growing regions and migration of the various wine-grape varieties grown throughout the state.

Jack Kelly Clark

Grape prices and total production continue to rise in California. Since 2000, an average of 175 new wineries have opened each year. *Above*, V. Sattui Winery in the Napa Valley was established in 1885.

The California wine industry has been in the midst of a prolonged boom for more than 30 years, with production expanding as the state's global reputation for producing high-quality wines steadily increased. In 1975, California was home to approximately 330 wineries; by 2006 there were nearly 2,500 (Wine Institute 2007). This trend was kick-started in large part by California's surprise victory over France in the Paris wine tasting of 1976, an international blind taste test immortalized in the movie *Bottle Shock*. There is no shortage of research on the trends and dynamics of the California wine industry, yet virtually none has been directed toward the California wine-grape industry.

As of 2004, California accounted for 92% of U.S. wine-grape production and nearly 90% of all domestic wine production (Wine Institute 2007). Moreover, wine grapes accounted for nearly 10% of California's total agricultural receipts in 2006, second only to fluid milk (CDFA 2007). The California wine-grape industry is of great economic importance to the state, nation and world. In this study we quantify the major trends that have shaped the industry over 30 years.

The California Department of Food and Agriculture (CDFA) divides the state into 17 wine-grape-growing districts, which are in turn aggregations of American Viticulture Areas (AVAs) for California. (The boundaries of AVAs are determined by the federal Alcohol and Tobacco Tax and Trade Bureau.) For the purposes of our analysis, we aggregate the major growing districts — with the exception of the Sierra foothills — into four growing regions (fig. 1). These are:

(1) North Coast, home to California's world-famous Napa and Sonoma valleys and, accordingly, the state's highest priced wines.

(2) Central Coast, which stretches from San Mateo County in the north to Ventura County in the south and includes such up-and-coming AVAs as Paso Robles and the Santa Ynez Valley.

(3) North Central Valley, which includes the Sacramento and northern San Joaquin valleys and the Lodi AVA.

(4) South Central Valley, which includes much of the San Joaquin Valley and extends to the southern terminus of the Central Valley in San Bernardino County.

In order to keep our analysis empirically manageable, we limited the focus to eight major wine-grape varieties. These include Cabernet Sauvignon, Merlot, Zinfandel and Pinot Noir as representative red grapes; and Chardonnay, Sauvignon Blanc, French Colombard and Chenin Blanc as representative white grapes. As of 2006, total production of these eight grapes was 2.2 million tons, or 71% of California's total wine-grape output. The average real price received per ton of crush for these varieties across the regions was $811. The comparable price received in 1976 was $642, but this 26% increase does not reflect a trend seen uniformly throughout the state. Over the 30 years, prices received grew by an average of 46% in the North Coast region, while prices actually fell slightly throughout much of the rest of the state.

Fig. 1. Major wine-grape growing regions of California. Source: CDFA Annual Crush and Acreage Reports, 2006.

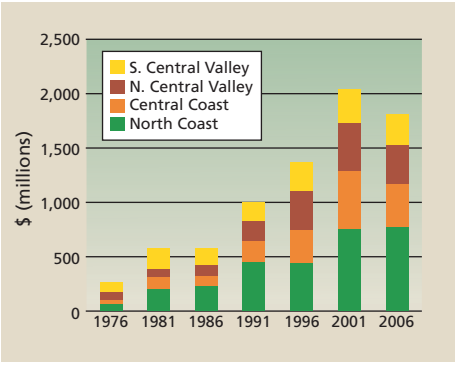

Fig. 2. Total regional revenues, in 2006 dollars, for four major grape-growing regions of California, 1976–2006. Source: CDFA Annual Crush Reports, 1976–2006.

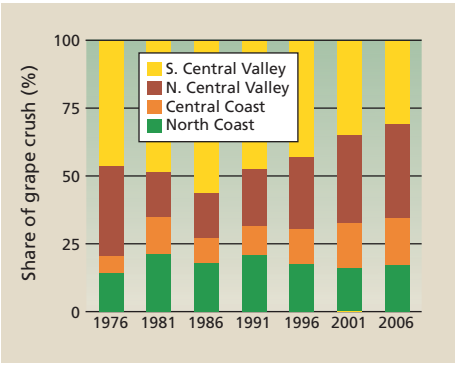

Fig. 3. Overall shares of output, as measured by tons of grape crush, for four growing regions of California, 1976–2006. Source: CDFA Annual Crush Reports, 1976–2006.

Of particular interest in this study are the changing production and price patterns across growing regions as well as the changing roles played by various wine-grape varieties. The identities of each of the four growing regions continue to take shape as do their particular roles within California's wine economy, while the production patterns and locations of the various varieties reflect constantly evolving consumer demand.

Lower coastal yield, higher prices

Domestically, there has been a dramatic shift in demand over the past 30 years toward higher priced and higher quality table wines. Premium wines, those priced between $7 and $14 per bottle, have seen their national revenue share increase 14% since 1995, while ultra-premium wines, priced at over $14 per bottle, have increased their share by 21% (Goodhue et al. 2008). Demand remains strong, however, for cheaper jug wines, which are typically sold in containers larger than bottles but sell for the equivalent of $3 or less per bottle throughout much of the United States and globally. Hence the wine-grape industry has become bisected. The coastal regions have become associated with high-quality wines, generally with limited distribution and an emphasis on wine tourism. The inland regions have become associated with lower quality wines, typically produced using grapes grown under long-term contracts and sold in jugs or boxes at low prices with large-scale distribution. The inland regions are home to the majority of production by wine industry giants such as Gallo, Sutter Home and Woodbridge by Mondavi.

"Brick-and-mortar" wineries are open to the public for wine tasting and on-site purchases. As of 2005, the inland regions produced nearly twice as much total crush as the coastal regions, yet were home to approximately one-ninth as many brick-and-mortar wineries (California WineOnline 2005). Napa and Sonoma counties hosted 404 such wineries in 2005, compared to only 42 in the entire north Central Valley. This disparity highlights regional differences in varietal emphasis.

Revenues and crush shares. The total revenues and crush shares of the four major growing regions also reflect this growing dichotomy in the California wine-grape industry (figs. 2 and 3). As of 2006, the North Coast generated by far the most revenue of the four regions, with $779 million in receipts, despite accounting for only 19% of the state's total output. The Central Coast region ranked a distant second overall in revenues, but grew the fewest grapes. Meanwhile, the vast southern portion of the Central

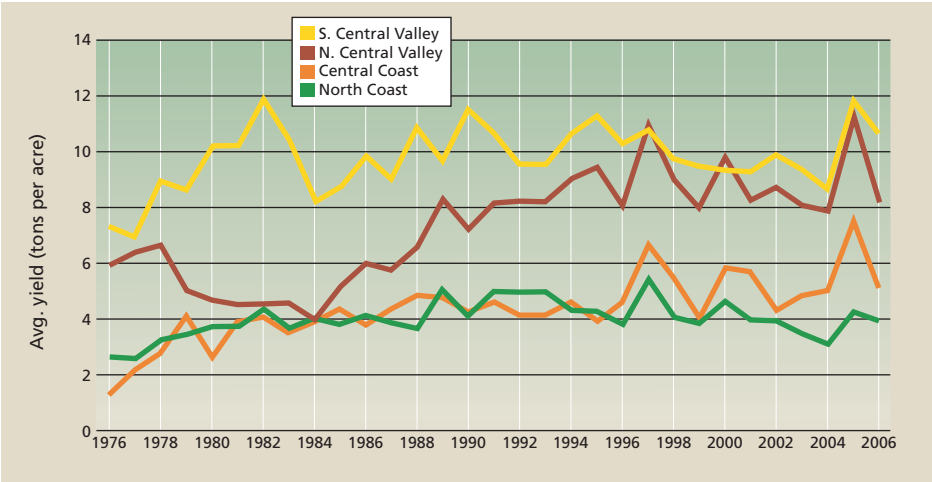

Fig. 4. Average yields for the wine-grape growing regions of California, 1976–2006. Source: CDFA Annual Crush and Acreage Reports, 1976–2006.

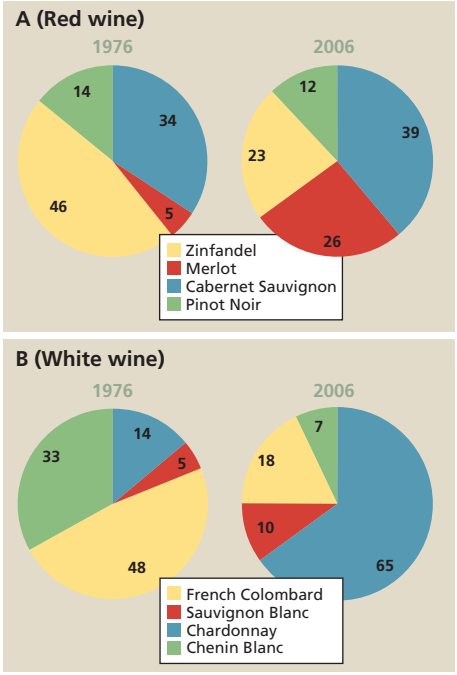

Fig. 5. Shares (%) of total (A) red and (B) white wine-grape production in California, 1976 and 2006. Source: CDFA Annual Crush Reports, 1976–2006. Figure 5A adds up to 99% due to rounding error.

Valley generated about one-third of the North Coast revenues, despite accounting for 30% of the state's total output.

In 1976 the picture was quite different, as the south Central Valley was dominant in terms of both crush and revenues. The Central Coast had the lowest overall share of revenues by a wide margin, as its AVAs had yet to rise to prominence, and the region was responsible for less than 7% of statewide output. The north Central Valley is the only region that showed a significant and sustained rise in output share, which increased steadily from the mid-1980s onward. This increase was driven by a rapid expansion in the production of Merlot, Cabernet Sauvignon and Chardonnay.

Yields. Another key factor differentiating the four growing regions is yield per acre (fig. 4). Low yields are typically associated with higher quality grapes and, by extension, higher quality wines. Lower yields imply that fewer grapes are being processed from each acre, and that only grapes meeting a certain quality threshold are being used. Moreover, lower yields frequently indicate that grape vines are grown spaced apart such that the grapes receive optimal amounts of water and sunlight (Bettiga et al. 2003).

Barring exceptional years over the 30-year time span, the North Coast has had the lowest average yields, while the south Central Valley has had the highest. In 2005, the latest year not seriously affected by droughts or frosts, the average south Central Valley acre produced nearly 12 tons of grapes, compared to approximately 11 tons in the north Central Valley region, 7 tons in the Central Coast and only 4 tons in the North Coast. This disparity not only illustrates fundamental production differences, but also helps to explain how the North Coast produced 19% of California's total grape crush in 2006 on one-third of its total grape-bearing acreage.

The magnitude of the yield disparity between coastal and inland growing regions varies widely among grape varieties. For example, in 2006 the North Coast produced an average of 3.75 tons of Chardonnay per acre, while the north Central Valley produced 9.25 tons of Chardonnay per acre. In the case of Merlot, however, the North Coast average yield was 3.57 tons per acre in 2006 compared to 6.80 tons per acre in the north Central Valley. Just as the North Coast is outdistancing the rest of the state in terms of revenues, there appears to be a growing divergence between even the North Coast and Central Coast in terms of yields over the last 10 years.

The north Central Valley managed to increase its share of total wine-grape production not only by expanding acreage throughout the San Joaquin and Sacramento valleys, but also by significantly increasing yields, mainly by decreasing the average spacing among planted vines. Average yields in the north Central Valley steadily increased from about 4 tons per acre in 1985 to 9 tons per acre in 2006, with occasional peaks and valleys resulting from weather conditions (fig. 4). During that time, average yields in the north Central Valley region more than doubled over 20 years, while those in the Central Coast increased by 33%, the south Central Valley increased by 30% and the North Coast remained statistically the same.

Migration of wine-grape varieties

Total bearing acreage for the eight grape varieties that we studied grew from just over 100,000 acres in 1976 to 337,000 acres in 2006. Throughout this growth spurt, the allocation of these varieties changed greatly. Their distribution reflects the evolution of domestic wine demand.

Merlot and Zinfandel. Overall, the aggregated picture for red grapes has remained fairly constant (fig. 5A). Merlot's total share increased from 5% to 26%, mostly by taking up the slack from relatively stagnant Zinfandel. Zinfandel grapes grow well in warmer climates and on closely spaced vines, making them well suited for production in the inland areas (Bettiga et al. 2003). As a result, production of Zinfandel grapes has remained steady in the North Coast and Central Coast regions for the last 30 years, while it expanded only in the in-

The disparity in perceived quality and prices between inland and coastal growing regions will continue to widen.

land areas. In parts of the north Central Valley, particularly in the Lodi AVA, growers are placing an emphasis on high-quality "old vine" Zinfandels that are processed into table wines. In other inland AVAs, the growth in Zinfandel production has been fueled by an increase in demand for white Zinfandel wine, which is typically sold as a low-priced jug wine. The general pattern of decreasing real prices for Zinfandel grapes over time suggests that the latter trend is overpowering the former.

Merlot, another red grape that thrives in warm climates, has seen significant growth in all four growing regions, with the greatest expansion in the north Central Valley. In 1976, the north Central Valley accounted for only 16% of California's total Merlot production, but by 2006 the region's share had grown to 40%.

Cabernet Sauvignon and Pinot Noir. Cabernet Sauvignon and Pinot Noir are grown almost exclusively to produce high-quality and high-priced table wines, and they are rarely blended. Both grapes, but especially Pinot Noir, flourish in the cooler coastal areas and diminish in quality when grown in hotter, drier areas. Nevertheless, these grapes are increasingly grown in the north Central Valley region as several AVAs such as Lodi and Clarksburg are working to assert themselves as high-quality growing regions. The Pinot Noir grape was not grown in sufficient quantities to be measured by CDFA surveys of the north Central Valley in 1976, but by 2006, output was nearly 20,000 tons. (The Academy-Award winning 2004 movie *Sideways* appears to have given Pinot Noir sales a boost.) This is approximately one-third of the Pinot Noir production of the Napa and Sonoma valleys, where it now yields the highest average grower returns in California for wine grapes.

Chardonnay. The white-wine-grape industry has been far more dynamic than the red-wine-grape industry (fig. 5B). Since the late 1980s, Chardonnay production has grown while the other three white varieties have fallen at varying rates. The total share of Chardonnay grape production among white grapes grew from 14% in 1976 to 65% in 2006. This reflects an increase in total Chardonnay production from 7,300 tons to over 530,000 tons in 30 years. Both supply and demand factors account for the rapid and sustained expansion of the Chardonnay crop, which occurred while the overall share of white-grape production in California fell from a peak of 73% in 1987 to 42% in 2006.

On the supply side, Chardonnay is among the most versatile grapes grown in the New World. It can grow in a wide range of soil and climatic conditions, its vine spacing can be varied significantly, and it lends itself to both hand and machine harvesting. On the market side, consumer demand has grown steadily for Chardonnay table wine, since it pairs well with food but can also be consumed on its own. At the same time, demand remains strong for cheaper Chardonnay jug wines, and Chardonnay grapes are commonly used to make sparkling wines.

Over time, Chardonnay production in California has become more evenly distributed across the four major growing regions. In 1976, more than half of California's total Chardonnay production took place in the North Coast region, but by 2006 that share was reduced to less than a quarter due to huge production growth in the north Central Valley and, to a lesser extent, the south Central Valley.

French Colombard and Chenin Blanc. The distribution of French Colombard and Chenin Blanc production, however, is increasingly concentrated in the south Central Valley region. Both grapes are used primarily as blends in cheap jug wines, so grower returns for these grapes have fallen sharply relative to most other varieties in California. Today they are grown in trivial amounts in the coastal regions and in modest amounts in the north Central Valley, while the south Central Valley accounts for 97% of total French Colombard production and 76% of total Chenin Blanc.

Sauvignon Blanc. Sauvignon Blanc, also known as Fume Blanc in California, has seen the least overall migration of the eight grape varieties examined. It is a very adaptable grape in that it can be grown vigorously in a variety of soil types and in both warm and cool microclimates, but the vines must be spaced a minimum of 6 feet apart. During the last 30 years, Sauvignon Blanc production has lagged in the Central Coast compared with the other three regions, because the Central Coast has come to focus almost entirely on the production of Chardonnay white grapes. In the North Coast, the

Photos: Jack Kelly Clark

Over the past 30 years, the demand for, *left*, wine grapes has continually increased, but the distribution of grape varieties grown has shifted dramatically. *Right*, acreage of Pinot Noir grapes was virtually nil in 1976; by 2006, about 20,000 tons were harvested.

In memory of Dale Heien

Professor Dale Heien joined the UC Davis Department of Agricultural and Resource Economics in 1982 and retired in 2003. His research interests were primarily in the areas of demand systems, pricing and markets, and in recent years the supply and demand of wine grapes and wine. He was a deep thinker, and colleagues frequently sought his advice. He co-authored a seminal article with Murray Brown, "The S-Branch Utility Tree: A Generalization of the Linear Expenditure System," in *Econometrica* in 1972, and published in journals that included *Journal of the American Statistical Association, Review of Economics and Statistics, Journal of Business and Economic Statistics,* and *American Journal of Agricultural Economics*. Heien was an avid Chicago Cubs fan and loved his family. He passed away on June 19, 2009.

Sauvignon Blanc grape is typically processed into a dry table-wine varietal, while inland it is blended to make sweeter jug wines or harvested late to produce very sweet varietals.

Looking to the future

Statewide, grape prices and total production appear poised to continue their ascent. On average, 175 new wineries have opened in California annually since 2000 (Wine Institute 2007). The trend of decreasing prices in regions such as the north Central Valley is not indicative of decreasing demand but rather of the constantly changing distribution of the major grape varieties. As long as Chardonnay retains its popularity among consumers, it will likely represent an ever larger percentage of the state's total white-wine-grape production, while ballooning prices for Pinot Noir grapes suggest that their production will expand significantly within the coastal regions.

The hierarchy of the four major growing regions in terms of perceived quality and prices received has remained unchanged for 30 years, with the North Coast on top, followed by the Central Coast, the north Central Valley and finally, the south Central Valley. However, the prices received for wine grapes in the North Coast region continue to outpace those in the rest of the state. In 1976, the average prices for grapes in the North Coast were 13% higher than those of the Central Coast, 2.25 times higher than the north Central Valley, and almost three times higher than the south Central Valley. In 2006, North Coast prices were 72% higher than Central Coast prices and about four times the average prices received inland.

While certain AVAs of the north Central Valley are establishing themselves as producers of high-quality table wines such as Zinfandel and Chardonnay, in aggregate the north Central Valley is not distinguishing itself from the south Central Valley in terms of wine quality or price. In fact, average prices received for grapes in the north Central Valley have fallen in real terms over the last 30 years as production has boomed, and today average grape prices of the north and south Central Valley are approximately equal. The high-quality AVAs of the Central Coast region, such as Paso Robles and the Santa Ynez Valley, are growing in size and prominence, but at present they remain small relative to the Napa and Sonoma valleys to the north.

Over time the Central Coast region may approach the North Coast in terms of total production and grape prices, particularly because appellation expansion in the North Coast is far more constrained than in the Central Coast. However, the evolving distribution of California's grape varieties, as well as trends in yields per acre, suggest that the disparity in perceived quality and prices between inland and coastal growing regions will continue to widen. The grapes commonly used to produce cheap jug wines, such as new-vine Zinfandel, French Colombard and Chenin Blanc, continue to concentrate in the AVAs of the north Central Valley, while higher priced varieties such as Pinot Noir and Merlot remain concentrated on the coast. The long-term trends of increasing yields per acre in the inland regions compared with stagnant or even decreasing yields per acre in the coastal regions suggest that this segmentation will continue unabated for a long time to come.

R.J. Volpe III is Ph.D. Candidate, R. Green is Professor, D. Heien (deceased) was Professor Emeritus, and R. Howitt is Professor, Department of Agricultural and Resource Economics, UC Davis. *This research was funded in part by a grant from the California Department of Food and Agriculture.*

References

Bettiga LJ, Golino DA, McGourty G, et al. 2003. *Wine Grape Varieties in California.* UC ANR Pub 3419. Oakland, CA. 188 p.

[CDFA] California Department of Food and Agriculture. Various years. Final Grape Acreage Report, 1976–2006. Sacramento, CA. http://www.nass.usda.gov/Statistics_by_State/California/Publications/Grape_Acreage/200804gabtb01.pdf.

CDFA. Various years. Final Grape Crush Report, 1976–2006. Sacramento, CA. http://www.cdfa.ca.gov/statistics/files/CDFA_Sec7.pdf.

CDFA. 2007. Agricultural Statistical Review. National Agricultural Statistics Service. http://www.cdfa.ca.gov/files/pdf/card/ResDir07_Overview.pdf.

California WineOnline. 2005. California Wine Data. http://www.california-wineonline.com/california_wine.htm.

Goodhue R, Green R, Martin P, Heien D. 2008. California wine industry evolving to compete in 21st century. Cal Ag 62(1):12–8.

Wine Institute. 2007. Industry Background & Statistics. http://www.wineinstitute.org/communications/statistics/#econ_industry.

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Special issue key
CC = Climate change
BF = Biofuels

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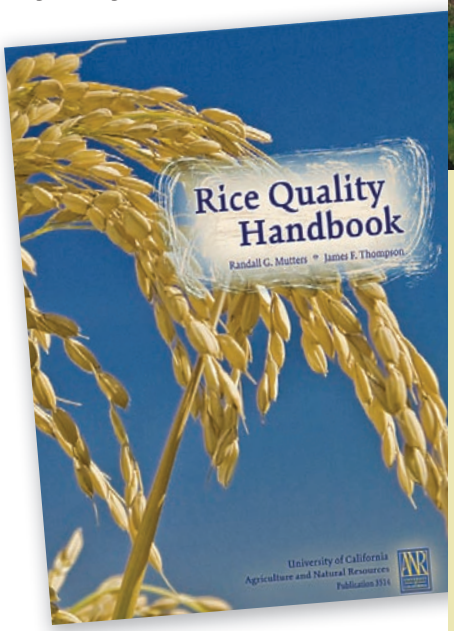

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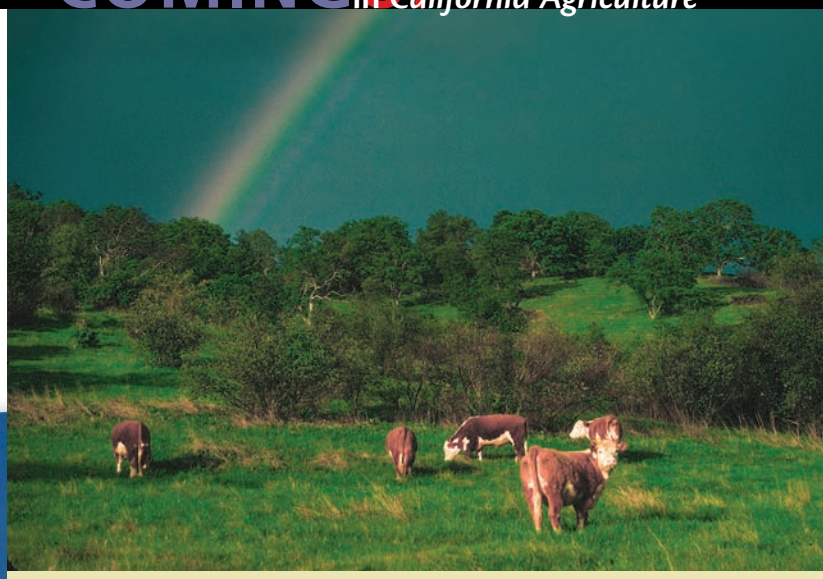

A half-century of research in the Sierra Foothills

The Sierra Foothill Research and Extension Center (SFREC) was established in June 1960, when UC acquired two large parcels near Browns Valley in Yuba County. The center is 60 miles northeast of Sacramento on 5,721 acres of oak-woodland, annual-grass rangeland. Its varied terrain includes several watersheds, Yuba River frontage and 160 acres of irrigated pasture. A small cattle herd roams the foothills. SFREC has thrived as a field laboratory for research on livestock and agronomic productivity, as well as the management of open spaces, watersheds, hardwoods and wildlife. Its public outreach includes field days, demonstration plots and a nature trail.

The next issue of *California Agriculture* looks back at 50 years of top-notch science at SFREC, and highlights current research including beef-cattle data collection, breeding efficiency in heifers, black rail and salmon habitat, soil hydrology and oak woodlands. A 50th anniversary field day and celebration will take place at SFREC on April 7, 2010.

Go to http://groups.ucanr.org/sierrafoothill for more information.