APRIL-JUNE 2008 • VOLUME 62 NUMBER 2

California Agriculture

Light brown apple moth:
Discovery, data and debate

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

UC agriculture programs: Investing in California's future

Robert C. Dynes
President,
University of California

With the state facing a tough budget year, this is a time for the University of California to cut costs and increase efficiencies. But given UC's transformative impact on California over 140 years, and given eroding state support for UC in recent decades, this also is a time for the University and its stakeholders to send a message to Sacramento: Funding for UC's missions of research, education and public service is an investment in the future of this state. California needs to sustain the innovative excellence that fuels our economy, educates our future leaders and safeguards our quality of life.

No one knows this better than California's agricultural community, and nothing demonstrates UC's impact more dramatically than the programs of our Agriculture and Natural Resources (ANR) division.

In my 4 years as UC president, I have visited growers from Redding to El Centro. At every stop, I have heard about UC's importance from family farmers. Half Moon Bay nurseryman Jack Pearlstein told me in 2005, "Without UC science, California will no longer be an agricultural state." Coachella Valley date grower Albert Keck told me last month, "We see UC's direct impact in agriculture every day."

Along the way, I have learned that UC and California agriculture have a common entrepreneurial spirit and a shared purpose in our three mission areas.

Innovation through research. UC has led the state and the nation into a new era of what I call "R, D and D": research, development and *delivery* of innovations to end-users. UC scientists on our campuses and county-based Cooperative Extension advisors are carrying out R, D and D to benefit agriculture in every corner of California.

I have seen firsthand how Central Valley almond and walnut farmers reduce airborne dust (and save fuel) by using new conservation tillage methods and more-efficient harvesters developed through UC research.

I have learned how UC integrated pest management programs curb chemical use on large Central Coast farms and improve water quality in backyard gardens from San Diego to Redding.

I have spoken to families in Los Angeles County who are eating more nutritious meals and reducing their risk of diabetes and other illnesses thanks to UC consumer education programs.

I have met with forest managers in the Sierra Foothills and rice farmers in the Sacramento Valley who are using UC land conservation practices to boost production, expand wildlife habitat and reduce carbon emissions.

And right now, you are reading one of our oldest and most successful models of R, D and D. *California Agriculture* disseminates timely, peer-reviewed research, and in this edition you will find articles about the invasive light brown apple moth, methyl bromide alternatives, sustainable production practices, and food safety and environmental quality.

Opportunity through education. Research creates ideas; education creates the next generation of creators. UC students working in ANR areas are learning to be innovators, like UC Santa Cruz graduate student Marcos Lopez, who is studying how the restructuring of California strawberry production, including the phase-out of methyl bromide, affects local labor markets and community redevelopment.

I am gratified at how industry visionaries like Bill Pauli, past president of the Farm Bureau Federation, have been our partners in pushing for an overhaul of K-12 science and math education to raise the tech literacy of future workers. And UC takes special pride in our 4-H Youth Development program, which has a long tradition of grooming California's future agriculture leaders.

Public service and public awareness. In many respects, UC and California agriculture have been the victims of our own success. The rest of the world marvels at our entrepreneurial excellence and envies the success it has generated. Here at home, many Californians do not fully grasp UC's impact on this state, and many think the plentiful food they eat originates at Ralph's or Safeway.

In concert with our mission of public service, we must work together to raise public awareness. We must remind our elected officials that California's $32 billion agricultural sector produces more than 350 commodities and employs 7% of the state's private-sector workforce. And we must remind them that UC helps make that possible by giving California farmers and ranchers the innovative technologies, research breakthroughs and real-world solutions they need to compete globally and farm more sustainably.

UC's commitment to bolstering California agriculture and preserving our natural resources is stronger than ever, especially with Dan Dooley in place as our new ANR vice president. But we must have the necessary support to fulfill that commitment. I am making the case for that support as vigorously as I can, and I need your help.

If UC has had an impact on your own life, I invite you to join "UC for California," a dynamic advocacy support network that mobilizes the UC community. The months ahead are critical. Please visit www.ucforcalifornia.org, sign up as a UC friend, and let your elected officials know why an investment in UC is an investment in California's future. Thank you.

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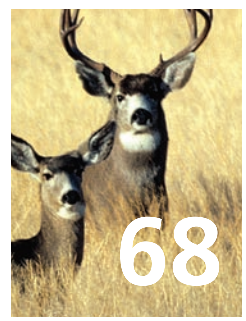

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About California Agriculture

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

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

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

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

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

Rejection rate. Our rejection rate is currently 26%. In addition, in two recent years the Associate Editors sent back 11% and 26% for complete resubmission prior to peer review.

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

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.ucop.edu/submissions.html for more information.

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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Impacts of research, and *Cal Ag*

California Agriculture has been part of my class at Butte College for 12 years. The course is "The Ecology of Insect and Disease Management." Many articles fit the curriculum, but the value of the journal goes far beyond its content.

In an era of $100-plus texts, instructors need to think carefully about what they require of students. *California Agriculture* is free; copies, as well as back issues, are online, so I can assign readings from it with a clear conscience. The research articles challenge students and force them to reexamine past practices by emphasizing the importance of developing better methods to meet future needs. The thematic format of each issue opens their eyes to the broad impact that research has on our daily lives — and for some students, it suggests future careers in agricultural research. Perhaps a subtler but equally important use of the journal is as a model for report writing. The articles, along with their illustrations and graphics, are examples of the way scientific reports should be prepared.

The journal has been invaluable in my class and again my thanks for keeping it going.

Herbert R. Jacobson
Associate Instructor, Butte College

Public access to UC Giannini libraries

I was pleased to see that *California Agriculture* has embarked on the digitization and development of its entire archive, going back to 1946, enabling full text and metadata searches. Through this project, the journal will make decades of peer-reviewed research openly accessible to the public.

Readers of *California Agriculture* may also wish to know of two specialized libraries in agricultural and environmental economics, located at UC Berkeley and UC Davis. Both are open to the public as well as to students and faculty on each campus, and are staffed by professional librarians who provide e-mail, phone and in-person research assistance in these subject areas.

The Giannini Foundation of Agricultural Economics Library at UC Berkeley is the oldest university agricultural economics library in the United States. It offers a digital archive of faculty research papers and a print collection of books, journals and rare unbound materials, including technical reports, historical trade journals and government documents (http://are.berkeley.edu/library).

The UC Davis Agriculture and Resource Economics Library also offers a specialized collection of unbound materials, books and scholarly, trade and popular journals. The ARE library has created a digital collection of United Farm Workers contracts and is currently digitizing the Cost and Return Studies for crops and commodities published by UC Cooperative Extension (http://arelibrary.ucdavis.edu).

Susan Garbarino
Librarian
Giannini Foundation Library
University of California, Berkeley

Sustainable includes ignition-proof

Thank you for "UC Cooperative Extension helps people cope with Southern California wildfires" (January-March 2008) by Robin Meadows.

We farm sustainably, and our farm plan calls for eventual conversions to fireproof structures. The ignition-proof home exhibits three features: a noncombustible envelope or outer shell; no ember entry (which can occur through unsealed tile roofs); and firewall protection for the structure in all doors, windows and walls. A stuccoed strawbale wall, made by California's rice growers, is rated a 2-hour firewall.

Our solarized well/tool shed, with its panels and Outback power inverter, is ignition-free and fireproof. The pump runs during outages. We recommend an interconnect system with battery backup rather than garbage cans. Also, hot tubs make good water-storage tanks.

Defensible space defends against flame contact, not falling firebrands and ember entry (see article by Jack Cohen http://www.nps.gov/fire/download/pub_pub_modelingpotential.pdf). "Fire-resistant plants" is a flat-out myth.

Bud Hoekstra
Berry Blest Farm
San Andreas

January–March 2008 *California Agriculture*

Winter gardens

I planted several vegetables late in 2007 with little hope of success. I was wrong. Several of them — including cabbage, beets, mustard greens, and dill — had enough warm weather to germinate and establish roots. In Arizona these vegetables can use the entire winter to grow. They do not go dormant or die off. I hope this is useful to California gardeners. What has been published on this?

Nicholas Terebey
Phoenix, Arizona

Statewide Master Gardener Coordinator Pam Geisel responds:

You have discovered the joys of the winter gardens: few weeds, little to no watering and few pests! For approximate planting dates of many cold-hardy crops, see the Master Gardener Handbook *(page 351, table 14.2). To order: http://anrcatalog.ucdavis.edu.*

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.


Robert J. Meese/UC Davis


Robert J. Meese/UC Davis

Cooperative conservation could save tricolored blackbirds

A new plan to keep the tricolored blackbird off the endangered species list will also benefit farmers. Found almost exclusively in California, the birds are down to about 260,000. More than half of the remaining tricolored blackbirds (*Agelaius tricolor*) nest in Central Valley triticale fields, and the crop is ready to harvest before the nestlings are ready to fledge.

"The birds and the farmers both want the triticale at the same time," says Robert Meese, a UC Davis tricolored blackbird expert. "They're on a collision course."

Meese is part of an alliance that developed a voluntary conservation plan for the tricolored blackbird. An agreement to implement the plan was signed in September 2007 by representatives of agricultural industry groups, conservation organizations and government agencies, as well as by Rick Standiford, ANR associate vice president.

"This is a fine example of how cooperative conservation can help resolve conflicts between agriculture and natural resources," Standiford says.

The conservation plan was spearheaded by Sustainable Conservation, a nonprofit organization that seeks practical solutions to environmental problems. "By building populations now, we will avoid the need for a listing in the future," says Sustainable Conservation's Susan Kester, who coordinates the Tricolored Blackbird Working Group that created the plan.

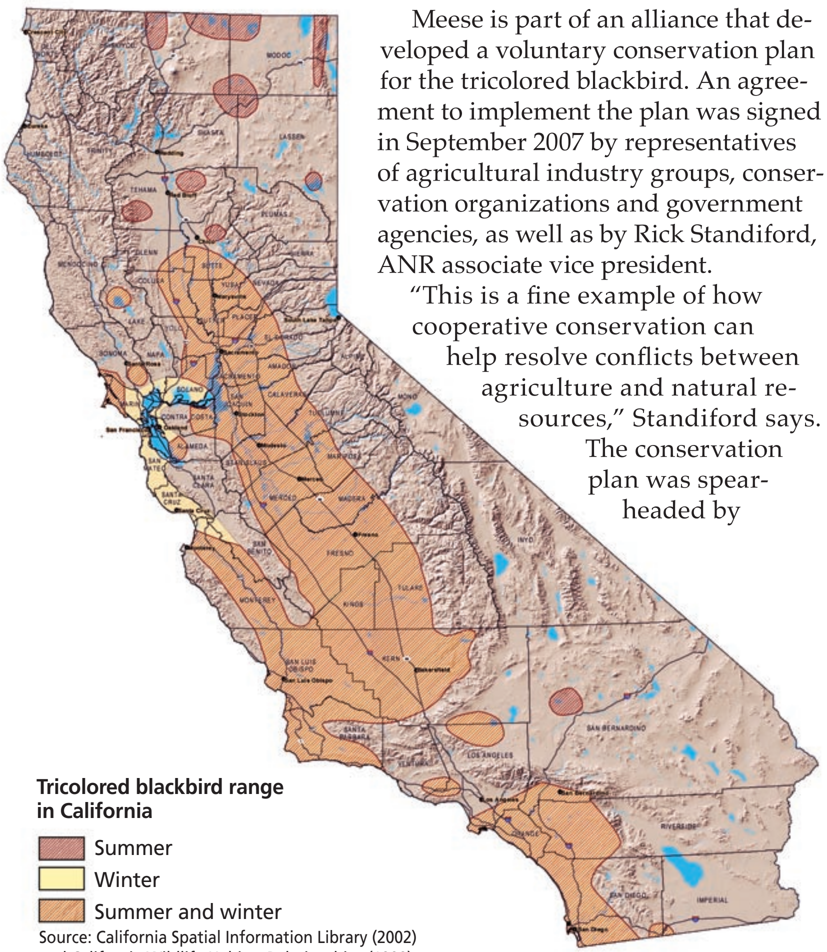
While the historical size of the tricolored blackbird population is unknown, by all accounts it was tremendous. Wintering flocks were described as darkening the sky in 1853, the species was the most common bird in San Diego County in 1870, and a roost in Sacramento County was estimated at close to 500,000 in 1937, according to the Conservation Plan for the Tricolored Blackbird.

Likewise, the tricolored blackbird can breed in huge colonies — the largest in recent years had 138,000 adults. With the decline of the freshwater marshes where they once nested, the birds have turned to triticale grown for silage on dairy farms. "The fields are flood-irrigated so it looks like a marsh, and there's a grain pile 30 feet away," Meese says. "It seems like nirvana to blackbirds."

The conservation plan's short-term goals include buying silage crops on farms with breeding colonies. To facilitate these buyouts, Meese spends the April-to-July breeding season monitoring colonies in the Central Valley. "My experience with landowners has been universally positive," Meese says. "It's not a case of 'good guys, bad guys.' They're just trying to make a living."

But to farmers, blackbirds are pests, and in a typical year only one out of eight colonies breeding in triticale is saved. "It's not a slam dunk — it's just a year-to-year fix," Kester says.

The plan's long-term goals include creating more freshwater marsh to tempt tricolored blackbirds away from farms. This approach is promising because when given the choice, the birds prefer nesting in cattails. The birds also need a



Source: California Spatial Information Library (2002) and California Wildlife Habitat Relationships (1999).

For more information:

Tricolored Blackbird Portal
http://tricolor.cain.ucdavis.edu

Tricolored Blackbird Project
www.suscon.org/tricolored_blackbird

William Hamilton

Due to habitat loss, colonies of tricolored blackbirds have been nesting in fields of triticale, but the crop is usually harvested before nestlings have fledged. A new agreement will help restore the bird's habitat. *Facing page left,* tricolored blackbirds at Owens Creek in Merced County; *facing page right,* a nest containing four eggs in triticale; *above,* a male tricolored blackbird in the breeding season; *below,* a colony in a triticale field adjacent to a dairy in Kern County.

Robert J. Meese/UC Davis

convenient source of insects, which females depend on for producing eggs and which are all the nestlings eat. Alfalfa and sunflower fields provide insects in agricultural areas, while shrublands provide them in the wild. Again, when given the choice, the birds prefer foraging in natural shrublands.

But before restoring breeding habitat, the group still needs to know more about the tricolored blackbirds' basic behavior. "They're often itinerant breeders and may not return to the same exact sites each year," Kester says. "What characteristics are they looking for?"

To find out what attracts the birds, she envisions testing various land-management techniques in the Kern and San Luis National Wildlife Refuges. For example, the birds seem to like lush, young growth in wetlands, which could be created by controlled burns or disking. Another priority is setting targets for how many birds there should be, and how much new breeding habitat they would need to stay away from farmers' fields.

"If there was enough marsh, I think that to a large extent the problem would go away," Meese says. Then dairy farmers would be able to make a living and the tricolored blackbird would be able to keep on living.

— Robin Meadows

Plans to control light brown apple moth stir controversy

The light brown apple moth, an exotic invader that feeds on hundreds of native plants and agricultural crops, continues to gain a foothold in California, but controversy swirls over how to control it.

State plans call for aerial applications of pheromones over parts of nine quarantined counties: Alameda, Contra Costa, Marin, Monterey, San Francisco, San Mateo, Santa Clara, Santa Cruz and Solano. The applications could start as early as June in a few areas, says Kevin Hoffman, primary state entomologist with the California Department of Food and Agriculture (CDFA) in Sacramento. (CDFA also applied aerial pheromones in Santa Cruz and Monterey counties in fall 2007.)

First detected on Feb. 27, 2007, in Berkeley (Alameda County), the light brown apple moth (*Epiphyas postvittana*) may have arrived in California via nursery stock from its native Australia, scientists speculate. A statewide survey conducted in 2005 found no signs of the leafroller moth, says Curtis Takahashi, biologist with CDFA's Pest Detection/Emergency Projects in San Jose.

According to CDFA, the light brown apple moth threatens the state's multibillion-dollar agricultural industry by potentially destroying, stunting or deforming young seedlings; spoiling the appearance of ornamental plants; and injuring citrus, grapes and deciduous fruit tree crops (also, see page 57).

However, of greater concern to growers is the threat of export restrictions imposed on California crops by trading partners. Already, Mexico and Canada have restricted imports of crops and plants from infested areas; China has taken steps toward such restrictions. Others — including Chile, Korea, Peru and South Africa — list the moth as a quarantine pest and might require certification that a California export is pest-free.

"Trade restrictions would cause the greatest hardship on the fruit, vegetable and nursery industries that export to foreign countries or sell to other states," notes Lucia Varela, UC integrated pest

Ed Show

Mark Bolda, farm advisor for strawberries and cane berries in Santa Cruz, Monterey and San Benito counties, demonstrates one method of sampling for leafroller pests in blackberry. This method would be useful for sampling for the light brown apple moth.

management advisor. “When the first light brown apple moth was found, Florida immediately threatened to impose restrictions on shipments of those commodities from California. Other states were getting ready to do the same when the USDA stepped in with the order imposing quarantine in areas where infestation has occurred.”

Pheromone applications planned

Pheromones are chemical signals shared by members of a species; the light brown apple moth sex pheromone is a perfumelike substance used by the female to attract the male. Wide application of this pheromone confuses males and disrupts the moth’s mating cycle, reducing its populations. CDFA officials hope that an early and aggressive program of aerial applications will lead to the moth’s eradication.

The synthetic pheromone being applied, called CheckMate, “doesn’t kill the moth,” Takahashi says. “But since it’s a control agent, it’s called a pesticide.”

“Tests are ongoing in New Zealand to determine the best kind of (pheromone) spray to use,” Hoffman says.

Last fall, there were hundreds of health-related complaints from residents after CDFA sprayed pheromones aerially in parts of Monterey and Santa Cruz counties. Takahashi told the February meeting of the Northern California Entomology Society (NCES) that he has responded to complaints related to respiratory problems, burning eyes and burning throats. Some residents expressed concern that the pheromone would kill honeybees. “It won’t kill the honeybees and it won’t kill the light brown apple moth, either,” Takahashi said. “It’s a pheromone.”

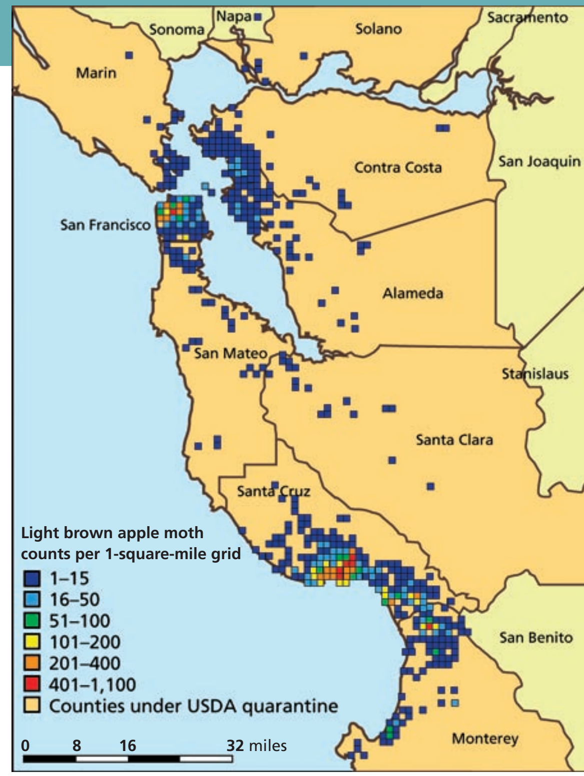
A handful of bills have been introduced in the state legislature to stop aerial applications over urban areas, and thousands of Bay Area residents have signed petitions. Four Bay Area city councils have passed resolutions against the aerial applications.

“A large part of the concern is that people don’t like to be sprayed by anything,” Hoffman says. “It’s a loss of control. It’s something they can’t see and the general perception is that anything sprayed is toxic, which it isn’t.”

Eradication prospects unclear

The light brown apple moth “is not going to be easy to get rid of,” Takahashi says. For one, “it has no true dormancy period in California.”

Hoffman agrees. “It can survive in so many microclimates, and it has a broad host range — it feeds on more than 2,000 different types of native and ornamental trees and can



Light brown apple moth finds in Northern California through Dec. 5, 2007. Source: USDA APHIS 2007, from CDFA data.

attack more than 250 agricultural crops — and it’s fairly widespread.”

As of February 2008, some 17,000 moths had been detected in 14 California counties. The latest was a single moth found in Sonoma County. In addition, single moths were recently reported in Santa Barbara, San Luis Obispo, Los Angeles and Napa counties.

“It can be anywhere — in the grass, clover and trees,” Hoffman says.

The U.S. Department of Agriculture has earmarked about $74.5 million for California to combat light brown apple moth in 2008, including eradication, research, monitoring and regulation.

UC Davis entomologist Frank Zalom says the state appears to be taking a “cautious approach in terms of the safety of [control] technologies both to humans and the environment. Two issues come to my mind — what is the potential impact of doing nothing, and is eradication possible with the available tools given the extent of the infestation?”

Zalom, an expert in integrated pest management, says a critical question concerns the economic impacts of doing nothing to control light brown apple moth. “What is the probability that extensive quarantines would be imposed by trading partners? What would be the resulting cost? Could containment instead of eradication be an acceptable approach?

”It seems that the state should assess whether it pays to try to eradicate, given the present tools, versus containing the pest.”

— Kathy Keatley Garvey and Editors

For more information:

CDFA
www.cdfa.ca.gov/phpps/PDEP/lbam/lbam_main.html

UC Statewide Integrated Pest Management Program brochure
www.ipm.ucdavis.edu/EXOTIC/lightbrownapplemoth.html

Light brown apple moth's arrival in California worries commodity groups

by Lucia G. Varela, Marshall W. Johnson, Larry Strand, Cheryl A. Wilen *and* Carolyn Pickel

Natasha Wright, Florida Dept. of Agriculture and Consumer Services, Bugwood.org

The light brown apple moth, a tortricid leafroller, is extremely variable and difficult to identify visually. The insect's reproductive organs must be examined in order to obtain a positive identification.

Light brown apple moth is an exotic pest that was confirmed in California in March 2007. It is a tortricid leaf-roller moth native to Australia, which has a broad range of plant hosts with the capacity to cause damage across a wide array of crops, natural areas and ornamental plants. California and federal agencies have issued quarantine orders affecting production and retail nurseries, and potentially fruit and vegetable exports. It is found thus far primarily in nurseries near urban areas. Eradication efforts are under way to prevent its spread into California crop areas and throughout the United States.

IN March 2007, the U.S. Department of Agriculture's Animal and Plant Health Inspection Service (APHIS) confirmed the presence of light brown apple moth (LBAM) (*Epiphyas postvittana*) in California, based on specimens from Alameda and Contra Costa counties. As of December 2007, a total of 15,594 male moths caught in pheromone traps had been confirmed as light brown apple moth. The largest numbers of moths are being trapped in southern Santa Cruz and northern Monterey counties. The second highest area of capture includes contiguous portions of northwest Alameda, western Contra Costa and San Francisco counties. Less than 1% of the captures are from mostly single trap catches in Los Angeles, Marin, Napa, San Luis Obispo, San Mateo, Santa Barbara, Santa Clara, Solano and Sonoma counties (CDFA 2007c). Although light brown apple moth has been present in Hawaii since the late 1800s, this is the first time this pest has been detected in the continental United States.

Although light brown apple moth has been confirmed in 14 counties, only portions of Alameda, Contra Costa, Marin, Monterey, San Francisco, San Mateo, Santa Clara, Santa Cruz and Solano counties are currently subject to quarantine (CDFA 2007d). According to current California Department of Food and Agriculture (CDFA) regulations, a county is quarantined if specimens representing more than one life stage of the moth or a mated female are confirmed within a 3-mile radius (USDA APHIS 2007b).

The light brown apple moth is a tortricid leafroller moth native to Australia. It is now established in New Zealand, New Caledonia, the British Isles and Hawaii (Danthanarayana 1975; Suckling et al. 1998). It has a broad range of plant hosts, including herbaceous plants, landscape trees, ornamental shrubs, fruit and certain vegetable crops (Rogers et al. 2003; Wearing et al. 1991). It is known to feed on 250 plant species in over 50 families, but prefers plants in the aster (Asteraceae), legume (Fabaceae), knotweed (Polygonaceae) and rose (Rosaceae) families (CDFA 2007a).

Elsewhere, light brown apple moth has been reported as a pest on apple, pear, peach, apricot, citrus, persimmon, avocado, walnut, grape, kiwifruit, strawberry, cane berries and cole crops. It may also infest oak, willow, poplar, cottonwood, alder, pine, eucalyptus, rose, camellia, jasmine, chrysanthemum, clover, plantain and many other plants (Brockerhoff et al. 2002; Buchanan 1977). In California, larvae identified as possible light brown apple moth have been found in apples, strawberries and grapes in commercial fields. The most common hosts in nurseries and the landscape have been *Prunus* spp. and California wax myrtle (*Myrica californica*). However, an extensive survey of possible hosts has not been conducted, so these initial findings may not be representative of the types of plants likely to be infested in California. Light brown apple moth is polyphagous (able to feed on many plants). It may encounter and infest additional hosts with which it has not been previously associated.

California and U.S. federal agencies have issued orders restricting intra- and interstate shipments of plant material from quarantine counties (CDFA 2007d; USDA APHIS 2007a). At present, production and retail nurseries are the industries most affected by these regulations. Equally important are the current or potential trade restrictions on fruits and vegetables imposed by importing countries (CFIA 2007; CDFA 2007b).

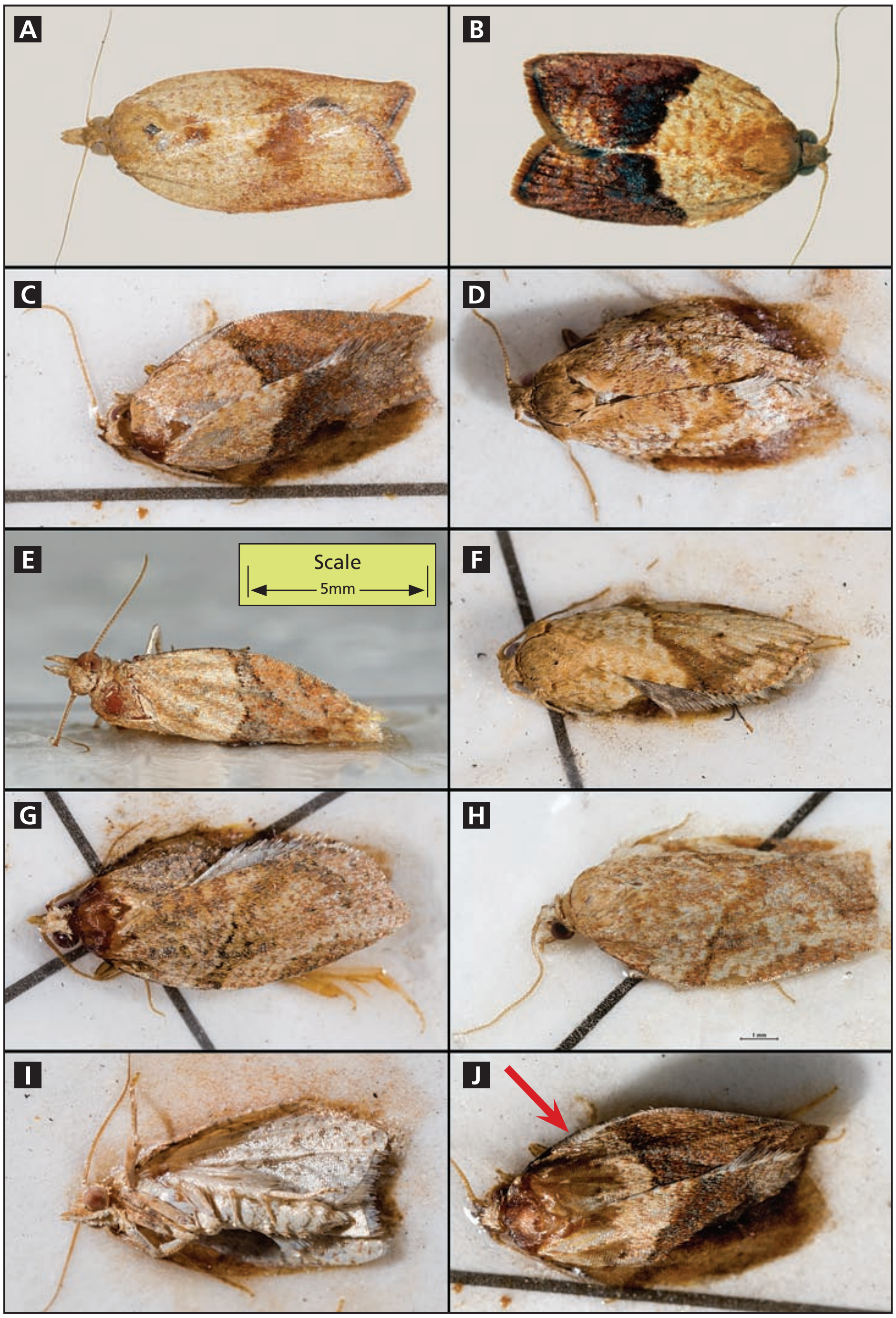
Identification and description

Positive identification of light brown apple moth can be made with certainty only by examining the adult moth's re-

Jack Kelly Clark

The leafroller's mature larva feeds on hundreds of different plants and agricultural crops.

A, B, by David Williams, State of Victoria Department of Primary Industries; C, D, F, G, I, J by Jack Kelly Clark; E, H by Brad Oliver, Monterey County Agricultural Commissioner's office



Female (A) and male (B) light brown apple moths. The wing-color pattern of light brown apple moth males (C–I) in pheromone traps can be highly variable. Males have a costal fold (arrow) on the forewing (J).

productive organs (Dugdale et al. 2005; Zimmerman 1978). Growers who wish to obtain positive identification of a suspect insect should bring the live larvae, if possible still inside the webbed nest of rolled-up leaves, to their agricultural commissioner's office.

Light brown apple moth closely resembles other native California tortricids such as orange tortrix (*Argyrotaenia franciscana*) and garden tortrix (*Clepsis peritana*). Adults hold their wings over their abdomens in a bell shape when at rest, and have protruding mouthparts that resemble a snout. The antennae are simple, not featherlike. Adult size may vary during the season, with larger individuals present during cool, wet months and smaller individuals present during warm, dry months (Danthanarayana 1976).

Wings. The length of the forewing (front wing, the most obvious wing when the moth is at rest) in the female is 0.27 to 0.5 inch (7 to 13 millimeters) and in the male approximately 0.23 to 0.4 inch (6 to 10 millimeters) (see photos A, B). There is considerable variation in the color patterns of the wings, especially on the males (Bradley 1973). The basal half (closest to the head) of the male forewing may be light brown to pale yellow, while the distal half (farthest from the head) is reddish-brown (see photos B, C). In deeply colored forms the distal half of the forewing may vary from reddish-brown (see photo C) to blackish with purplish mottling (see photo B), and the basal half is sparsely speckled with black. In some males, the two-tone wing coloration of the forewings may be absent. Instead they are light brown with a slightly darker oblique marking (see photos D, E, F, G, H). While all color patterns of the wing have been found in males caught in California, by far the most prevalent pattern has been light brown with slightly darker oblique marking (see photos D, E, F, G, H).

In the female, forewing color varies from uniform light brown, with almost no distinguishing markings or with a dark spot in the center-front of the folded wings, to the typical oblique markings of the male, but with less contrast between the basal and distal halves (see photo A). The hindwings (back wing) of both sexes are pale brown to grey, either uniform in color or mottled with wavy dark-brown markings (see photo I).

Males have an extension of the "forward" outer edge of the forewing called the costal fold (see photo J), which runs from the base of the wing to two-fifths of the length of the wing edge. This is an expanded part of the wing that folds up over the front edge of the wing as a flap. Females do not have this costal fold.

Eggs. The eggs are pale yellow to light green, broadly oval and flat with a pebbled surface. They are laid slightly overlapping each other like fish scales. The egg mass is covered with a greenish transparent coating. An egg mass may contain from 2 to 170 eggs, but typically has 20 to 50 eggs. A female may lay multiple egg masses, depositing them on the upper surface of host leaves and occasionally on fruit and young stems. As the eggs develop, they change to paler yellow-green. Immediately prior to hatching, the dark head of the developing caterpillar is visible (Danthanarayana 1983).

Larvae. The newly hatched larva is pale yellow-green, 0.06 to 0.08 inch (1.5 to 2 millimeters) long and has a dark brown head. There are five to six larval instars (stages). Mature larvae range from 0.4 to 0.7 inch (10 to 18 millimeters). The head is light yellow-brown and the prothoracic shield (segment behind the head) is light greenish-brown with no dark markings. The body is medium green with a darker green central stripe that may continue to the prothoracic shield; larvae may also have darker longitudinal stripes on both sides. The hairs on the body are whitish. The thoracic legs are the same color as the head, but paler, and are also unmarked. Larvae have a greenish anal comb with seven teeth — a comb-shaped structure at the tail end of the larva. An overwintering larva may have a darker head and prothoracic shield (Danthanarayana 1975, 1983). Larvae can be screened using morphological characters and DNA analysis to determine if the specimens are possibly light brown apple moth. However, absolute certainty is not possible because there are still many California tortricid larvae whose morphological characters or DNA have not been studied.

Pupae. The pupa is found in a thin-walled silken cocoon, often between two leaves webbed together. It turns from green to brown as it matures and is dark reddish-brown and 0.4 to 0.6 inch (10 to 15 millimeters) long. Pupae of all tortricids are very similar in appearance (Danthanarayana 1975).

If light brown apple moth is found in fruit-production counties, the inability to export fruit to some countries may cause severe economic hardship.

Life cycle of a pest

Light brown apple moth is found in southeastern Australia; it was introduced on the western coast, but does not survive well at high temperatures and is a more serious pest in cooler areas with mild summers (Geier and Springett 1976; Buchanan 1977; Danthanarayana et al. 1995). The pest performs best under cool conditions (mean annual temperature of approximately 56°F) with moderate rainfall (approximately 29 inches annually) and moderate-high relative humidity (approximately 70%). Hot, dry conditions may reduce populations significantly, and it is unknown whether the insect will be able to establish in locations such as the Central Valley and inland deserts of California.

A degree-day model (which predicts the moth's growth and development according to mean temperatures over time) indicates that there would most likely be two generations a year in California's Central and North Coast areas, and three or four generations a year in the Central Valley and Southern California. The lower and upper developmental thresholds for light brown apple moth are 45°F and 88°F, respectively (Danthanarayana 1975). Completion of the entire life cycle requires 620 degree-days above 45°F. In Australia, New Zealand and the British Isles, generations overlap. Light brown apple moth does not have a winter resting stage (diapause). Cold winter temperatures slow larval development considerably (Geier and Briese 1980). Thus, the pest overwinters as second to fourth instar larvae that feed on herbaceous plants, buds of deciduous trees or shrubs, mummified fruit and other plant material. Larvae may survive for up to 2 months in the winter without feeding.

Adult moths emerge after 1 to 3 weeks of pupation and mate soon after emergence. They stay sheltered in the foliage during the day, resting on leaf undersides. Moths fly 2 to 3 hours after sunset and before daybreak. The light brown apple moth is capable of flying only short distances to find a suitable plant host (Suckling et al. 1994). Most moths fly no farther than 330 feet (100 meters), but some may fly as far as 2,000 feet (600 meters). Males disperse farther than females. Adults are less likely to leave areas with high-quality hosts. Adult life span is 2 to 3 weeks, with longevity influenced by host plant and temperature.

Females begin to lay eggs 2 to 3 days after emerging, depositing eggs at night. They prefer to deposit their eggs on smooth leaf surfaces, and usually lay a total of 120 to 500 eggs, but can lay up to 1,500 eggs (Danthanarayana 1975). An egg takes from 5 to more than 30 days to hatch, depending on temperature.

Larvae emerge from eggs after 1 to 2 weeks. Although egg masses may include 20 to 50 eggs, the resulting larvae disperse widely, each creating a nest on a separate leaf. When a larva finds a feeding site, it forms a silken shelter near the midrib on the leaf underside and begins to feed. Second and later stages feed on two to several leaves

HortResearch, New Zealand

Eggs of the light brown apple moth are typically deposited on the upper surface of host leaves in masses of 20 to 50.

Photos: HortResearch, New Zealand

Originally from southern Australia, the light brown apple moth can feed on and damage a broad range of crops such as, *above*, apple. If the pest becomes established in California the most important impact to growers will likely be trade restrictions on crop exports.

webbed together, a leaf webbed to a fruit, or in the center of a fruit cluster. The larvae feed within these shelters, and they may feed on fruit when it touches a leaf. Larvae on fruit are most likely to be found near the calyx, the residual basal flower parts. When disturbed they wiggle violently, suspend themselves from a silken thread and drop to the ground, where they feed on groundcover hosts. Larval development can take from 3 to 8 weeks, depending on temperature. Pupation is completed inside the silken feeding shelter. The pupal stage lasts 1 to 3 weeks.

Potential crop damage

Like other tortricid leafrollers, light brown apple moth feeds from within the sheltering nest it constructs. Light brown apple moth has attained pest status only in southeastern Australia and New Zealand (Danthanarayana 1995). Foliar feeding is usually considered minor in fruit crops, though it might be of economic importance on nursery stock and of cosmetic importance on landscape ornamentals. On fruit crops the primary concern is fruit damage (Wearing et al. 1991; Lo et al. 2000). Larvae remove the outermost layers of the fruit surface as they feed. Superficial feeding injury to the fruit is typically caused by later immature stages. Young larvae may enter the interior of a pome fruit through the calyx. They can cause internal damage to stone fruits as well.

Minor feeding damage can take the form of pinpricks, or "stings," on the fruit surface. In grapes, larvae can cause extensive loss of flowers or newly set berries in the spring. Later in the season, grapes can be severely damaged by larvae feeding among the berries, allowing plant pathogens causing mold to enter (Buchanan 1977; Buchanan et al. 1991; Lo and Murrell 2000). In citrus, larval feeding causes fruit drop or halo scars around the stem end of the fruit. In crops such as kiwifruit, plum, citrus and pome fruit, the maturing fruit produces a layer of corky tissue over the leafroller damage. Buds of deciduous host plants are vulnerable to attack in the winter and early spring. Conifers are damaged by larval activity such as needle tying, chewing of buds and boring into stems. In tree nurseries, damage to terminal buds on seedlings and saplings can cause multiple or crooked leaders (Wearing et al. 1991).

California impacts and control

In California, light brown apple moth has been detected on agricultural lands mostly in production and retail nurseries located near urban areas. Light brown apple moth may be inadvertently moved during the transport of nursery stock. Currently the brunt of the economic cost is borne by the nursery industry in the most infested counties.

If light brown apple moth continues to spread, several vegetable and fruit crops may be affected such as apples, pears, caneberries and peppers. California growers already deal with one or more leafroller pest species on most of these crops. Management practices are available for suppressing leafrollers, and the same approaches would be used against light brown apple moth. However, the primary concern is the trade restrictions imposed by importing countries. Mexico and Canada already have restrictions on the importation of crops and plants from the infested areas of California. China has begun the information gathering that frequently leads to trade restrictions. Many countries such as Chile, Korea, Peru and South Africa list light brown apple moth as a quarantine pest and may require certification attesting that commodities such as pome fruits, grapes, citrus and stone fruits are pest-free. If light brown apple moth is found in fruit-production counties, the inability to export fruit to some countries may cause severe economic hardship to some sectors of California's agricultural industry.

APHIS has called together experts from the United States, Australia and New Zealand to form a Technical Working Group to advise on steps for managing the light brown apple moth infestation in California. APHIS and CDFA's current long-term goal is to eradicate light brown apple moth from California (see page 55). However, no single control technique currently exists that can be effectively implemented over an entire infested area. Eradication will require a multiphase approach.

Eradication will focus initially on specific localities to determine its feasibility. While eradication attempts are under way, it is important to ensure that light brown apple moth infestations do not continue to increase in size and expand to uninfested areas. Environmentally compatible methods of pest management are needed to maintain public support for the eradication effort and to keep light brown apple moth at low numbers across agricultural, urban and natural areas.

Several reduced-risk insecticides are registered in agricultural and ornamental crops that effectively control leafrollers. These include insect growth regulators, spinosyns and *Bacillus thuringiensis* (Bailey et al. 1996)

In Australia, light brown apple moth has been managed in citrus, grapes and other crop systems using mating disruption (Mo et al. 2006). Light brown apple moth pheromone has two key components, both of which must be present for optimal control (Bellas et al. 1983; Suckling and Clearwater 1990). Presently, mating disruption is being implemented in some infested areas of California.

There are numerous leafroller species in California, and many of these have effective parasitoids (such as *Cotesia*, *Exochus*, *Macrocentrus*, *Nemorilla* and *Trichogramma* species) and predators (such as spiders, minute pirate bugs, lacewings and *Phytocoris* bugs). It is highly probable that some of the California native natural enemies will expand their prey ranges to include light brown apple moth eggs, larvae and pupae. Natural enemies could also be collected in the native home of light brown apple moth and introduced into California. In Australia, as many as 25 different parasitoid species have been reared from light brown apple moths collected in the field (Charles et al. 1996; Geier and Briese 1980; Paull and Austin 2006). Imported natural enemies require extensive host specificity testing, which may take several years to ensure that they are not a threat to endangered endemic species.

Currently, light brown apple moth is found in limited areas of California. However, it has the potential to establish widely in California as well as other important agricultural states (such as Arizona, Texas and Florida). Although eradication from its present California distribution may seem difficult and expensive, the effort is worthwhile given the possible economic and ecological ramifications should the species establish itself and proliferate throughout agricultural acreage in California and the United States.

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Methyl bromide alternatives evaluated for California strawberry nurseries

by Steven A. Fennimore, John M. Duniway, Greg T. Browne, Frank N. Martin, Husein A. Ajwa, Becky B. Westerdahl, Rachael E. Goodhue, Milton Haar *and* Christopher Winterbottom

The recent phase-out of the soil fumigant methyl bromide (MB) due to its impact on stratospheric ozone presents a huge challenge to strawberry nursery producers. We evaluated the effectiveness of alternative fumigants on soil pests and plant productivity, as well as production costs in California strawberry nurseries. Our trials followed nursery stock through low- and high-elevation phases of runner-plant propagation and a complete cycle of fruit production in coastal fields. Plant yields from the nurseries and fruit yields from Oxnard and Watsonville indicated that nursery plots treated with iodomethane plus chloropicrin, with 1,3-dichloropropene followed by dazomet, and with chloropicrin followed by dazomet produced runner-plant yields that were similar to methyl bromide plus chloropicrin. However, our economic analysis suggests that nursery profitability may nonetheless suffer from the loss of methyl bromide.

California strawberry runner plants are propagated in high-elevation nurseries such as this one near Macdoel, north of Mt. Shasta. The harvested runner plants are transported to fruiting fields in California or exported to other states or countries.

Methyl bromide (MB) is a fumigant that is applied to the soil before planting to provide season-long control of soilborne pathogens, insects, nematodes and weeds. Several vegetable, fruit and perennial crops rely on methyl bromide for pest control (USDA ERS 2000). In the United States, tomatoes, strawberries and peppers account for most of the methyl bromide used in soil fumigation (30%, 19% and 14%, respectively) (Carpenter et al. 2000). Other crops that use methyl bromide include almonds, eggplants, grapes, melons, peaches, nectarines, plums, prunes, sweet potatoes, walnuts and ornamental as well as nursery crops. Of the 7.1 million pounds of methyl bromide used in California in 2004, strawberry producers applied 3.2 million pounds (45%), primarily for soil fumigation (DPR 2006). The benefits of methyl bromide use are clear; for example, in one study strawberry yields were 94% higher with methyl bromide fumigation than without fumigation (Shaw and Larson 1999).

However, methyl bromide that escapes into the atmosphere can reach the stratosphere, where it depletes ozone. An international treaty and domestic legislation completed a phase-out of methyl bromide in 2005, but the treaty allows for critical-use exemptions and quarantine for cases where no technically and economically feasible alternatives exist, or when significant market or regulatory disruptions would result without use of the fumigant. These exemptions are reviewed annually and are only considered where a critical need has been demonstrated (Martin 2003).

The economic consequences of the methyl bromide phase-out could be severe. Goodhue, Fennimore and Ajwa (2005) estimated that revenues for California strawberry growers would decline by roughly 25%. Although the price of strawberries would increase, the reduction in the quantity sold would be large enough that revenues would decline. As the price of strawberries increases, consumers would purchase fewer strawberries. Consequently, consumer surplus, the difference between what consumers are willing to pay for strawberries and what they pay in the market, would decline by an estimated 50%. Osteen and Caswell (1999) estimated that U.S. strawberry producers and consumers could lose $131.5 million annually due to the methyl bromide phase-out.

Alternative fumigants

In the short term, growers will likely turn to other registered fumigants, which include: chloropicrin (trichloronitromethane), 1,3-dichloropropene (1,3-D), metam sodium (so-

Time is growing short, and California strawberry fruit and nursery plant producers need to know if alternatives to methyl bromide are effective.

dium N-methyldithiocarbamate) and dazomet. Fumigants are often used in combination. Trade names for different formulations of 1,3-D plus chloropicrin are Telone C35 and InLine; for chloropicrin (CP) alone, Chlor-O-Pic, Metapicrin, Tri-Clor and others. Metam sodium, available as Vapam HL and Sectagon 42, and dazomet, available as Basamid, are broad-spectrum biocides that are effective on pathogens, nematodes and weeds. The new fumigant iodomethane (IM; Midas) now has a federal registration and is being considered for registration in California (US EPA 2007).

Nonchemical alternatives such as solarization have been tested (Hartz et al. 1993), but due to the cool and foggy conditions in most strawberry production areas, it is not likely to be an economically viable alternative to methyl bromide for most producers. Organic strawberry fruit production is still a small part of the industry, currently (in 2008) grown on about 1,600 of California's 35,700 acres in strawberries. Production of strawberries without use of fumigants is an active area of research for both organic and conventional systems.

The potential for 1,3-D use in California is limited due to the classification of this product as a possible human carcinogen. Its use is restricted to 90,250 pounds per 36-square-mile township per year (Carpenter et al. 2001). Chloropicrin is regarded as more effective against fungal pathogens than methyl bromide and degrades rapidly in sunlight and soil into environmentally benign products (EXTOXNET 2001), but it is less effective on nematodes and weeds (Himelrick and Dozier 1991). Metam sodium is less expensive than most of the alternative fumigants and controls many weeds effectively (Goodhue et al. 2005), but it does not provide adequate control of Verticillium wilt, a major strawberry disease. Iodomethane is not yet registered in California.

Information needs

Time is growing short, and California strawberry fruit and nursery plant producers need to know if alternatives to methyl bromide are effective, how they should be applied and what rates should be used. Producers also need to know if these fumigants are cost-effective. Regulators need information on fumigant emissions and worker safety to regulate the use of these potentially hazardous products. Nursery stock certification agencies, such as the California Department of Food and Agriculture, must determine whether alternative fumigants can be used to grow clean nursery stock (CDFA 2001). The public has health and environmental concerns. Available information on the efficacy and economics of the alternatives to methyl bromide does not meet these needs.

California strawberry nurseries annually produce approximately 1 billion vegetatively propagated transplants (runner plants) that are used in fruiting fields, 40% of which are shipped to other states and countries (CSC 1999). Aside from the logical need for nurseries to provide pathogen-free plants for transplanting into commercial fruit-producing fields, the industry also must comply with rigorous phytosanitary and certification requirements to ensure that the transplants are pathogen- and nematode-free (CDFA 2001). For these reasons, the nursery industry relies heavily on preplant fumigation with methyl bromide and chloropicrin (MB + CP).

The production of strawberry runner plants is a multiyear and multilocation process that begins in virus-free rearing facilities such as screen houses. Plants are then vegetatively propagated in the field for two or three seasons. One or two 8-month-long propagation seasons at a low-elevation (< 500 feet) nursery are followed by a 5-month-long propagation at a high-elevation (> 3,500 feet) nursery. Favorable warm climatic conditions at the low-elevation nursery allow rapid plant propagation (Voth 1989). The high-elevation nursery is important to provide additional plant number increases and proper conditioning for fruit production in commercial fields (Voth and Bringhurst 1990).

University of California researchers Larson and Shaw (2000) evaluated alternative fumigant treatments in low- and high-elevation nurseries to measure the effects on runner-plant production. However, until we began this project, no comprehensive studies had been con-

The fumigant methyl bromide — which is being phased out due to its impacts on the ozone layer — was used as a standard for the control of soilborne pests and diseases in all the nurseries and fruiting fields in this study. *Above*, methyl bromide is applied in a fruiting field near Watsonville.

Fig. 1. Nursery production evaluations were conducted at a low-elevation site at Ballico. Harvested runner plants were then transported to Macdoel for use in the high-elevation experiment. Fruit evaluations were conducted on the coast at Watsonville and Oxnard.

At Lassen Canyon's trim shed in Redding, workers sort strawberry plants harvested the previous day from high-elevation nursery fields. The workers separate healthy, marketable plants, trim them and then pack them for shipment to fruiting fields on the California coast.

ducted in strawberry nursery and fruit production systems to evaluate the effects of alternative fumigants on disease, nematode and weed control. We monitored the movement of plants through the system, allowing inferences to be made about the cumulative effects of fumigation. In addition, we gathered and evaluated information on the economics of production for each treatment. To our knowledge iodomethane has never before been evaluated in California strawberry nurseries. More detailed methods and results are published elsewhere (Kabir et al. 2005).

Nursery and field research

Treatments. Field evaluations of alternative fumigants were conducted in 2000 and 2001, in a low-elevation (390 feet) nursery at Ballico in Merced County and in a high-elevation (4,200 feet) nursery at Macdoel in Siskiyou County (fig. 1). Commercial-grade formulations of fumigants were used.

The treatments evaluated at Ballico were: (1) a mixture of iodomethane and chloropicrin (50% IM + 50% CP) at 350 pounds per acre (lb/ac); (2) a mixture of methyl bromide and chloropicrin (57% MB + 43% CP) at 400 pounds per acre; and (3) an untreated control.

At Macdoel, the treatments evaluated were: (1) equal amounts of iodomethane and chloropicrin at 350 pounds per acre; (2) methyl bromide plus chloropicrin at 400 pounds per acre (57% MB + 43% CP); (3) chloropicrin alone at 300 pounds per acre followed by (fb) 250 pounds per acre of dazomet (DZ); (4) 1,3-D plus chloropicrin (61% 1,3-D + 35% CP) at 392 gallons per acre followed by 250 pounds per acre of dazomet; and (5) an untreated control.

The fumigants were shank-injected and the soil was simultaneously covered with plastic film that was left in place for 7 days. The day after the film was removed at Macdoel, dazomet was applied to treatments 3 and 4 using a granular spreader and incorporated with sprinkler irrigation according to label directions. The strawberry variety 'Camarosa' was used in all studies, primarily because it accounted for approximately 40% of the California strawberry acreage when this study was conducted (Hokanson and Finn 2000) and is grown in both Oxnard and Watsonville fruit-production areas.

Strawberry plants produced at the Ballico low-elevation nursery were harvested and used to plant the high-elevation experiment at Macdoel (fig. 1). Plants produced at the Macdoel nursery were harvested and used to plant plots located in commercial strawberry fields at Oxnard and Watsonville, where fruit production was evaluated. In the experimental design, plants from all three Ballico treatments were planted in all plots at Macdoel. Plants from all five treatments at Macdoel were planted at Oxnard and Watsonville in soils fumigated with chloropicrin, and with methyl bromide plus chloropicrin. Equal numbers of plants were established in each plot at the beginning of every experiment.

Careful tracking of the strawberry plants produced on soils treated with iodomethane plus chloropicrin or with methyl bromide plus chloropicrin, or untreated soils at Ballico, allowed us to measure whether plant productivity at the Macdoel high-elevation nursery was affected by Ballico low-elevation fumigant treatments (fumigant carryover effect). Similarly, the tracking of plants from the five Macdoel fumigation treatments to the fruiting fields in Oxnard and Watsonville allowed us to measure the effects of high-elevation nursery fumigation on fruit yield (table 1).

TABLE 1. Study parameters for strawberry growing periods

Location	Trial type*	Fumigation date	Plant source	Plant date	Harvest date
Ballico	LEN	Apr. 25, 2000	MB + CP stock	May 12, 2000	Jan. 15, 2001
Macdoel	HEN	Aug. 26, 2000	Ballico trial 1	April 20, 2001	Oct. 2, 2001
Watsonville	Fruit	Sept. 27, 2001	Macdoel trial 2	Oct. 26, 2001	Mar. 19–Aug. 7, 2002
Oxnard	Fruit	Aug. 17, 2001	Macdoel trial 2	Oct. 8, 2001	Feb. 5–June 24, 2002

*LEN = low-elevation nursery, HEN = high-elevation nursery; both produce runner plants.

Efficacy evaluation. Fumigant efficacy was evaluated by burying pathogen and nematode samples before fumigation, retrieving the samples after fumigation, and determining the viable percentage. Sachets containing inoculum of *Phytophthora cactorum* (causes Phytophthora crown rot), *Pythium ultimum* (part of a pathogen complex that causes black root rot), *Verticillium dahliae* (causes Verticillium wilt) and citrus nematode (*Tylenchulus semipenetrans*) were buried 6, 12, 24 and 36 inches deep at two locations in each plot (only the 12- and 36-inch data are discussed here; they are representative of the shallow and deep samples, respectively).

Weed control. Two methods were used to assess weed control: (1) prior to each hand-weeding event, weed densities were measured in two or four randomly selected, 0.25-square-meter samples per plot; and (2) the effect of treatments on hand-weeding was determined by measuring the time required for an experienced fieldworker to hand-weed one row 150 feet long. The cooperating growers determined when cultivation or hand-weeding would be conducted. Season-long totals for weed density were used for statistical analysis.

Data analysis. Means and standard errors for the pathogen-sample survival data were determined using an Excel spreadsheet. Weed control, runner-plant production and fruit yield data were subjected to analysis of variance using SAS statistical software, and mean separation was performed using Duncan's multiple range test at the 5% level of significance.

Soil pathogen control

Citrus nematode. Citrus nematodes in the sachets were killed by iodomethane plus chloropicrin, and methyl bromide plus chloropicrin, at Ballico (data not shown). At Macdoel, 1,3-D plus chloropicrin followed by dazomet controlled citrus nematode, and a small number of nematodes survived the treatments with iodomethane plus chloropicrin and with methyl bromide plus chloropicrin, but chloropicrin followed by dazomet did not control nematodes (fig. 2).

P. cactorum. *P. cactorum* in the sachets was killed by iodomethane plus chloropicrin at 350 pounds per acre to a depth of 36 inches at both nurseries. The methyl bromide–plus-chloropicrin standard controlled *P. cactorum* to 24 inches at Ballico (not shown) and 36 inches at Macdoel. Chloropicrin followed by dazomet controlled the pathogen to 12 inches and 1,3-D plus chloropicrin followed by dazomet controlled *P. cactorum* down to 36 inches.

P. ultimum. All of the fumigant treatments controlled *P. ultimum* at both nursery locations.

V. dahliae. Iodomethane plus chloropicrin controlled *V. dahliae* to 12 inches at Ballico and Macdoel, with 2% or less survival at 24 and 36 inches at both locations. Methyl bromide plus chloropicrin controlled *V. dahliae* to 12 inches at Ballico and 36 inches at Macdoel. Chloropicrin followed by dazomet controlled *V. dahliae* to 12 inches, but 1,3-D plus chloropicrin followed by dazomet did not control this pathogen fully at any depth.

Soil samples. In addition to the pathogen sample bags installed in the plots, bulk soil samples were taken before and after fumigation at Ballico and Macdoel to measure control of pathogens in the field soil. Prefumigation populations of *P. cactorum* were low at both sites, but *P. ultimum* was more abundant. All but the iodomethane-plus-chloropicrin treatment completely controlled *P. ultimum* populations in Macdoel (IM + CP had 7% survival). All fumigation treatments at Macdoel, except 1,3-D plus chloropicrin, fully controlled *V. dahliae* present in bulk soil at depths of 0 to 8 inches; 1,3-D plus chloropicrin reduced survival by approximately 85% (Duniway, unpublished).

Weed control

Common weeds at the Ballico low-elevation nursery were carpetweed (*Mollugo verticillata*) and prostrate spurge (*Euphorbia humistrata*). The iodomethane-plus-chloropicrin and methyl bromide–plus-chloropicrin treatments reduced densities of these weeds compared to the untreated control, and weed densities did not differ significantly between these two treatments (table 2). All fumigants tested at the Macdoel high-elevation nursery reduced hairy nightshade (*Solanum sarrachoides*) and pigweed (*Amaranthus* spp.) densities compared to the untreated control, and none of the alternative fumigants differed from methyl bromide plus chloropicrin in effect.

Less time was required to hand-weed the plots treated with methyl bromide plus chloropicrin or iodomethane plus chloropicrin at the

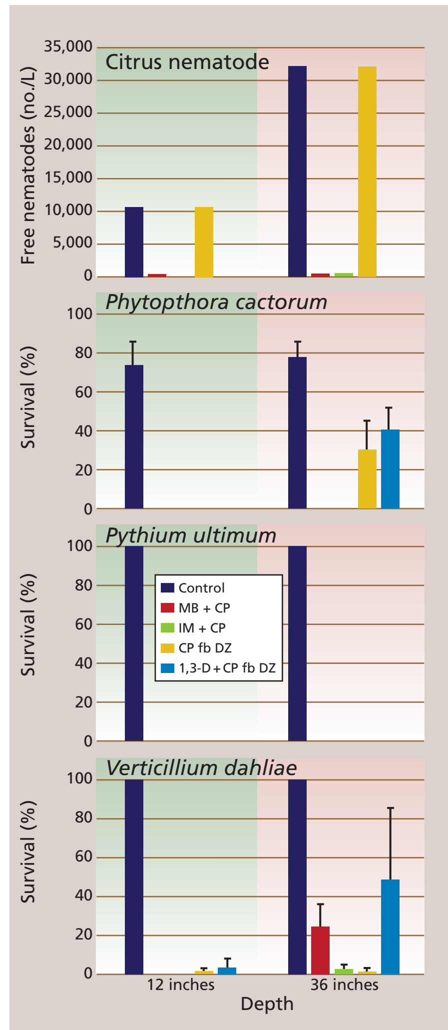

Fig. 2. Survival of citrus nematode (*Tylenchulus semipenetrans*), *Phytophthora cactorum* (causes Phytophthora crown rot), *Pythium ultimum* (part of a pathogen complex causing black root rot) and *Verticillium dahliae* (causes Verticillium wilt) buried at 12 and 36 inches at Macdoel in August 2000, with fumigation prior to the 2001 production season. Standard errors are plotted for all pathogens, and are shown.

TABLE 2. Effect of alternative fumigants on season-long weed densities at Ballico low-elevation and Macdoel high-elevation nurseries

Ballico 2000				
Treatment*	Rate	Carpetweed	Prostrate spurge	Hand-weed time
	· · · lb/acre · · ·	· · · · · · · · · · · · no./m² · · · · · · · · · · · ·		· · · · · hr/acre · · · ·
IM + CP	350	0.0 b†	17.0 b	57.8 b
MB + CP	400	0.5 b	35.8 b	45.3 b
Untreated	0	160.8 a	324.8 a	93.2 a

Macdoel 2001				
Treatment	Rate	Hairy nightshade	Pigweed	Hand-weed time
	· · · lb/acre · · ·	· · · · · · · · · · · · · no./m² · · · · · · · · · ·		· · · · · hr/acre · · · ·
IM + CP (50:50)	350	0.0 b	0.3 b	3.8 b
MB + CP (57:43)	400	0.0 b	0.0 b	3.7 b
CP followed by (fb) DZ	300 fb 250	0.0 b	0.0 b	3.8 b
1,3-D + CP (61:35) fb DZ	392 fb 250	0.0 b	0.0 b	4.0 b
Untreated	0	10.8 a	8.3 a	23.1 a

* IM + CP = iodomethane plus chloropicrin; MB + CP = methyl bromide plus chloropicrin; CP fb DZ = chloropicrin followed by dazomet; 1,3-D + CP fb DZ = 1,3-dichloropropene plus chloropicrin followed by dazomet.
† Means sharing the same letters within a column are not different according to Duncan's multiple range test (*P* = 0.05).

low-elevation nursery compared to untreated plots, and the weeding times between plots treated with methyl bromide plus chloropicrin and iodomethane plus chloropicrin did not differ significantly (table 2). At the high-elevation nursery, weeding times were similar for all fumigants, and all fumigated plots had lower weeding times than the untreated plots.

Plant yield and economics

Runner-plant yields per acre at the low-elevation nursery (Ballico) in plots treated before planting with iodomethane plus chloropicrin (626,300 plants) did not differ significantly from those treated with methyl bromide plus chloropicrin (705,300 plants), and both fumigation treatments yielded more plants than the untreated plots (292,700 plants). At the high-elevation nursery (Macdoel), all of the preplant fumigation treatments significantly increased plant production to similar levels (452,200 to 486,600 plants), which were greater than the numbers produced in the nonfumigated control soil (355,900 plants). No carryover effects from the low-elevation nursery were detected in plant yields at the high-elevation nursery. Similarly, Larson and Shaw (2000) found that the greatest effects of fumigants were on the "final runner propagation cycle" or high-elevation nursery, rather than carryover effects.

Methyl bromide plus chloropicrin had the highest net return per acre. Treatment costs, hand-weeding costs and yields varied, while other costs and the price of plants were assumed to be identical across treatments. Net returns per acre were $9,906 lower for the untreated control than for methyl bromide plus chloropicrin at Macdoel, which was a decline of 23.8%. Net returns per acre for iodomethane plus chloropicrin were $942 lower than those for methyl bromide plus chloropicrin, a reduction of 2.3%. Net returns per acre for chloropicrin followed by dazomet were $944 lower (2.3%), and net returns for 1,3-D plus chloropicrin followed by dazomet were $2,539 lower (6.1%) than those for methyl bromide plus chloropicrin.

For the fumigation treatments, these differences were relatively small in percentage terms, due largely to differences in treatment costs. If the relative price of methyl bromide plus chloropicrin became higher or the cost of the other treatments went down, then the differences in net returns per acre would be smaller. If the price of methyl bromide plus chloropicrin increased by 50%, then the average net returns per acre for iodomethane plus chloropicrin, and chloropicrin followed by dazomet, would be virtually identical to the methyl bromide–plus-chloropicrin net returns per acre.

Because all of the fumigation treatments had weeding times that were significantly lower than those for the untreated plot but not significantly different from each other, and because all of the fumigation treatments had yields that were significantly higher than those of the untreated plot but not significantly different from each other, differences in net returns per acre were driven largely by differences in treatment costs.

Fruit production evaluation

Plants harvested on Oct. 2, 2001, at the high-elevation Macdoel nursery were transplanted to commercial fruit production fields near Oxnard and Watsonville about 1 week after harvest. To determine whether nursery treatment influenced responses to fruiting field treatments, half of the plots at Oxnard and Watsonville were fumigated with chloropicrin and the other half with methyl bromide plus chloropicrin (Kabir et al. 2005). At both sites, fruit yields were higher in the soils fumigated with methyl bromide plus chloropicrin than with chloropicrin alone (table 3).

Fumigants used at the Macdoel nursery did not affect fruit yields at Oxnard or Watsonville, with one exception: plants at Macdoel on soil previously fumigated with chloropicrin followed by dazomet and transplanted

TABLE 3. Marketable strawberry fruit yields at Oxnard and Watsonville in soils fumigated with MB + CP or CP alone

Macdoel fumigant*†	Local fumigant	Oxnard‡	Watsonville
		· · · · · grams/plant · · · · ·	
MB + CP	MB + CP	585.3 a	1,474.0 bc
Untreated	MB + CP	569.9 ab	1,520.3 ab
IM + CP	MB + CP	579.4 ab	1,526.8 ab
CP fb DZ	MB + CP	582.4 a	1,634.5 a
1,3-D + CP fb DZ	MB + CP	575.4 ab	1,434.1 bcd
MB + CP	CP	517.5 c	1,235.8 e
Untreated	CP	520.4 c	1,301.7 de
IM + CP	CP	527.1 c	1,278.2 de
CP fb DZ	CP	524.9 c	1,388.4 bcde
1,3-D + CP fb DZ	CP	544.9 bc	1,346.4 cde

* Indicates 2001 fumigation of runner plants in nursery; local fumigant column indicates fumigation in Oxnard or Watsonville fruiting fields.
† See table 2 for abbreviations and application rates.
‡ Means sharing the same letters within a column are not different according to Duncan's multiple range test (*P* = 0.05).

into soils fumigated with methyl bromide plus chloropicrin at Watsonville yielded significantly more marketable fruit than plants grown on methyl bromide plus chloropicrin at both the Macdoel nursery and Watsonville fruiting field (table 3). The failure to detect a loss in fruit yield on the plants produced on untreated soils at Macdoel may be due to the fact that the high-elevation nursery's field was relatively clear of soilborne pathogens, and runner plants of conventional commercial quality were selected for transplanting (Kabir et al. 2005).

Methyl bromide replacements

Based on these production and pest management evaluations, the alternative fumigants evaluated here are all potential replacements for methyl bromide in runner-plant nurseries. However, the economic analysis suggests that methyl bromide plus chloropicrin is still most cost-effective (although the differences were small in percentage terms) and that nursery plant producers could be at an economic disadvantage when the methyl bromide phase-out is fully implemented. The international competitiveness of strawberry nursery production may also change based on whether producers in other countries can continue to produce strawberry plants with methyl bromide.

The relative economic performance of the alternative treatments will depend on the relative cost of methyl bromide compared to the price of the alternative fumigants. The sequential application of chloropicrin (300 lb/ac) or 1,3-D plus chloropicrin (392 lb/ac) for pathogen control, followed by dazomet (250 lb/ac) for weed control, in the nurseries resulted in runner-plant production equivalent to the standard methyl bromide–plus-chloropicrin treatment. The mixture of iodomethane plus chloropicrin resulted in plant yields in the low- and high-elevation nurseries that were similar to methyl bromide plus chloropicrin.

However, iodomethane is not yet registered as a soil fumigant in California, and further research is needed to optimize the iodomethane-plus-chloropicrin mixture and rates for the management of specific soilborne pests. Treatment with iodomethane plus chloropicrin, chloropicrin followed by dazomet, and 1,3-D plus chloropicrin followed by dazomet all provided runner plants of sufficient quality and vigor to support fruit yields in commercial production fields similar to the standard nursery fumigation treatment, methyl bromide plus chloropicrin.

Fruit yields from nursery stock produced on soils previously fumigated with chloropicrin followed by dazomet were comparable to methyl bromide plus chloropicrin. At the high-elevation nursery, chloropicrin followed by dazomet was the more promising alternative treatment, and net returns were within 3.5% of methyl bromide plus chloropicrin. The lower fruit yields of chloropicrin-only plants compared to methyl bromide–plus-chloropicrin plants at Oxnard and Watsonville suggest that chloropicrin alone at the rates used is not an acceptable substitute for methyl bromide in fruit production fields (Kabir et al. 2005).

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Food safety and environmental quality impose conflicting demands on Central Coast growers

by Melanie Beretti *and* Diana Stuart

Growers of leafy greens and vegetables must balance the need to improve water quality and wildlife habitat in and around farms, with concerns about food safety.

Growers of fresh produce on the Central Coast of California currently face conflicting demands regarding measures to protect food safety and those to protect environmental quality. To explore the extent of conflicting pressures and identify the range of possible impacts on the environment, we conducted a survey of Central Coast irrigated-row-crop growers during spring 2007. The results indicate that growers are experiencing a clear conflict, and some are incurring economic hardships because their practices to protect the environment have resulted in the rejection of crops by buyers. In addition, some growers are being encouraged to or are actively removing conservation practices for water quality, and most growers are taking action to discourage or eliminate wildlife from and adjacent to croplands. These actions could affect large areas of land on the Central Coast and, as indicated by growers, they are likely to increase over time.

The Central Coast of California supports unique biodiversity and some of the most productive agricultural lands in the United States. The Salinas Valley in Monterey County, often referred to as the "Salad Bowl of America," produces the majority of the nation's lettuce. Since the 1990s, food safety has become increasingly important, especially with respect to outbreaks of *E. coli* O157:H7 associated with leafy greens: lettuce, escarole, endive, spring mix, spinach, cabbage, kale, arugula and chard (see www.caleafygreens.ca.gov).

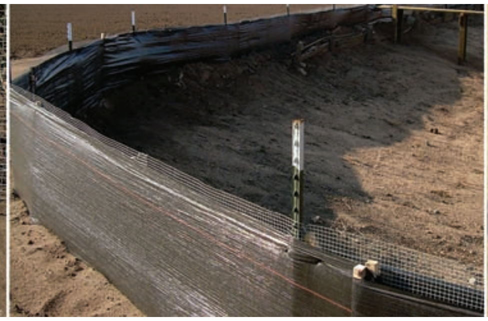
Simultaneously, growers on the Central Coast face increasing demands to protect the environment and have taken a proactive approach to improve environmental quality. An important aspect of these efforts is the adoption of conservation practices, which aim to improve and protect water quality, prevent soil erosion, reduce the use of agricultural chemicals and protect wildlife. However, some food safety requirements — or field-level interpretations of these requirements — conflict with management practices intended to improve water quality and enhance natural habitat.

In response to grower concerns over contradictory guidelines and requirements for food safety and environmental protection, the Resource Conservation District (RCD) of Monterey County conducted a mail survey of 600 irrigated-row-crop growers throughout the Central Coast. The purpose was to better understand the impacts of conflicting demands on growers, and to provide information to aid attempts to reconcile the goals of food safety and environmental protection.

Protecting environmental quality

The Central Coast contains some of the greatest biodiversity of any temperate region in the world. At its heart is the Monterey Bay National Marine Sanctuary, the largest marine sanctuary in the United States, and the Elkhorn Slough National Estuarine Research Reserve.

While the Central Coast houses many natural resources, according to the Central Coast Regional Water Quality Control Board (CCRWQCB), it also has some of the most polluted waters in California. The Pajaro River and Elkhorn Slough are listed as impaired for sediment and nutrients under California's 2002 Section 303(d) of the 1972 Clean Water Act. The Salinas River is 303(d)-listed as impaired for sediment, nutrients, pesticides and pathogens. In 2003, the 20-year-old state Agricultural Waiver of Nonpoint Source Discharge ended, meaning that growers are no longer exempt from water qual-


Mule deer/U.S. Department of the Interior

***Left*, a poison bait trap and fence to keep small animals out of fields; *center*, a small mammal/amphibian exclusion fence constructed around a tail-water recovery pond; *right*, mule deer. In the survey, a Central Coast grower could not sell $17,500 worth of crops because a food safety audit found deer tracks near the field.**

ity laws. In response, the CCRWQCB adopted a Conditional Waiver Program in 2005, which requires growers to enroll in the program, attend water-quality training sessions, adopt farm water-quality management plans, complete management practice checklists and participate in water quality monitoring (Cal EPA 2007).

An important aspect of these efforts is the adoption of conservation practices, which aim to improve and protect water quality, prevent soil erosion, reduce the use of agricultural chemicals and protect wildlife. Vegetation on and around farmland is a key component, including vegetated field borders, grassed waterways, riparian buffers and constructed wetlands. For the past decade, the Central Coast farming community has been proactively working with resource agencies to develop and implement voluntary conservation practices to improve water quality and reduce water consumption through the adoption and implementation of the Monterey Bay National Marine Sanctuary's Agricultural and Rural Lands Plan (MBNMS 1999). Adoption of these practices has now become a key component for compliance with the CCRWQCB's Conditional Waiver Program.

Protecting food safety

Since the late 1990s, government agencies, researchers and the produce industry have worked to develop and implement voluntary guidelines, or Good Agricultural Practices, to minimize the risk of food contamination (FDA 1998; Bihn 2004). These practices aim to protect consumer health at all levels of leafy greens production and distribution, and they have become increasingly important in light of recent outbreaks. The September 2006 outbreak of *E. coli* O157:H7 associated with bagged spinach from the Central Coast resulted in the loss of three lives and caused more than 200 illnesses. This outbreak affected consumers in 26 states, drawing national attention (CDC 2006) and acting as a catalyst for rapid change in food safety protection efforts for leafy greens. Despite an intensive investigation, the U.S. Food and Drug Administration (FDA) and the California Department of Health Services (CDHS) have not been able to conclusively determine the specific causes of the spinach outbreak (CDHS/FDA 2007).

In early 2007, with oversight by the California Department of Food and Agriculture (CDFA), produce industry representatives developed the California Leafy Green Products Handler Marketing Agreement (see www.caleafygreens.ca.gov). More than 100 handlers (companies that move fresh produce products from growers to retail and food-service buyers) are signatories. Representing more than 99% of the leafy greens production in California, they are obligated to handle leafy green produce only from growers who adhere to the best management practices detailed in the Commodity Specific Food Safety Guidelines for the Production and Harvest of Lettuce and Leafy Greens, known as the "Metrics" (see www.caleafygreens.ca.gov). The Metrics were developed and continue to be updated through a process involving the produce industry, government agencies, natural resource organizations and scientists.

In addition to the Metrics, many companies and retailers who handle or sell leafy greens have developed their own company-specific food safety requirements, which also affect farm management practices. Because growers often sell their crops to multiple buyers, most now must meet at least one if not several different sets of requirements. In addition, field interpretations of the Metrics and company-specific guidelines vary. Depending on the size and type of operation, a grower may conduct self-audits as well as undergo food safety inspections and audits by the CDFA, processors, grower-shippers or third-party auditors representing the companies that purchase their products.

Specific measures stated or implied in the Metrics and company-specific requirements may potentially conflict with efforts to improve and protect water quality and support wildlife habitat. For example, the Metrics identify "animals of significant risk" for contaminating crops and provide remediation guidelines. Measures to deter animals and comply with food safety requirements, such as fencing and bare-ground buffers around fields, can also result in adverse impacts to the environment. This may include the alteration or elimination of wildlife habitat, including the removal of surrounding vegetation. Noncrop vegetation is a key component of conservation practices such as field borders, grassed waterways and riparian buffers. Because vegetation provides water filtration and absorption, and reduces the deposition of sediment and pollutants into waterways, widespread vegetation removal could have significant environmental impacts.

Mail survey to row-crop growers

The Monterey County RCD conducted a mail survey in spring 2007, which was co-sponsored by the Grower-Shipper Association of Central California, the Central Coast Agriculture Water Quality Coalition and the Monterey County Agricultural Commissioner's office. The survey packet and cover letter were mailed to

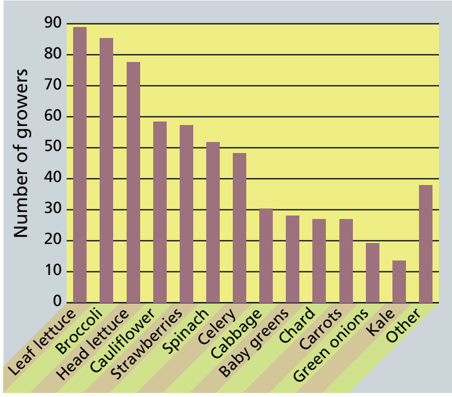


Fig. 1. Number of respondents who grow each commodity; most grow more than one crop.

TABLE 1: Responding growers who have adopted specific conservation practices (n = 181; most growers adopted more than one)

Conservation practice	Respondents
	%
Cover crop	72.1
Stormwater pond	38.5
Filter strip	36.3
Grassed waterway	33.5
Irrigation reservoir	30.2
Tailwater recovery pond	29.6
Hedgerow	25.7
Riparian restoration	18.4
Constructed wetland	6.1
Other	3.9

all 600 row-crop operations listed on the CCRWQCB Conditional Waiver Program's mailing list. These growers had operations in Monterey, San Benito, Santa Barbara, Santa Clara, Santa Cruz and/or San Luis Obispo counties. Three weeks following the initial mailing, a reminder postcard was sent to the entire mailing list.

The four-page survey contained 39 questions, consisting of multiple choice, yes/no, five-point Likert-scale and open-ended questions. Questions included details on farm operations, participation in conservation programs, the adoption of conservation practices, specifics about food safety requirements, information on how respondents are changing or have changed their practices, and opinion-oriented questions to allow respondents to make comments and voice concerns.

The survey also asked respondents about the circumstances under which they have had crops rejected by buyers and auditors due to food safety concerns as well as the economic impacts of these rejections. Growers were asked a series of questions related to food safety, and practices to protect water quality and the environment. The survey sought responses on three main categories of practices and/or natural features: (1) noncrop vegetation, (2) ponds or waterways and (3) wildlife.

Analysis of the results included descriptive statistics as well as the comparison of data between different groups of respondents. We looked at differences between respondents who indicated that they grow leafy greens and those who grow other crops. In addition, we explored how other characteristics such as operation size and type (conventional or organic) affect management decisions. We used the Pearson Chi Square statistic to test for significance.

Food safety vs. water quality

A total of 181 growers returned surveys, for a 30% response rate. Almost all respondents indicated that they grow more than one crop, primarily leaf lettuce, broccoli, head lettuce, cauliflower, strawberries, spinach, celery, cabbage and baby greens (fig. 1). Approximately 86% grow conventional only or both conventional and organic, whereas 13% were organic only.

More than 80% of the respondents met education requirements of the Conditional Waiver Program through attendance at the Farm Water Quality Planning Short Course and had completed Farm Water Quality Plans. Ninety-one percent (91.1%) had adopted one or more conservation practices aimed to improve water quality and/or wildlife habitat. Sixty-three percent (62.8%) had received technical assistance for water quality or habitat improvement projects from a local resource agency or expert such as the RCD or USDA Natural Resources Conservation Service. Cover cropping was the most common practice adopted by respondents (72.1%) (table 1).

TABLE 2: Survey responses (n = 181) regarding experiences with food safety audits, concerning the presence of noncrop vegetation, ponds/waterbodies and wildlife

Question	Affirmative responses
	%
"It has been suggested that I should remove *noncrop vegetation*"	18.6
"I have lost points on audit reports because of *noncrop vegetation*"	9.6
"It has been suggested that I should remove *ponds or waterbodies*"	9.5
"I have lost points on audit reports because of *ponds or waterbodies*"	10.8
"It has been suggested that I should remove *wildlife*"	39.0
"I have lost points on audit reports because of *wildlife*"	13.0

Crop rejection. Eight percent (8.0%) of growers reported that their crops had been rejected based on the presence of practices to improve water quality or wildlife habitat on the farm. Some of the explanations shared by respondents included:

- Lost $17,500 worth of crop due to deer tracks.
- 1 acre of romaine lettuce rejected due to proximity to horse pen.
- 23 acres of head lettuce and 2 acres of mixed lettuce rejected due to contact with Salinas River floodwater.
- Crop rejected due to potential frog habitat.
- Portions of fields rejected by processor if frogs, tadpoles, snails, mice or other small animals were found.
- Harvest stopped due to the presence of frogs and tadpoles in creek.
- Crop rejected due to deer intrusion.
- Crops planted for processor near trees needed a buffer of 100 to 150 feet.

In some cases crops were not rejected outright; however, growers responded that their buyers, auditors or others had suggested either discouraging or eliminating noncrop vegetation, water bodies and wildlife in and around fields. Growers reported they had lost points on food safety audits due to the presence of noncrop vegetation (9.6% of respondents), water bodies (10.8%) and wildlife (13%) near their crops (table 2). Growers also indicated that in some cases they acted in response to buyer/auditor suggestions and actively removed these features or adopted mitigation measures accepted by their auditors or buyers. In all three categories (noncrop vegetation, water bodies and wildlife), growers of leafy greens were more likely to have been told to discourage or eliminate these features than growers of other crops. In two of the three categories (noncrop vegetation and wildlife) leafy greens growers were

TABLE 3: Comparison of affirmative responses by leafy green versus nonleafy green growers (n = 181) to questions concerning the removal of conservation practices or natural features in or adjacent to cropland

Question	Growers of Leafy greens	Growers of Nonleafy greens
	.... %	
"It has been suggested that I should remove *noncrop vegetation*"	32.1*	2.8
"I have actively removed *noncrop vegetation* in response to comments by auditors or others"	32.1*	6.9
"It has been suggested that I should remove *ponds or water bodies*"	14.8*	3.0
"I have actively removed *ponds or water bodies* in response to comments by auditors or others"	7.4	6.0
"It has been suggested that I should remove *wildlife*"	47.7†	27.9
"I have actively removed *wildlife* in response to comments by auditors or others"	40.7*	23.5

* $P < 0.05$.
† $P < 0.10$.

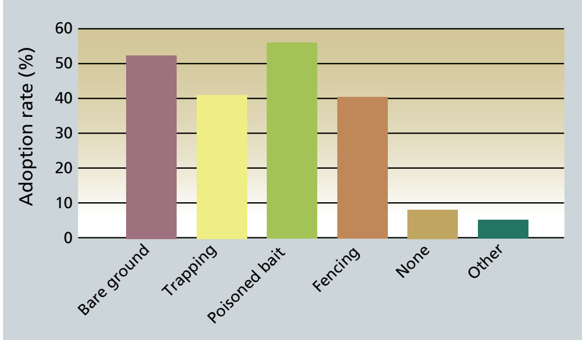


Fig. 2. Percentage of respondents who indicated they have adopted specific mitigation measures for wildlife.

significantly ($P < 0.05$) more likely than growers of other crops to have acted on these suggestions (table 3).

Conservation practice abandonment. Approximately 15% of all growers surveyed indicated that they had removed or discontinued the use of previously adopted conservation practices in response to suggestions made by auditors or buyers due to food safety concerns. Growers of leafy greens were significantly ($P < 0.05$) more likely to have taken out conservation practices than other growers: 21.1% indicated that they had actively taken out one or more conservation practices due to food safety concerns, as compared to 7.4% that grow nonleafy green crops.

Practices that had been removed or were planned for removal included: (1) ponds and/or reservoirs (such as irrigation reservoirs, duck habitat and ponds); (2) irrigation reuse systems (such as tail-water recovery ponds and water reuse); and (3) noncrop vegetation (such as grassed waterways, filter/buffer strips and trees/shrubs). In addition, some growers stated that although they had not yet removed conservation practices, they were planning to or felt they would be required to in the near future. Several respondents suggested that a follow-up survey would reveal more changes being made.

Wildlife exclusion. Some 88.9% of the survey respondents indicated that they had adopted at least one measure to actively discourage or eliminate wildlife from cropped areas (fig. 2). The most commonly adopted measures were: bare-ground buffers, fencing, trapping and poisoned bait stations. Bare-ground buffers and poisoned bait stations were each used by more than half of the respondents to protect crops from wildlife intrusion. Trapping and fencing were each used by approximately 40%. Growers of leafy greens were significantly more likely to be using bare-ground buffers ($P < 0.05$), poisoned bait stations ($P < 0.05$) and traps ($P < 0.01$).

Growers most affected. Results from the survey suggest that the conflict between food safety and environmental protection disproportionately affects respondents who sell to shippers and packers, operate on more than 500 acres and grow conventionally (as opposed to organic only). Of respondents who had removed conservation practices, 87.8% sell to shippers and packers, whereas only 67% of all respondents sold to shippers and packers. Of respondents who had removed conservation practices 89% operate more than 500 harvested acres, whereas only 39% of all respondents operated more than 500 harvested acres.

In addition, large farm operators (> 500 acres) were significantly ($P < 0.05$) more likely to have been told to eliminate wildlife and waterways and significantly more likely to have adopted mitigation measures. Of the respondents who had removed conservation practices, 100% grew conventionally (conventional, and conventional and organic operations), whereas 86% of all respondents grew conventionally.

Acreage affected. The growers who responded to the survey manage more than 140,000 acres of row-crop land on the Central Coast. Of these, those who had actively removed conservation practices for water quality or wildlife habitat (in response to suggestions by food safety auditors or others) manage nearly 30,000 acres. In addition, respondents who had adopted measures to actively deter or eliminate wildlife manage more than 133,000 acres. Survey respondents that use bare-ground buffers manage 91,890 acres (65% of the total land reported); trapping manage 87,279 acres (62%); poisoned bait stations manage 108,283 acres (77%); and fencing manage 66,380 acres (47%).

Grower comments. More than 30% of all respondents also chose to share their personal opinions and concerns at the end of the survey. These comments indicated that many growers face serious pressure regarding food safety, and they are concerned about doing things that may have negative impacts on the environment. Their responses suggested that in many cases growers have little choice in their management practices and must be responsive to buyers' and auditors' suggestions in order to sell their crops. For example, one grower wrote: "I am afraid many positive environmental programs and practices are going to be abandoned due to retailers'/shippers' new food safety practices. I am all for the environment and safe food, but feel many new food safety ideas are being driven by fear and uncertainty rather than sound science."

And another wrote: "Our experience has been that the food safety auditors have been very strict about any vegetation that might provide habitat. We are very concerned about upsetting the natural balance, but we have to comply with our shipper's requests."

Conflict on the Central Coast

The survey results illustrate that growers are in the middle of a clear conflict between current food safety standards and continued efforts to address water quality and environmental concerns on the Central Coast. It appears that growers of leafy greens who operate larger acreages are especially affected by food safety concerns; however, other growers are also affected to a lesser extent. Growers are incurring economic hardships due to the rejection of crops based on the presence of practices to protect the environment. Some growers are encouraged to or are actively removing conservation practices in response to food safety audits and concerns. Many growers are taking action to discourage or eliminate wildlife and other noncrop vegetation. These actions could have impacts over large areas of land in the region. In addition, comments from growers indicated that these actions are likely to increase over time as food safety standards become more established. The survey also indicated that growers are concerned about being put in the unfair position of choosing between being able to sell their crops or protecting the environment.

Growers are concerned about being put in the unfair position of choosing between being able sell their crops or protecting the environment.

Protecting human health and insuring the viability and sustainability of California agriculture demands safe food, clean water and biodiversity. However, the virulence of *E. coli* O157:H7 coupled with the consumption of raw leafy greens poses an unprecedented challenge to the produce industry. Our survey results indicate that current practices to address food safety in the field may result in environmental concessions including habitat loss, degradation and continued water-quality impairment. The removal of noncrop vegetation, for example, can include common conservation practices such as filter or buffer strips, grassed waterways, riparian habitat, natural lands, hedgerows and windbreaks. Discouraging or actively removing these features will have negative environmental impacts and, in some cases, could actually *increase* the risk of crop contamination (Stuart 2006; Stuart et al. 2006).

For example, contamination in overland water flows may be reduced by filtration through perennial forage or grasses (Tate et al. 2006). Vegetated treatment systems (such as grassed waterways and vegetated basins) have also been shown to reduce the presence and transport of pathogens (Kadlec and Knight 1996; Koelsch et al. 2006). Lastly, constructed wetlands have been found to effectively remove pathogens in water through filtration in dense vegetation, sedimentation, microbial competition and predation, high temperatures, and UV disinfection (Hench et al. 2003; Nokes et al. 2003; Greenway et al. 2005). Given the results of these studies, further evaluation of food safety standards requiring the removal of vegetation may be necessary.

Scientific uncertainty plays a significant role in the current conflict, particularly regarding animal sources of *E. coli* O157:H7. Although studies agree that cattle (Hancock et al. 1998; Chapman et al. 1997) and some commensal wildlife species (associated with humans) are known sources of *E. coli* O157:H7 (Fenlon 1981; Meerburg et al. 2004), most studies on pastoral wildlife (associated with natural environments) do not illustrate a substantial threat to food safety. Studies looking at pastoral small mammals and deer showed minimal prevalence of *E. coli* O157:H7 (Hancock et al. 1998; Sargeant et al. 1999; Fischer et al. 2001). Studies also indicate that there is a very low probability (0–1%) that birds associated with natural environments will carry pathogenic bacteria that could contaminate food crops (Brittingham et al. 1988; Hancock et al. 1998). More recently, *E. coli* O157:H7 was isolated in feral swine near spinach fields and cattle on the Central Coast following the 2006 spinach outbreak (Jay et al. 2007). Deer and geese residing in high densities in watersheds heavily populated by humans and dairies have been identified as sources of *E. coli* O157:H7 in New York state (Somarelli et al. 2007). Despite these studies, there is still much uncertainty regarding the role of wildlife specific to the Central Coast region.

New scientific studies are already under way to investigate the role of wildlife and vegetation in food safety, as well as other sources and vectors of *E. coli* O157:H7 on the Central Coast. Although new studies will improve our understanding of risks to food safety, they will not be able to provide 100% certainty or eliminate all possible sources of contamination. Therefore, it becomes essential to weigh relative risks and focus attention and resources on the most likely sources of contamination. How current and future standards affect the risk of contamination should be evaluated. For example, conservation practices that have been shown to reduce the presence and transport of human pathogens could be an asset in meeting food safety goals. Keeping produce as safe as possible is a critical goal; however, the means to achieve this goal should be carefully investigated to insure those measures actually reduce risks of crop contamination, do not increase other human health risks as a result of environmental degradation, and are cost-effective and practical to implement.

This survey was conducted during the spring of the first growing season following the development and adoption of the California Leafy Green Products Handler Marketing Agreement. Because food safety pressures have continued to intensify — with a proliferation of food safety guidelines and increased field audits — our results likely present a conservative estimate of the on-the-ground impacts of this conflict. As standards and measures are developed to protect food safety, government and industry leaders should be conscious of how these measures affect growers as well as the environment.

The process and standards for protecting food safety in leafy greens on the Central Coast of California set a precedent that will certainly be modeled for other crops and growing regions nationwide. As of January 2008, efforts were being put forth to develop a Federal Marketing Agreement and provide the foundation for a Federal Marketing Order for leafy greens. In addition, private industry and companies that buy fresh produce continue to develop mandatory field-level food safety requirements that go beyond the currently adopted Metrics.

Based on the survey results — and ongoing efforts of the agricultural community and local, state and national organizations — there is a clear need to alleviate conflicting pressures facing growers. Resolving this conflict will require an open dialogue between scientists, environmental and food safety organizations, and leaders in the produce industry to create management standards that support both food safety and environmental stewardship. We have the opportunity and responsibility to learn from this conflict on the Central Coast, and insure that our agricultural and natural resources are successfully co-managed for human and environmental health.

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Border strips around fields, shown on a Central Coast farm, help improve water quality by filtering runoff into and off of farmland. However, such strips may also create habitat for small animals, which may be perceived as a food safety risk.

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RESEARCH ARTICLE

Transition to conservation tillage evaluated in San Joaquin Valley cotton and tomato rotations

by Jeffrey P. Mitchell, Randal J. Southard, Nicholaus M. Madden, Karen M. Klonsky, Juliet B. Baker, Richard L. DeMoura, William R. Horwath, Daniel S. Munk, Jonathan F. Wroble, Kurt J. Hembree, *and* Wesley W. Wallender

We compared standard tillage (ST) and conservation tillage (CT) for tomato and cotton production systems, with winter cover crops (CC) and without (NO), in Five Points, Calif., from 1999 to 2003. Conservation tillage reduced tractor trips across the field by 50% for tomatoes and 40% for cotton compared to standard tillage. When averaged over the 2001 to 2003 period (when the conservation tillage systems were established), tomato yields in CTNO were 6 to 8 tons per acre higher than the other treatments. In cotton, the STNO cotton yields during this period were the highest of all treatments and were 276 pounds per acre higher than the CTNO system. In-field dust concentrations were also significantly reduced by conservation tillage. Our results suggest that conservation tillage may be a viable alternative for managing tomato and cotton crops in the San Joaquin Valley, but that fine-tuning of the systems is needed.

Conservation tillage allows growers to reduce the number of times that tractors are run through their fields, for savings in time, energy and labor. The authors studied how the practice, with and without cover crops, affects yields, dust production and other factors in a cotton-tomato rotation. *Above*, cotton grown in a cover crop.

In the San Joaquin Valley, cotton and tomato production systems rely on considerable intercrop tillage to prepare the soil for seeding. Tillage clears the soil surface of residues, permits greater soil warming in the spring and clean harvest conditions in the fall, and provides weed control. In cotton, tillage facilitates pink bollworm (*Pectinophora gossypiella*) pest control following harvest by mixing cotton residues with the soil. Many tillage practices, however, can be a significant production cost, a cause of soil organic matter losses and a source of particulate matter emissions.

On average, 9 to 11 separate tillage-related operations, each involving heavy equipment, are conducted during the fall through spring to prepare the soil for summer cropping in most current San Joaquin Valley cotton and tomato production fields. Deep tillage often is used in these systems to alleviate compaction that results from frequent tillage passes and harvest operations. These operations account for up to 20% of production costs (Carter 1996), and require high energy and increased subsequent effort to prepare seed beds.

The adoption of conservation tillage (CT), or reduced tillage practices, may be a viable means for improving field-crop production systems if their profitability and capacity to conserve natural resources can be demonstrated. In their many and varied forms, conservation tillage systems aim at reducing primary, intercrop tillage operations such as plowing, disking, ripping and mulching. As a result of these deliberate reductions in tillage, surface residues may accumulate and must be managed, and new techniques for crop establishment must be developed. Despite the potential attractiveness and utility of reduced-tillage production alternatives, conservation tillage adoption rates in agronomic row crops are very low in California, less than 2% (CTIC 2004).

Reasons for California's low adoption rate include a lack of locally available conservation tillage equipment, inexperience with conservation tillage techniques, the predominance of surface, or gravity, irrigation systems and the fact that the tillage-intensive systems used in the San Joaquin Valley for several decades are generally quite productive (Mitchell et al. 2007).

Key

STNO	**standard tillage without cover crop**
STCC	**standard tillage with cover crop**
CTNO	**conservation tillage without cover crop**
CTCC	**conservation tillage with cover crop**

In tomato, yields were maintained or even slightly improved with conservation tillage.

CT field comparison

In fall 1999, we established a field comparison of conservation and standard tillage in cotton and tomato rotations, with and without winter cover crops, at the University of California West Side Research and Extension Center in Five Points, Calif. The objectives of the study were to compare conservation tillage and conventional tillage practices in crop rotations common to the San Joaquin Valley in terms of productivity and profitability, key soil quality indicators (Veenstra et al. 2006) and the quantity of dust produced. We report here aspects of how the tillage systems performed during the first 4 years of the study.

Conventional intercrop tillage practices that knock down and establish new beds following harvest were used in the standard tillage (ST) systems (tables 1 and 2). The conservation tillage systems were managed from the general principal of trying to reduce primary, intercrop tillage to the greatest extent possible. Zone production practices that restrict tractor traffic to furrows were used in the conservation tillage systems, and planting beds were not moved or destroyed in these systems during the entire 4 years.

An 8-acre field in a map unit of Panoche clay loam (fine-loamy, mixed, superactive, thermic Typic Haplocambids) (Arroues 2006) was used for the study, and a uniform barley (*Hordeum vulgare*) crop was grown over the entire field before beginning the treatments. The field was divided into two halves with a processing tomato (*Lycopersicon esculentum*)/cotton (*Gossypium hirsutum* L.) rotation on one half and a cotton-tomato rotation on the other. Management treatments of standard tillage without cover crop (STNO), standard tillage with cover crop (STCC), conservation tillage without cover crop (CTNO) and conservation tillage with cover crop (CTCC) were replicated four times in a randomized complete block design on each half of the field. Treatment plots consisted of six beds, each measuring 30 feet by 270 feet. Six-bed buffer areas separated tillage treatments to enable the different tractor operations that were used in each system.

Cover crops. A cover crop mix of Juan triticale (*Triticosecale* Wittm.), Merced ryegrain (*Secale cereale* L.) and common vetch (*Vicia sativa*) was planted at a rate of 100 pounds per acre (30% triticale, 30% ryegrain and 40% vetch by weight) in late October in the standard and conservation tillage plus cover crop plots, and irrigated once in 1999. In each of the subsequent years, no irrigation was applied to the cover crops, which were planted in advance of any early winter rains. The cover crops were chopped in mid-March of the following years using a Buffalo Rolling Stalk Chopper (Fleischer, Neb.). In the STCC system, the chopped cover crop was disked into the soil to a depth of about 8 inches, and 5-foot-wide beds were reformed prior to tomato transplanting. The chopped cover crop in the CTCC system was sprayed with a 2% solution of glyphosate and left on the surface as a mulch.

Tomato. In the tomato-planted half of the field, plants of the variety '8892' were transplanted in the center of beds at an in-row spacing of 12 inches during the first week of April in each year, using a modified three-row commercial transplanter fitted with a 20-inch coulter ahead of each transplanter shoe. Treatments received the same fertilizer

TABLE 1. Comparison of standard (ST) and conservation tillage (CT) with and without cover crops for tomato ("X" indicates a separate instance of each operation)

	With cover crop		Without cover crop	
Operation	ST	CT	ST	CT
Shred cotton	X		X	
Undercut cotton	X		X	
Disk	XXXX		XX	
Chisel	X		X	
Level (triplane)	X		X	
List beds	XX		X	
Incorporate/shape beds	X		X	
Clean furrows		X		X
Shred bed		X		X
Spray herbicide trifluralin	X		X	
Incorporate trifluralin – rolling cultivator	X		X	
Spray herbicide glyphosate			X	X
Spray herbicide rimsulfuron	X	X	X	X
Cultivate – sled cultivator	XXX		XXX	
Cultivate – high residue cultivator		XXX		XXX
Plant tomatoes	X	X	X	X
Fertilize	XX	XX	XX	XX
Plant cover crop	X	X		
Mow cover crop	X	X		
Custom harvest	X	X	X	X
Total times over field	23	12	19	11

TABLE 2. Comparison of standard (ST) and conservation tillage (CT) with and without cover crops for cotton ("X" indicates a separate instance of each operation)

	With cover crop		Without cover crop	
Operation	ST	CT	ST	CT
Disk	XX		XX	
Chisel	X		X	
Level (triplane)	X		X	
List beds	X		XX	
Spray herbicide trifluralin	X		X	
Incorporate trifluralin – rolling cultivator	XX		XX	
Spray herbicide glyphosate	XX	XXXX	X	XXX
Cultivate – rolling cultivator	XX		X	
Chain beds	X	X		
Plant cotton	X	X	X	X
Fertilize	X	X	X	X
Plant cover crop	X	X		
Mow cover crop	X	X		
Spray insecticides/growth regulator	XX	XX	XX	XX
Spray defoliant	X	X	X	X
Spray insecticides	XX	XX	XX	XX
Custom harvest	X	X	X	X
Total times over field	23	15	19	11

With conservation tillage, tractor trips were reduced about 50% for tomato and 40% for cotton at the Five Points study site. *Above*, processing tomatoes are transplanted into cotton and cover crop residues.

applications, with dry fertilizer (11-52-0 NPK) applied preplant at 100 pounds per acre. Additional nitrogen (urea) was side-dress applied at 125 pounds nitrogen per acre in two lines about 7 inches from the transplants and about 6 inches deep, about 4 weeks after transplanting.

Cotton. The RoundUp Ready (glyphosate-resistant) upland cotton (*Gossypium hirsutum*) variety 'Riata' was used each year in all cotton systems and was established using a John Deere (Moline, Ill.) 1730 No-till Planter. Cotton was planted in two lines on the same 5-foot "permanent" beds that were not broken down and reshaped following tomatoes, as is customarily done and as we did in our standard tillage plots, which were disked down and reworked into 30-inch beds for cotton. The preemergent herbicide trifluralin (Treflan) was applied and soil-incorporated twice as is the regional custom, to better mix the chemical with the soil. An application of 140 pounds of urea fertilizer per acre was made in each year in each system, using a fertilizer shank fitted with an 18-inch coulter to cut residues about 10 inches to the side of plants and about 6 inches deep.

Tractor use. All tractor traffic was restricted to the furrows between planting beds in the conservation tillage systems; no tillage was done in the conservation tillage plots following tomatoes and preceding the next cotton crop, and only two tractor passes were conducted following cotton and preceding each subsequent tomato crop. These operations included shredding and uprooting the cotton stalks in order to comply with "plow down" regulations for pink bollworm control in the region and a furrow sweep operation to clean out furrow bottoms to improve irrigation water movement down the furrows.

In the 4-year study, researchers successfully established and harvested a cotton-tomato rotation using conservation tillage, with some equipment modifications. *Above*, a no-till cotton planter (into tomato residue) is evaluated and adjusted.

Yields. Tomato yields were determined in each year using field weighing gondola trailers following the commercial machine harvest of each entire plot. Cotton lint yields were determined using whole-plot seed cotton weights multiplied by gin turnout percentages determined on samples sent through the UC Shafter Research and Education Center research gin.

Dust. Total dust (TD) (< 100 μm [micrometers] aerodynamic diameter) and respirable dust (RD) (4 μm aerodynamic diameter) were collected on Teflon (PTFE) membrane filters suspended in the plume generated by field implements during each tillage operation in 2001 and 2002, in order to describe relative in-field dust production of each tillage system (Baker et al. 2005). The samplers were attached to each field implement about 15 inches above the ground surface, with the exception of the cotton harvester samples, which were placed at approximately 6 feet above the ground. The samplers were attached to battery-operated pumps operated at a flow rate of 2.2 liters per minute. Dust concentrations from each tillage or harvest operation were calculated from the mass of dust collected on preweighed filters, the pump air-flow rates and the duration of the operation. Cumulative dust concentrations for the four treatments were calculated by summing the mean values of all operations contributing to a particular treatment over a complete cotton-tomato rotation.

Data analysis. The data were analyzed as an unbalanced mixed model using SAS statistical software (SAS Institute 2003). This model took into account variability associated with switching crops (such as tomato-cotton, cotton-tomato rotation) on experimental plots nested in blocks year after year. Treatments were not analyzed as a factorial combination of cover crop and tillage. Therefore, simple and main factorial effects are inferred in this paper.

Trips across the field

During the 4 years of this study, the number of tractor trips across the field was reduced by about 50% for tomato (table 1) and 40% for cotton (table 2) in the conservation tillage systems relative to standard tillage. Differences in the tillage intensity between systems

TABLE 3. Cotton plant stand establishment for standard and conservation tillage systems with and without cover crops, Five Points

	2000	2001	2002	2003
	1,000 plants/acre			
Standard tillage no cover crop (STNO)	35.3 ab*	44.5 a	42.9 b	51.6 a
Standard tillage cover crop (STCC)	37.5 ab	44.3 ab	42.7 b	49.9 a
Conservation tillage no cover crop (CTNO)	43.1 a	45.3 a	45.8 a	51.9 a
Conservation tillage cover crop (CTCC)	32.5 b	43.3 b	32.4 c	40.8 b

* Different letters within columns indicate statistical significance at $P = 0.05$.

TABLE 4. Processing tomato yields for standard and conservation tillage systems with and without cover crops, Five Points

	2000	2001	2002	2003	Average 2001–2003
	tons/acre				
Standard tillage no cover crop (STNO)	58 a,a*	61 a,a	46 b,b	42 b,b	50 b†
Standard tillage cover crop (STCC)	53 bc,b	63 a,a	43 b,c	45 b,c	51 b
Conserv. tillage no cover crop (CTNO)	56 ab,b	64 a,a	56 a,b	54 a,b	58 a
Conserv. tillage cover crop (CTCC)	51 c,b	61 a,a	43 b,c	52 a,b	52 b

* First set of letters indicates least square means separation within year; second set within treatment. Different letters indicate statistical significance at $P = 0.05$.

† Least square means separation of averaged data takes into account between-year variations.

were due primarily to reductions in soil-disturbing operations commonly associated with postharvest land preparation, including disking, chiseling, leveling and relisting beds — operations that are typically performed in the fall.

The operations listed in tables 1 and 2 represent average sequences for all years; slight differences occurred in certain years. For instance, we originally performed two operations following cotton harvest in the conservation tillage systems: a one-pass Shredder-Bedder (Interstate Mfg., Bakersfield, Calif.) to shred and undercut the cotton plant, and a furrow sweeping operation using a Buffalo 6000 High Residue Cultivator (Fleischer Mfg., Columbus, Neb.) modified and fitted with only furrow implements. In 2003, however, we fitted our no-till tomato transplanter with furrow "ridging wings," and thereby cleared out residues from furrow bottoms at the time of transplanting.

The general conservation tillage approach pursued in this study was to more severely restrict tillage operations than is customarily done today. As a result, more residues accumulated on the soil surface, particularly in the CTCC systems, and this at least partly explains the lower numbers of cotton plants that were established in this system in each year relative to the STNO system (table 3).

In addition, we were initially concerned that residues would interfere with the action of the "over-the-top" tomato herbicide rimsulfuron (Shadeout), which can be sprayed after transplanting and sprinkled in to activate. By 2003, however, we used it in all systems with observed benefits. For conservation tillage cotton, we relied solely on one or two in-season applications of glyphosate; no cultivation was done in these systems. For tomatoes, we typically cultivated two to three times, but based on visual estimates of weed populations this did not achieve a comparable level of weed control in the conservation tillage systems as in the standard tillage systems in all years. This is one aspect of our conservation tillage approach that needs to be improved.

While the conservation tillage systems we employed in this study dramatically reduced overall tillage and soil disturbance relative to the standard tillage norms for the San Joaquin Valley, they by no means constitute what is customarily considered "no-till" production. In classic no-till, or "direct seeding" systems, crops are planted directly into residues and no additional soil disturbance is generally done prior to harvest. We employed an intermediate or incremental tillage reduction strategy in part to clear channels for the movement of irrigation water down furrows and in part to meet California Department of Food and Agriculture (CDFA) mandates for pink bollworm control in cotton. Current CDFA regulations require uprooting cotton roots postharvest and potentially some residue burial. Recent changes in the CDFA Pink Bollworm Management Program allow for reduced postharvest tillage in cotton fields with no pink bollworm findings, or in fields outside of a 9-square-mile radius from a pink bollworm trapping find. These changes should make it easier to adopt conservation tillage practices.

Crop performance

Tomato. Tomato yields during the first 4 years of this study were generally similar in the conservation tillage and standard tillage systems, with some years showing significant differences (positive and negative) (table 4). Processing tomato yields in 2000 were slightly lower in each of the cover-cropped systems relative to both the standard and conservation tillage systems without cover crops. This may have been caused in part by slower early-season tomato growth that was observed in each of the cover-cropped systems. We speculate that this growth reduction resulted from nitrogen immobilization following cover crop termination each spring, and, in the case of the CTCC system, lower soil and near-surface air temperatures. Additional testing is now under way to evaluate each of these hypotheses.

Data from the 2001 tomato harvest indicates that yields in conservation tillage both with and without cover crops were similar to those in the standard tillage plots. In both 2002 and 2003, the highest-yielding system was conservation tillage without a cover crop, although yield was significantly higher than all other treatments only in 2002. Using a cover crop meant lower yields for the conservation tillage system in all years, although yield was not significantly lower in 2001 or 2003.

Interestingly, for the standard tillage system a cover crop increased yields in 2001 and again in 2003 compared to the STNO treatments. Using the averages for 2001 to 2003, the period during which the tillage systems had become "established" following the 1999–2000 set-up year, CTNO had significantly higher yields than the other treatments (table 4). This suggests a possible

TABLE 5. Cotton yields for standard and conservation tillage systems with and without cover crops, Five Points

	2000	2001	2002	2003	Average 2001–2003
	pounds lint/acre				
Stand. tillage no cover crop (STNO)	360 a,c*	1,861 a,a	1,930 a,a	1,228 ab,b	1,756 a†
Stand. tillage cover crop (STCC)	360 a,d	1,505 c,b	1,921 a,a	1,336 a,c	1,587 b
Conserv. tillage no cover crop (CTNO)	200 b,c	1,646 b,a	1,736 b,a	1,059 c,b	1,480 c
Conserv. tillage cover crop (CTCC)	372 a,c	1,557 bc,a	1,252 c,b	1,157 bc,b	1,326 d

* First set of letters indicates least square means separation within year; second set within treatment. Different letters indicate statistical significance at $P = 0.05$.

† Least square means separation of averaged data takes into account between-year variations.

TABLE 6. Cumulative in-the-field total and respirable dust concentrations for tillage systems with and without cover crops during one complete cotton-tomato rotation, Five Points

	Total dust	Respirable dust
	µg/L	
Stand. tillage no cover crop (STNO)	2,716	450
Stand. tillage cover crop (STCC)	2,637	422
Conserv. tillage no cover crop (CTNO)	921	159
Conserv. tillage cover crop (CTCC)	1,643	314

Source: Baker et al. (2005); see for details of dust production for each operation.

tillage-system-by-cover-crop interaction, where cover crops significantly lowered tomato yields in the conservation tillage system but not in the standard tillage system.

Tomato fruit quality (% soluble solids and pH) data were not collected in every year of the study and did not indicate consistent system or treatment trends when determinations were made, presumably because similar irrigation water volumes were applied to all systems. Though we did not consistently monitor weed populations during this study, we did generally observe more weeds with cover cropping, and particularly in the furrows, for both tomato and cotton. There is a need to improve weed management in these systems, particularly late in the season.

Cotton. Cotton yields (table 5) were low in all systems in 2000 due to a devastating infestation of mites that persisted all season, exacerbated by likely pesticide resistance problems that developed with repeated miticide applications. In 2001 and 2002, STNO yields were significantly higher than in both conservation tillage systems. The STCC system was comparable to the CTNO system in 2001, but higher in 2002 and 2003. When the period 2001 through 2003 is averaged, the STNO system yielded 276 pounds more cotton lint than the CTNO system (table 5). While plant populations in these systems were similar, lower yields in the CTNO system may have resulted from reduced early-season crop vigor and a greater incidence of plant "skips" (areas within the row greater than 3 feet in length where no plants emerged) in this system. In addition, the lower yields may have been due to larger plants with more bolls in the first position (located closest to the main stem on a fruiting branch), which are typically correlated with greater yields in the STNO system.

Unlike tomatoes, there seemed to be no tillage-system-by-cover-crop interactions in cotton. The systems without cover crops consistently had higher yields than those with cover crops. Reduced yields in the conservation tillage systems, and the STCC system in 2001, may in part be related to difficulties we experienced establishing the crops in these systems, which resulted in lower average plant populations (table 3) and reduced early-season crop vigor. A combination of factors may be involved, however, as prior UC studies of cotton yield responses to plant population would not predict yield reductions at populations shown in table 3 (Kerby et al. 1996). Further work to refine and improve our planting, establishment, weed and nutrient management of cotton in these systems is under way.

Dust production

In-the-field dust concentrations, both total and respirable, measured on tillage and harvest implements were significantly reduced in the conservation tillage treatments compared to standard tillage for the 2001 to 2002 period of measurements (table 6). Gravimetric analysis showed that dust concentrations for CTNO were about one third of their STNO counterparts for both cumulative total and respirable dust measured throughout the 2-year rotation, primarily due to fewer in-field operations and to the elimination of the dustiest operations that cause significant soil disturbance. For example, both standard tillage systems utilize disking and power incorporation during land preparation, and these two operations are the dustiest of all operations (average of 60 to 65 micrograms per liter [µg/L] TD for each disking and 105 to 164 µg/L TD for power incorporation) (Baker et al. 2005). The elimination of cotton cultivation, the dustiest in-season operation in the standard tillage systems (average of 51 µg/L TD per cultivation) (Baker et al. 2005), also contributed significantly to overall dust reduction in the conservation tillage systems. Planting and harvesting operations, which cause little soil disturbance, produced similar amounts of dust in all treatments.

The total and respirable dust production for STNO and STCC were comparable, even though STCC entailed more field operations. The CTCC system produced about twice as much total and respirable dust as CTNO due to an increased number of field operations to manage the cover crop and an increased organic fraction in the dust (Baker et al. 2005). We did not measure PM10 and PM2.5 (particulate matter with aerodynamic diameters of 10 and 2.5 µm, respectively) at locations downwind from our field sites, so the effects of the conservation tillage systems on ambient air quality in relation to U.S. Environmental Protection Agency standards are not completely clear. However, our data does allow comparisons of the relative dustiness of the production systems. It is reasonable to assume that reduced dust measured at the implement level would translate to reduced ambient dust if conservation tillage practices were adopted widely. At this point, it remains unclear whether the reduced dust in conservation tillage treatments is due solely to a reduction in the number of field operations, or if it is also related to changes in soil properties such as aggregation and soil organic matter content.

Transitioning to CT

Our results indicate short-term outcomes and issues associated with a conversion to conservation tillage production in an irrigated region such as California's Central Valley. These preliminary results suggest that establishing and harvesting processing tomatoes and cotton with conservation tillage is possible given some equipment modification. In tomato, yields were maintained or even slightly improved with conservation tillage compared with standard tillage practices.

The negative impacts of conservation tillage systems on cotton yields were more problematic during the course of this study. A number of possible constraints to the adoption of these high-residue production systems were observed during this "transition" period and these require further investigation. First, the continued, long-term accumulation of large quantities of crop residues on the soil surface may eventually present problems in terms of planting, cultivating and harvesting both tomatoes and cotton. Transplanting and cultivating tomatoes took more time in the CTCC plots relative to the standard till systems, in part due to the need to deal with residues.

Second, although we did not quantify the actual amount of residue picked up by harvesting equipment, it is possible that high surface-residue systems may result in greater "material other than tomatoes" being harvested, which would ultimately require increased cleaning efforts and perhaps expense at harvest.

Third, although "zone production" theory might suggest that soil compaction constraints may, to a large extent, be avoided by keeping tractor traffic away from "crop growth zones," (Rechel et al. 1987), longer-term studies that investigate the implications of reduced till on compaction zones in a bed system are needed. An additional area of study worthy of evaluation is the determination of fertilizer application methods under conservation tillage. The adequacy of these approaches in meeting crop requirements will need to be determined for more soluble nutrients (such as nitrogen), as well as for less mobile or highly fixed nutrients (such as phosphorus and potassium).

Tomato yields were maintained or improved in the 4-year conservation tillage study, but cotton yields were more problematic. *Above*, tomato residues are ring-rolled prior to no-till cotton planting.

Finally, this transition-phase study has identified problems with cotton productivity and profitability in conservation tillage that will need to be addressed and improved. Achieving robust and vigorous cotton stands and developing reliable fertility and fertilizer application programs for conservation tillage are important areas that need further attention.

This study is the first of its kind in California to systematically compare tillage system alternatives through an agronomic field-crop rotation. The extent to which such alternatives are adopted in this region will ultimately depend on: yield impacts, true input costs, and how these affect profitability; equipment costs for alternative systems; decisions about weeding; the management of insect and disease pests over time; and possibly, whether processors and ultimately consumers find sufficient value in these types of production approaches to provide cost offsets to support their adoption.

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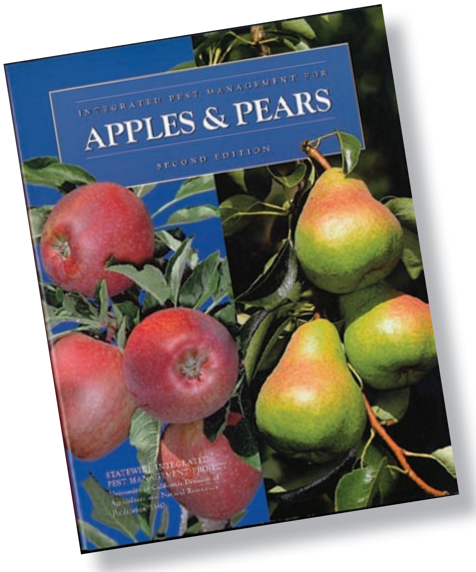

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