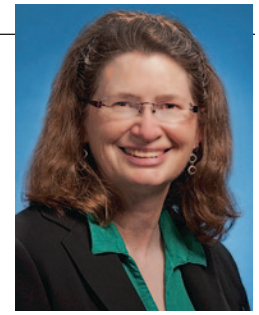
JANUARY–MARCH 2012 • VOLUME 66 NUMBER 1

California Agriculture

Community Supported Agriculture:
Popular and profitable in the Central Valley

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

150 years after Morrill Act, land-grant universities are key to healthy California



Barbara Allen-Diaz
Vice President
UC Agriculture and
Natural Resources

This issue of *California Agriculture* explores a range of topics representing the breadth of scientific expertise and focused inquiry found across UC Agriculture and Natural Resources (ANR). It explores new business models for direct marketing, targeted nutrition research, genetic resistance to plant disease, biological control of pests and improved production methods for California's strawberry industry. These are clear examples of the legacy of research and innovation documented in the journal's 66-year history.

President Abraham Lincoln signed the Morrill Act into law 150 years ago, launching publicly supported land-grant institutions nationwide — including the University of California. President Lincoln and those who wrote and supported the legislation had a revolutionary vision of accessible and affordable higher education that would advance our nation's agricultural and industrial knowledge and expertise. Their imagination and foresight led to a system that remains unique in the world. There can be no question that this system has been critical to the growth of our nation and what is, for now, the world's largest economy. We are no less certain that UC, and ANR's outstanding scientists and educators, have been essential to the development of California's dynamic food system, our rich natural resources and our youth and families.

In 2014, we will celebrate the centennial of the signing of the Smith-Lever Act, establishing Cooperative Extension in partnership with the land-grant universities and their Agricultural Experiment Stations. This Act enabled an equally original vision of a continuum of scientists discovering and delivering research-based information to solve local and global problems and contributing to the growth of California's world-leading agricultural economy dedicated to healthy food systems, environments, communities and Californians.

Since assuming the role of ANR vice president, I am even more convinced that these revolutionary visions and landmark pieces of legislation, and the challenges and opportunities described in our Strategic Vision 2025 (http://ucanr.org/About_ANR/Strategic_Vision) are important, necessary and compelling.

As I write, UC again finds itself at the center of a fundamental and passionate discussion about the future of public investment in higher education and the system of universities that conduct research, extend science-based solutions, and educate professionals and scientists whose innovation and entrepreneurship support the benefits we all enjoy. All partners in the ANR community are affected by these issues.

Both human- and financial-resource issues present a daunting array of obstacles and an exciting set of difficult choices. Meanwhile, the contributions of our academics and staff continue to demonstrate an unmatched body of creative and relevant inquiry and a commitment to extending that knowledge in the form of practical solutions and critical feedback.

Our near-term and strategic goals are to ensure that all elements of the community thrive and that we act swiftly and effectively to support and focus the extraordinary resources of our people to solve critical issues and address complicated problems. Guided by our Strategic Vision, we have taken important steps:

- Launched five strategic initiatives.
- Begun critical academic recruitments.
- Completed our first round of competitive grants.
- Captured significant administrative efficiencies.
- Enhanced statewide program leadership.
- Expanded consultation and leadership interactions.
- Focused our communications, both internal and external.

Much more remains to be done. We are increasing efforts to: (1) engage with key external stakeholder groups and leaders; (2) increase proactive communications and active responses to critical issues, focusing on solutions and relevant research; (3) restructure our county partner relationships to improve program delivery and operate more efficiently; (4) develop improved collaborative processes for recruiting extension specialists and advisors; (5) efficiently support program planning and multidisciplinary interactions; and (6) improve the support structure for UC ANR academics.

We have taken many steps toward achieving our Strategic Vision in the past 4 years, despite the fact that we are operating with reduced resources and the loss of expertise in critical areas as many academics retire. Meanwhile, an array of issues evolve and develop with profound implications for California's agriculture, natural resources and communities.

We must acknowledge that we face real constraints in people, resources and time, which make it even more critical to work together. While we continue to look for more efficient ways operate, we must promise only what we can deliver and deliver all that we promise. The opportunities to discover and implement science-based solutions and make a real difference are only enhanced by close collaborations and a shared vision in our various units of ANR.

In spite of all the hurdles we face, as a community we enjoy amazing and unmatched academic talent and a dedicated and involved staff. As we recruit new academics, carefully focus our resources and move to address critical issues, I believe that a thriving UC ANR community will help renew and reinvent the vision of President Lincoln, Justin Smith Morrill and others. I am committed to continuing the work of those who have realized that vision to the benefit of us all and to demonstrating our commitment to excellence in research, problem-solving and public service.

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COVER: The popularity of Community Supported Agriculture (CSA), farms that deliver fresh produce to members, has been increasing rapidly. In a survey, 54% of CSA farmers in the Central Valley and surrounding foothills were profitable, with average gross sales per acre of $9,084 (see page 8). At Live Power Community Farm CSA, long-time members Sean Cotter (left) and Robin Chandler volunteer to sort winter produce, which they then deliver to members in their neighborhoods. *Photo: Nancy Warner*

Community Supported Agriculture:
Popular and profitable in the Central Valley

Research and review articles

News departments

E-Edition

Now in print

This article was published online with the October–December 2011 *California Agriculture* and now appears in print after page 26. (The version of record for citation purposes is October–December 2011, pages 211–5.)

About *California Agriculture*

University *of* California
Agriculture and Natural Resources

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

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

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

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

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

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

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

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WHAT DO YOU THINK?

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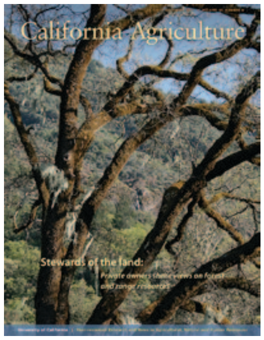
Research on forest clear-cutting

Regarding "Forest and rangeland owners value land for natural amenities and as financial investment" by Ferranto et al. (October–December 2011): Have the authors considered doing a survey of how Californians feel about the clear-cutting that is occurring throughout the state's private forest lands? The cumulative effects on water, soil, air and quality of life for Californians are not being discussed enough by the people who will be affected by the loss of these forests, which are owned by big logging companies.



October–December 2011
California Agriculture

Patricia Lawrence
Executive Producer
Travel Radio International
Shingletown, CA

The authors (Mike De Lasaux, Sabrina Drill, Shasta Ferranto, Christy Getz, Lynn Huntsinger, Maggi Kelly and Bill Stewart) respond: The research you suggest would be especially valuable if it examined how people respond to the tradeoffs that are always part of making decisions about forests. For example, different kinds of trees and wildlife species respond to various options for forest management in different ways, whether management is for timber, fire hazard reduction, recreation or preservation. However, the tradeoffs involved in making decisions about forests go beyond that, and include impacts to the economy, ecology, local communities, households, price of homes and wood products, carbon sequestration, scenic values, water and property rights. These tradeoffs eventually affect us all, and policy- and decision-making should be based on their careful consideration. Research should inform this process.

An important finding from our landowner survey was that the vast majority of forest landowners valued "preservation" and "protecting the environment" much higher than income generation from their lands, including many landowners that harvest timber. The choice of which harvest system to use should be grounded in an understanding of the conditions and history specific to each particular forest. There are tree species and forest conditions that make clear-cutting a viable approach to meet the owner's goals within the state's legal requirements. California's Forest Practice Rules require the protection of watersheds, wildlife and forest health and also require landowners to make sure their forest regrows after timber harvest.

Nonetheless, there is a lot of room for dialogue among researchers, managers and the public. In our opinion, research that would be the most valuable to this conversation would focus on improving our understanding of the ecological, social and economic tradeoffs associated with different types of forest management.

IPM for light brown apple moth

I am a third-year undergraduate student of viticulture and enology in England. My final dissertation project is looking into control methods for light brown apple moth (LBAM), which was recently detected in our English vineyards.

I have been conducting a trial of Exosect mating disruption treatments, with the aim of creating an integrated pest management (IPM) model that can be implemented if population numbers exceed that of the economic threshold. I am after up-to-date research information to include in my report. I have read with interest research in *California Agriculture* ("New Zealand lessons may aid efforts to control light brown apple moth in California," by Varela et al., January–March 2010) and would like to know if there is anything happening in the progression of IPM for LBAM.

Light brown apple moth

Leah de Felice Renton
Plumpton Agricultural College
University of Brighton
East Sussex, England

Lucia Varela, UC Cooperative Extension North Coast IPM advisor, responds: LBAM was first reported in California in 2007 and probably was introduced several years before. Up to now, LBAM has not been reported as a pest in vineyards. We have trapped LBAM since 2007 in North Coast vineyards, but in the past 5 years of looking have only found LBAM in clusters once, and it did not warrant control. One hypothesis as to why LBAM has not become a pest in North Coast vineyards may be climate; we have hot, dry summers. As far as I am aware, cane berries in Santa Cruz County are the only crop and area where LBAM must be controlled in California. Nursery stock is highly regulated to prevent pest movement to the rest of the country; it is the other commodity in which treatments are needed, including mating disruption.

Correction:

Table 1 in the news article "Water workgroup recommends new salinity guidelines for regulatory agencies," published in the October–December 2011 issue, contained an incorrect entry supplied by the authors. For the leaching fraction 0.10, at 15% annual rainfall to total water applied, the salinity of irrigation source waters should have been 0.91 (not 1.01) dS/m.

Uncertain future for California's biomass power plants

Gareth Mayhead, Academic Coordinator, Center for Forestry, UC Berkeley
Peter Tittmann, Postdoctoral Researcher, Institute of Transportation Studies, UC Davis

Biomass power plants convert organic plant matter such as sawmill residues, green waste, orchard prunings, nut shells and fruit pits into electricity. Despite policy changes that have made the economics challenging, California has the most biomass power plants of any state. Yet according to the California Energy Commission, biomass-derived power only contributes about 2% of the state's electricity.

Government incentives to develop renewable energy date to 1978, when Congress passed the Public Utilities Regulatory Policies Act (PURPA). A response to the 1970s oil crisis, PURPA aimed to reduce U.S. reliance on imported oil. California implemented PURPA to encourage biomass, wind and solar energy, leading to emergence of the biomass-to-electricity industry in the 1980s and early 1990s.

The California Renewable Portfolio Standard (RPS), created in 2002 and subsequently strengthened several times, now requires utilities to source 33% of electricity from renewable sources by 2020. In 2010, California's three largest Investor Owned Utilities (IOUs) procured 17% of electricity from renewable sources, according to the state Public Utilities Commission. All new capacity brought online under the RPS in 2011 (830 megawatts) was either solar or wind — intermittent renewable energy sources that cannot provide consistent baseload power (the amount which utilities must make available to meet minimum demand, at all times on all days). With no new contracts, biomass-derived electricity appears to have less appeal to California utilities than it once did, when PURPA first passed.

Current trends in biomass power in California

Existing public information on solid-fuel biomass power plants in California is often outdated or difficult to access. Figure 1, a map developed by the Woody Biomass Utilization Group at UC Berkeley, shows the current status of the state's biomass-to-electricity industry. We attempted to identify all existing biomass power plants, whether currently operational or not. (Online map links to contacts.)

Of the existing 40 solid-fuel biomass power plants, 23 are currently operational, eight are idle, six are nonoperational and three are the subject of restart projects. There is one new proposed solid-fuel plant at a sawmill in Anderson. Many of the existing plants have suffered in recent years: They are locked into 30-year contracts with IOUs that pay them low prices for electricity produced, resulting in facilities shutting down for periods of time when they cannot afford to run. This has significant implications for the communities where these facilities are based, as they are often a major employer and contributor to the tax base.

In recent years, a number of attempts have been made to restart nonoperational facilities, which is significantly less expensive than building a new facility; in some cases this may be the only way to add biomass capacity since the old plant retains its original permits, and regulations make it difficult to get new permits. Another major trend has been in co-fire/conversion projects. Co-firing or conversion is direct substitution for fossil fuels and, similar to restarts, often makes financial sense. Developers restarting facilities, working on co-fire/conversion or building new projects have been able to negotiate new RPS contracts with the IOUs and receive higher prices for electricity than existing facilities, creating in effect a dual market. Despite the low electricity prices received, during the past year at least six of the existing power plants have been sold to investors. This trend may be driven by speculation that the IOUs will pay more for electricity as the 2020 RPS deadline approaches.

Three pilot projects are demonstrating gasification as a way to produce electricity from biomass at a smaller distributed scale (40 to 200 kilowatts [kW]) in addition to a small commercial unit (500 kW). All the small projects have faced significant challenges — both bureaucratic and financial — in connecting to the electricity grid. This is in contrast to the streamlined interconnection procedures available for small solar projects.

A clean alternative

Biomass power plants not only generate renewable baseload power, they offer a clean and cost-effective disposal option for biomass residuals from the agricultural, urban and forestry sectors while sustaining rural jobs and communities. For example, the U.S. Forest Service relies on the industry to take biomass material from National Forest System ecosystem restoration projects in California, helping to offset the cost to taxpayers. If the industry did not exist, the Forest Service believes that fewer acres would be treated, increasing catastrophic wildfire risks.

As people interested in California agriculture and forestry, we should recognize the environmental and social values of biomass-to-electricity. Regulators and policymakers could identify methods to recognize these co-benefits in the rates that utilities pay for electricity from biomass. The current rulemaking process for the Feed-in Tariff presents an opportunity to offer a higher price that would incentivize small-scale (less than 3 megawatts) biomass-to-electricity facilities. Reauthorization of the Public Goods Charge (a fee to electricity retail consumers that funds public programs including biomass research and development and existing biomass power plants), which expired at the end of 2011, would also help. Solar, wind and other sources are all part of a balanced energy portfolio; electricity rates should reflect the range of environmental and social co-benefits that biomass-to-electricity delivers in California.

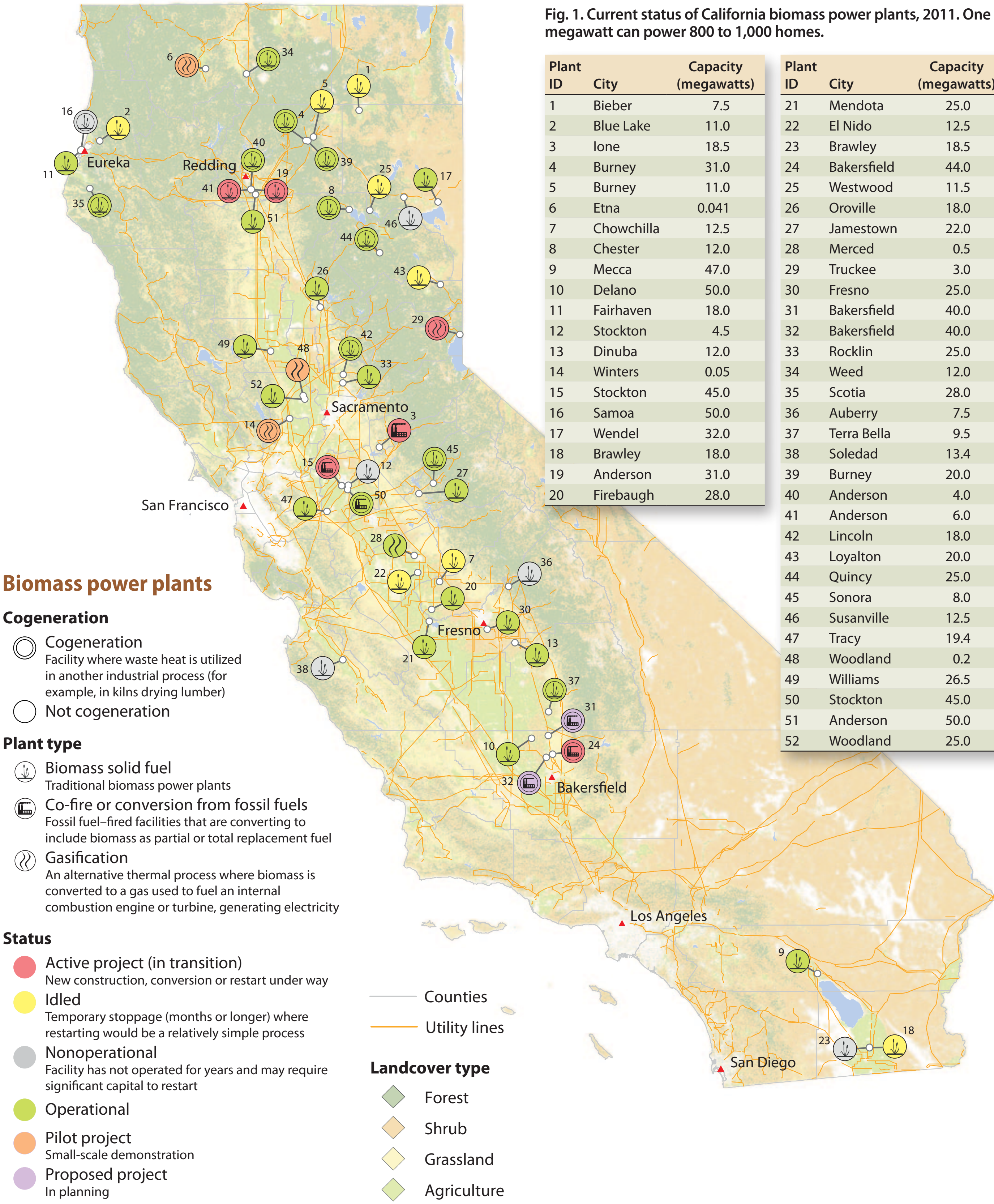
For more info:

Biomass power map, updated quarterly:
http://ucanr.org/BiomassPower

Renewable Portfolio Standard and other information:
www.cpuc.ca.gov/PUC/energy/Renewables

Fig. 1. Current status of California biomass power plants, 2011. One megawatt can power 800 to 1,000 homes.

Plant ID	City	Capacity (megawatts)
1	Bieber	7.5
2	Blue Lake	11.0
3	Ione	18.5
4	Burney	31.0
5	Burney	11.0
6	Etna	0.041
7	Chowchilla	12.5
8	Chester	12.0
9	Mecca	47.0
10	Delano	50.0
11	Fairhaven	18.0
12	Stockton	4.5
13	Dinuba	12.0
14	Winters	0.05
15	Stockton	45.0
16	Samoa	50.0
17	Wendel	32.0
18	Brawley	18.0
19	Anderson	31.0
20	Firebaugh	28.0
21	Mendota	25.0
22	El Nido	12.5
23	Brawley	18.5
24	Bakersfield	44.0
25	Westwood	11.5
26	Oroville	18.0
27	Jamestown	22.0
28	Merced	0.5
29	Truckee	3.0
30	Fresno	25.0
31	Bakersfield	40.0
32	Bakersfield	40.0
33	Rocklin	25.0
34	Weed	12.0
35	Scotia	28.0
36	Auberry	7.5
37	Terra Bella	9.5
38	Soledad	13.4
39	Burney	20.0
40	Anderson	4.0
41	Anderson	6.0
42	Lincoln	18.0
43	Loyalton	20.0
44	Quincy	25.0
45	Sonora	8.0
46	Susanville	12.5
47	Tracy	19.4
48	Woodland	0.2
49	Williams	26.5
50	Stockton	45.0
51	Anderson	50.0
52	Woodland	25.0



RESEARCH ARTICLE

Community Supported Agriculture is thriving in the Central Valley

by Ryan E. Galt, Libby O'Sullivan, Jessica Beckett *and* Colleen C. Hiner

Community Supported Agriculture operations (CSAs) have grown rapidly in recent years. The original model, in which members support a farming operation by paying for produce in advance and receive a share of the farm's produce in return, has been adapted, with much innovation. Since little research existed on CSAs in the Central Valley, we surveyed and carried out in-depth interviews with 54 CSA farmers and two CSA organizers in the Central Valley and surrounding foothills. Here we focus on four aspects of these CSA operations: type, economic viability, farmer characteristics and farm attributes. We found two main CSA models, box and membership/share. Fifty-four percent of the CSAs reported being profitable, and the average gross sales per acre were $9,084. CSA farmers are diverse in political orientation, yet are generally younger, better educated and more likely to be women than the general farming population. CSA farms are relatively small, with a median size of 20 acres; have a median membership of 60 (585 average); use agroecological methods; cultivate agrobiodiversity; and utilize growing practices that generally meet or exceed National Organic Program standards.

There are more than 3,500 Community Supported Agriculture operations in the United States. Farmers generally supply boxes of fresh, seasonal produce to their members weekly.

Community Supported Agriculture (CSA) connects farmers and the consumers of their products. In the original CSA model, members support a farm by paying in advance, and in return they receive a share of the farm's produce; members also share in production risks, such as a low crop harvest following unfavorable weather.

An important social invention in industrialized countries, Community Supported Agriculture addresses problems at the nexus of agriculture, environment and society. These include a decreasing proportion of the "food dollar" going to farmers, financial barriers for new farmers, large-scale scares from foodborne illness, resource depletion and environmental degradation. Together with farmers markets, farm stands, U-picks and agritourism, CSAs constitute a "civic agriculture" that is re-embedding agricultural production in more sustainable social and ecological relationships, maintaining economic viability for small- and medium-scale farmers and fulfilling the non–farm-based population's increasing desire to reconnect with their food (Feenstra 1994; Hinrichs 2000; Lyson 2004).

The first two CSAs in the United States formed in the mid-1980s on the East Coast (Adam 2006). By 1994, there were 450 CSAs nationally (Feenstra 1994), and by 2004 the number had nearly quadrupled to 1,700 (McFadden 2004). There were an estimated 3,637 CSAs in the United States by 2009 (Galt 2011). This rapid expansion left us knowing little about CSA farmers and farms and raised questions about their social, economic and environmental characteristics. Knowing these features of CSAs would allow for more-precise policy interventions to support and extend these kinds of operations, and could inform more in-depth analyses, in addition to giving farmers and the public a better understanding of them.

CSA interviews and survey

We conducted a study of CSAs in 25 counties in California's Central Valley and its surrounding foothills — from Tehama in the north to Kern in the south, and Contra Costa in the west to Tuolomne to the east. The valley's Mediterranean climate, combined with its irrigation infrastructure, fertile soil, early agrarian capitalism and technological innovation have made it world renowned for agricultural production (Walker 2004). In addition to its agricultural focus, we chose this region because we wanted to learn about how CSAs were adapting to the unique

Online: http://californiaagriculture.ucanr.org/landingpage.cfm?article=ca.E.v066n01p8&fulltext=yes

DOI: 10.3733/ca.E.v066n01p8

context of the Central Valley. Many of the region's social characteristics — relatively low incomes, high unemployment rates and conservative politics — differ from those in other regions where CSAs are popular, such as the greater San Francisco Bay Area and Santa Cruz (Galt 2011; Schnell 2007).

An initial list was compiled from seven websites that list CSAs in the state: Biodynamic Farming and Gardening Association, California Certified Organic Farmers, Community Alliance with Family Farmers, Eat Well Guide, LocalHarvest, the Robyn Van En Center and Rodale Institute. Of the 276 CSAs that we found, 101 were in our study area. We contacted them by e-mail and phone. It became evident that some did not correspond, even loosely, to the definition of a CSA in which members share risks with the farm and pay in advance for a full season of shares. As the study progressed, we revised our definition of a CSA to mean an operation that is farm based and makes regular direct sales of local farm goods to member households. We removed some CSAs that did not meet the revised definition, based on operation descriptions on their websites or details provided by phone or e-mail if a website was not available. Some interviews that we had already completed could not be used for our analysis because the operations did not meet the revised definition.

As the study progressed, we augmented the initial list with snowball sampling by asking participating farmers about other CSAs, which added 21 CSAs. Of these 122 farms, 28 were no longer operating as CSAs, seven turned out to be CSA contributors without primary responsibility for shares and 13 did not meet our revised CSA definition. We called the 28 CSAs no longer operating "ghost CSAs" because of their continued presence on online lists. We do not know the fate of 15 ghost CSAs, as no definite statement of closure could be found and all contact attempts failed. Of the other 13, some left farming, some were still farming but without CSAs, and one moved out of state and continues to farm. Removing all of these from the study left 74 CSAs that met our definition.

Primary data collection occurred from January 2010 to April 2011 and involved two components: a semistructured interview and a survey conducted through an online questionnaire. All 74 CSAs were contacted by phone and e-mail. Fifty-four CSA farmers and two CSA organizers, together representing 55 CSAs, agreed to participate in the study and were interviewed. In most cases, we interviewed the farmers directly responsible for the CSA operation, but two cases were different. In one, a CSA organizer worked with two farms to create an independent CSA; one of these farms also had its own CSA, while the other farm only sold through the CSA run by the organizer — these two farms and the organizer count as two CSAs. In the other case, the CSA organizer brought many farmers, none of whom have their own CSA, together to form one CSA.

Together with farmers markets, farm stands, U-picks and agritourism, CSAs constitute a "civic agriculture" that is re-embedding agricultural production in more sustainable social and ecological relationships.

Forty-eight of the 54 CSA farmers interviewed completed the survey; the others did not after repeated reminders. We did not request survey responses from the CSA organizers. We used the qualitative data from farmers and the two CSA organizers who did not complete the questionnaire, but we were unable to include their information for most quantitative data. Qualitative data was analyzed through coding responses to specific questions. We analyzed the quantitative data by creating summary statistics of various characteristics, with some bivariate statistical analysis.

Two main types of CSAs

In the interviews, we asked CSA farmers about the prices for their CSA shares, how their CSA delivery systems worked, whether they bought supplemental produce from other farms, and the extent that they used volunteers on the farm; and in the survey, we asked about the types of food and other products in their shares, minimum payment periods and events hosted at the CSAs. As a result, CSA types emerged that differed from our original conception of a CSA — that members shared risk with the farm and paid for a full season up front. None of the CSAs had a formal core member group deciding what to produce, none had mandatory member workdays, and many did not require long minimum payment periods or share production risks with members.

We found two main CSA types:

Box model. The box model is a farm subscription. Of the 48 farms that responded to the online survey, 46 used this model. Members pay up front, though the minimum payment period varies from a week to a full season. Payments are made in advance of receiving the product, so a minimum payment period of 1 month means that the member pays for four boxes before receiving any box. The average minimum payment time was 8 weeks, while the median was 1 month. Box-model CSAs used different distribution systems, including on-farm pickup, neighborhood or institutional drop-off sites and door-to-door delivery.

The box model had three subtypes. A *single-farm* box CSA produces the majority of foods in its box; 34 of the 46 box-model farms were this type. Many offered other farms' produce as occasional additions, or as optional add-ons (such as fruit or eggs) for purchase.

A *collaborative* box CSA consists of several farms cooperatively marketing their products and managing the CSA; seven of the 46 box-model farms worked this way. These CSAs sometimes have organizers who are independent of the farms (Flora and Bregendahl 2007).

A *farm-linked aggregator* box CSA is a business tightly linked to a single farm

Paul Muller of Full Belly Farm in Yolo County explains farm operations to visiting members.

Zoey Farms, a CSA in Shingle Springs (El Dorado County), shows a wide diversity of crops. The farms surveyed each grew 44 different crops on average.

that combines the farm's produce with produce consistently purchased from other farms or a wholesale market. Five of the 46 box-model farms had chosen this approach. Most required no upfront payment and allowed customers to customize the produce in their box. We did not consider nonfarm aggregators to be CSAs and therefore excluded them from our study. Nonfarm aggregators grow nothing themselves; they are retailers who purchase produce from a wholesale market or from farms not directly connected with their business. Although not included in our study, nonfarm aggregators often call themselves CSAs and place themselves on online CSA listings.

Membership/share model. The membership/share model requires customers to make an upfront membership or share payment. It is rare; only four of the 48 CSAs operated this way. Two of the four CSAs used only the membership model; the other two combined it with the box models by offering member discounts. The membership payment is paid prior to actually picking up the produce. Members give the farmer some amount of money, which becomes credit for use at the farm's U-pick, farm stand or farmers market stall. Members do not pick up a set amount of produce but are able to pick and choose, and receive a discount by paying in advance.

With share payments, members can sign a contract to own a share of a farm animal, and the share payment covers the animal's feed. The member then purchases that animal's products. The member does not get any discount for their share but is able to gain access to locally raised and processed animal products, which are not widely available in the region. He or she is also sharing the risks associated with raising livestock with the rancher or farmer.

Innovations in CSAs

These differently arranged enterprises, all called CSAs by their operators, demonstrate a central finding: Much innovation is occurring in how farmers and consumer members connect through a CSA. Farmers have adapted the CSA model to their ambitions for their farm, to innovative products and to regional conditions. CSA farmers have different preferences for their operations. Some want to remain small, while others want to grow; these goals require different strategies. Farmers have added new products, especially meat and dairy, into their CSAs, although the processing of those products does not fit easily with handling practices developed for fruits and vegetables.

Other innovations include changing CSA payment and delivery systems so that they are more attractive and accessible to people who are not familiar with the concept and to consumers who cannot afford a large upfront cost, both of which are important realities in the Central Valley. For example, 20% of CSAs in the study had no minimum payment period, allowing week-by-week payments, which extends membership to a broader population, including those hesitant or unable to commit to extended payments.

Requiring no long-term commitment was also a common practice among meat CSAs in our sample, which often do not know exactly which products will be available and when, including both individual cuts and type of meats. This uncertainty stems from maturation, slaughtering and butchering processes. Few slaughter and butcher facilities serve small-scale producers. Consequently, CSA meat producers compete with large-scale operations for limited processing capacity, and there is greater variability in their animals' maturation because they are raised primarily on pasture. Scheduling difficulties can result; for example, during the summer, CSA ranchers may need to schedule slaughtering months in advance, but their animals may not be ready by the scheduled date. Meat CSAs rely on committed customers who agree, typically on a monthly basis, to buy some amount of a variety of meat.

Economic viability

To understand their economic viability, we asked CSA farmers about gross annual sales and net profits in 2009, the CSA's contribution to the total economic activity of the farm, other marketing channels used and how the farmers valued their labor. In the survey, we asked about whether partners held off-farm jobs and the CSA's general profitability. We found that the CSA was a crucial direct-to-consumer marketing channel for the small- and medium-scale farmers in our study. On average, the farmers obtained 58% of gross sales from their CSA. In general, small-scale farmers were more dependent on their CSA than larger-scale CSA farmers. Most farmers also sell into other channels, including wholesale and direct-marketing venues, especially farmers markets. Some farm-linked aggregator box CSAs act as wholesale outlets for small farms with their own CSAs.

Farmers in our study commonly chose the CSA as a marketing outlet to diversify their income channels. Some had little access to organic wholesale markets, while others wanted to increase sales beyond farmers markets and other direct sales. Some newer farmers started with a CSA to help raise needed capital. As motivations for choosing a CSA, most respondents mentioned the advantages of knowing sales volumes in advance and being paid up front, before the growing season begins.

Assessing the economic viability of CSA operations is difficult because it involves both the baseline profitability of the business and the need to generate sufficient income for retirement, health insurance, college for children, land purchases and so on. In addition, farmers conceptualize profit differently. Some consider their salaries as profit, while others set aside a salary for farm partners and consider profit to exclude this salary. Not all farmers amortize their accounting, and many reinvest surpluses in the farm to make it more productive or reduce taxes. Consequently, we asked a variety of questions about farm economics.

Profitability. Regarding profitability, 54% of the respondents indicated that their CSA was profitable, 32% broke even and 15% operated at a loss. One-third said that they paid themselves a salary in 2009, ranging from $3,600 to $100,000 annually, with a median of $60,000. The majority, however, reported living off operating surpluses, taking, as farmer 32 said, "What's left at the end of the year."

Off-farm jobs. Forty-two percent of surveyed farms had partners who held off-farm jobs. Although not strictly comparable, CSA operators tended to be less dependent on off-farm employment than California organic farmers generally, among whom 67.7% have farm partners working off-farm (USDA NASS 2010). However, the CSA farms were similar to U.S. non-CSA farms in having some reliance on off-farm jobs for income, and in the lack of profitability of some operations and infrequency of formal salaries.

Gross sales. Another way we looked at economic viability was by asking about gross farm sales from all market channels (including the CSA), which in 2009 ranged from a few thousand dollars to multiple millions, with a median of $57,000. Since CSAs vary greatly in size, standardizing gross sales by farm size was important. The median gross sales per acre were $4,341 for all CSAs in our study, while the mean was $9,084. These figures for CSA farms are considerably higher than for California agriculture generally — where the mean gross sales per acre is $1,336 (USDA NASS 2010) — and almost all other kinds of organic agriculture in California (fig. 1). When we focused only on crop-oriented CSAs and looked at gross sales per acre, the average for CSAs was $13,354 and the median was $10,000 (fig. 1).

Farmer motivations

When we asked farmers in the interviews why they wanted to do a CSA and the general philosophy behind their farm and CSA operation, most were not interested solely in maximizing sales, profit or their salaries. When asked about their motivations and farming philosophy, CSA farmers said they loved farming, felt satisfaction in providing fresh food to their communities and educating people about food and agriculture, and wanted to make positive change. As one farmer noted, "The world's messed up, and we're fixing it — one family at a time, one farm at a time" (farmer 44). Although that sentiment was common, CSA farmers' political commitments ranged from libertarianism to socialism to evangelical Christianity to feminism. We also found a diversity of views on the CSA as a business: Many saw their CSA as promoting their deeply held values, independent of maximizing profit. For example, one newer CSA farmer said: "I really want to empower other women to work in sustainable agriculture . . . Almost all our applications for internships are from women, probably 75%, but there aren't that many women farmers" (farmer 56A).

CSA farmers frequently mentioned receiving nonmonetary forms of compensation: tangible benefits such as living and/or raising children on a farm, benefiting from improvements to the property, eating well and living healthfully; and intangible ones such as the lifestyle and deeply rewarding hard work. One farmer noted: "We don't keep track of hours 'cause that would be depressing from a pay standpoint. But we just love it. We probably should [do time tracking], but on the other hand, it's part of the lifestyle. It isn't jobby at all. We have what we need to get by, but we don't pay ourselves an official wage" (farmer 50).

Some farmers in our study ran their CSAs to make money, although all did so within the context of broader social and environmental commitments. As an example, farmer 39A and farmer 39B, a husband and wife team, respectively said their philosophy for the CSA was to "make money to send children to college," and "capitalism — you have to be greedy, grubbing capitalists." However, they went on to illustrate their underlying environmental and social commitments. When farmer 39A said, "We always try to be the top of the market in terms of quality and price," farmer 39B added that they value growing the "most nutrient-dense food [and] finding a supportive community to reward us for doing it." Driving home the point that their profit orientation is securely underpinned by a broader ethos, farmer 39A added, "We are also committed to offering our employees year-round employment in a toxic-free environment."

Characteristics of CSA farmers

The survey asked for demographic information on up to six farm partners, people who are essential players in farm management or operations. The majority (69%) of CSAs studied had more than

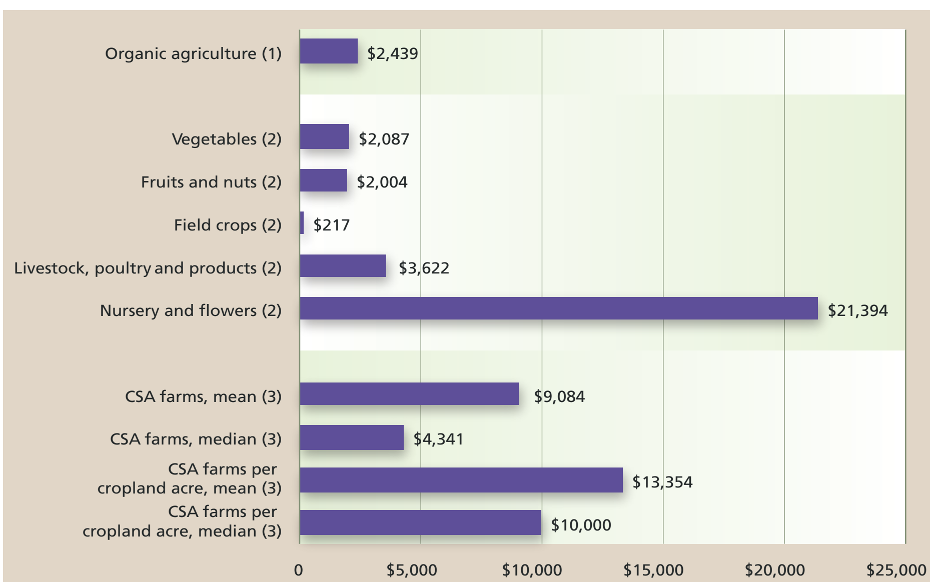


Fig. 1. Mean gross sales per acre for CSAs in the study compared with that of organic agriculture in California, and by crop type. CSAs have comparatively high gross sales per acre. Sources: (1) USDA NASS 2010, (2) Klonsky 2004, (3) authors' field work.

one partner; the average number was 2.7, while the median was 2. We collected data on 115 farm partners in charge of the 48 CSA farms that completed the survey.

We studied the characteristics of two categories of CSA farmers: "farmer A," which, following Lass et al. (2003), is the partner whose information was completed first in the survey and was assumed to be closest to the USDA category of "primary operator" (we did not require respondents to identify a primary operator); and CSA farmers as a general category, for which we pooled data on all 115 CSA partners.

Age. CSA farmers were comparatively young. On average, farmer A was 43 years old, while CSA farm partners were 42 years old. In comparison, the average U.S. farmer's age is 57 (USDA NASS 2009b).

Women. Women made up 35% of farmer As and 40% of the farm partners. Women make up 19.2% of primary operators on California organic farms (USDA NASS 2009a) and 13.9% on farms nationally (USDA NASS 2009b). Although not directly comparable since we did not ask for a principal operator, these figures suggest that a greater proportion of women are in decision-making positions in CSAs than in organic agriculture in California and the United States.

Ethnicity. CSA farmers in the study tended to be slightly less ethnically diverse than California farmers in general. The vast majority (87%) of CSA farmers self-identified as white, while 6% did not specify an ethnicity, 5% were Latino, 1% were Filipino and 1% were North African/Middle Eastern.

Our study population was more diverse than in CSAs nationwide, where 97% are white/non-Latino (Lass et al. 2003), but less diverse than in California agriculture, where farm operators (with up to three per farm counted in the 2007 Census of Agriculture) are 80% white, 11.8% Latino, 4.5% Asian, 2.4% Native American, 0.5% black and 0.4% Native Hawaiian/other Pacific Islander (USDA NASS 2009a).

Education. The CSA farmers that we studied were well educated. Seventy-nine percent of farmer As held bachelor's degrees and 13% graduate degrees. For CSA farmers, 82% held bachelor's degrees and 27% graduate degrees. This is considerably higher than for California and U.S. agriculture, where 39% and 24%, respectively, of farmers have completed 4 years or more of college (USDA ERS 2011).

Most CSA farmers were motivated by their love of farming and the satisfaction of providing fresh produce to members. *Above,* Jim Muck runs Jim's Produce, a CSA in Wheatland (Yuba County).

When asked in the interview about how they learned to farm, only 26% of farmers had completed on-farm apprenticeships or internships, despite the fact that these are offered by many CSAs. Instead, many farmers gained knowledge primarily by learning while doing; 55% said they had learned much of what they knew from farming experience or gardening with family members.

Features of CSA farms

We asked many questions about the CSA farms, including survey questions about start year, farm size, area in various land uses, number and kinds of crops and farm animals, general practices in relation to the federal organic standard, electricity generation, farm inputs, water use and land tenure. In the interview, we asked open-ended questions, including "How did you get access to the land you're currently using for your CSA?" and "What practices do you do that you think are most beneficial to the environment?" We found out that most CSAs in our study were relatively new, in existence for 5.7 years on average. CSA farms shared certain core features, especially a commitment to environmental conservation, agroecology (the application of ecological principles in agriculture) and agrobiodiversity (the support of many organisms within agricultural systems, including those directly related to food production, like crops, and others that exist on or move through the farm, such as predators). The farms were diverse across a range of characteristics, including farm size, land ownership, organic certification and membership numbers.

Agroecology. CSA production is generally based on agroecological methods (Altieri 1995). Two-thirds of CSA farmers in our study used green manures for fertilization, a practice abandoned in the 1940s by most farmers in the United States, who rely now on synthetic nitrogen. Eighty-two percent of CSA farmers in our study used animal manures or green manures, compared with 49% of California organic growers (USDA NASS 2010), suggesting more commitment among CSA farmers to maintaining on-farm or near-farm nutrient cycles.

Agrobiodiversity. CSA farmers in our study cultivated a tremendous amount of agrobiodiversity, growing 44 crops (fig. 2) and raising three types of livestock on average. Most CSAs studied focused on vegetables, although some were exclusively focused on fruit, one on grain, and a handful on meat and other animal products. About half of CSAs studied (49%) had livestock in 2009. The most common animals were layer chickens (43%), followed by hogs and pigs (23%), goats and kids (21%) and broilers, sheep and lambs, and beef cattle (13% each).

Many CSA farms also had some land devoted to conservation plantings, such as hedgerows where birds and beneficial insects can live. As one farmer noted, "I have a very strong view that agriculture doesn't need to and shouldn't decrease the vitality, the biodiversity of the environment . . . [agriculture] can actually enhance it" (farmer 2). In the Central Valley, the CSA farmers' commitment to agrobiodiversity contrasts with the monocultures that dominate the landscape.

Agrobiodiversity is supported by the unique nature of CSAs. Many farmers noted that providing diversity in the box is a key strategy for maintaining CSA members, and that this had translated directly into diversity in crops and varieties on the farm.

Regarding her CSA's first member survey, one farmer noted that members wanted "more fruit and more diversity. We immediately planted fruit trees and told our members, 'We are planting these fruit trees for you; wait 4 years for some peaches'" (farmer 1).

Resource use. CSA farmers were conscious of their use of resources, including fossil fuels, farm inputs, packing materials and electricity. Twenty-two percent had on-farm renewable energy production, mostly solar, considerably higher than the 1.1% average for U.S. farms (USDA NASS 2009b).

Farm size. While the above characteristics were widely shared, CSA farms exhibited differences in other traits, including farm size. The median CSA farm size in our study was 20 acres, while the average was 151 acres. In comparison, 20 acres is the median size of California farms, and the average is 313 acres (USDA NASS 2009a). CSA farm acreage devoted to cropland in our study ranged from under 1 acre to hundreds of acres, with a median of 6.3 acres and 41 acres on average.

Land tenure. The land tenure arrangements that we found were diverse. Forty percent of CSA operators owned the land they farmed, 25% owned some of their land and rented the rest, and 35% rented their land. There were three main types of rental arrangements: Of CSAs that rented, 55% had an agreement at below market value due to a service provided by the farmer to family or other close relationships; 45% had leases at market value; and 10% had a sharecropping arrangement, where the farmer promised a certain percentage of their crop to the landowner (usually just a CSA share).

Organic certification. Forty-five percent of CSAs in our study were certified organic, although 87% of farmers reported meeting or exceeding National Organic Program (NOP) standards (table 1). CSA farm practices described as "beyond organic" came up consistently. Beyond organic refers to methods that exceed those specified in the National Organic Program (NOP) and are seen as more true to the original conception of organic. Across both certified organic CSAs and noncertified CSAs who follow the letter of NOP rules but do not call themselves organic, many described their practices that way (table 1).

Membership. Membership in the CSA farms that we studied ranged by several orders of magnitude (table 2), from more than 10,000 members to fewer than 10. The median CSA membership in 2009 was 60, and the average was 585. In our study, the rapid rise of CSA operations since 2000 was accompanied by an even larger growth in CSA membership (fig. 3). From 1990 to 2010, CSA membership increased by 49 times (4,900%). By decades, membership grew 3.4 times between 1990 and 2000, and 14.2 times from 2000 to 2010. Farmers noted a membership boom between 2005 and 2008, but between 2008 and 2009, at the height of the Great Recession, 22 farms reported gaining members, six maintained members and eight lost members (fig. 4). Many farmers who experienced membership declines noted the difficult economic situation as the likely reason. From 2008 to 2009, the median annual growth rate for those that experienced membership growth was 50%, while the median loss rate was 24% for CSAs that lost members.

Multiple benefits of CSAs

Community Supported Agriculture appeals to an increasing number of people. In recent decades, CSA farm and member numbers have grown rapidly in the United States (Galt 2011) and in California's Central Valley and foothills. CSA numbers in our study area grew from a few in the early 1990s to 74 in 2010. The loss of 28 CSAs found in our initial online search, which were actually defunct when contacted, merits further research. Membership growth has similarly exploded: CSA membership in our sample increased from less than 700 in 1990 to almost 33,000 expected members in 2010. CSA membership characteristics also deserve further study.

The CSA expansion has been accompanied by innovation in CSA types. The CSA concept appears to be both robust

TABLE 1. CSA farmers' description of their practices and their NOP* certification status

Description of farm practices	Certified	Not certified	Total
Beyond NOP standards	8	10	18
Meet NOP standards	13	10	23
Do not meet a small part of NOP standards	—	4	4
Don't know/not enough information	—	2	2
Total	21	26	47

* National Organic Program.

TABLE 2. CSA membership size, 2009

Members	Number of CSAs
Below 20	7
20–49	12
50–99	8
100–499	10
500–999	3
1,000 or more	3

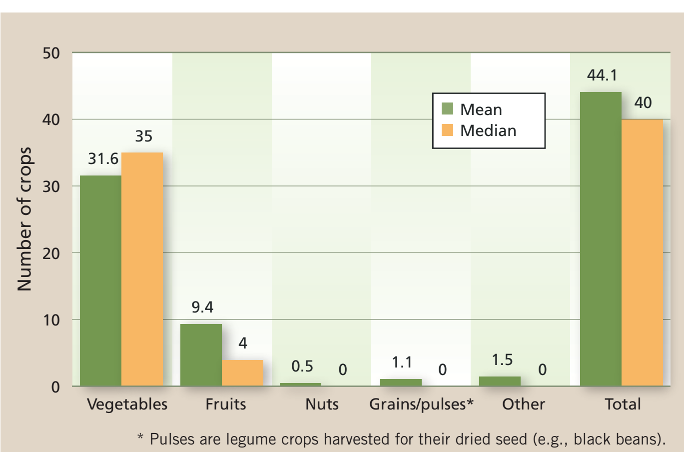


Fig. 2. Number of crops (not varieties) grown per CSA, by crop type ($n = 45$).

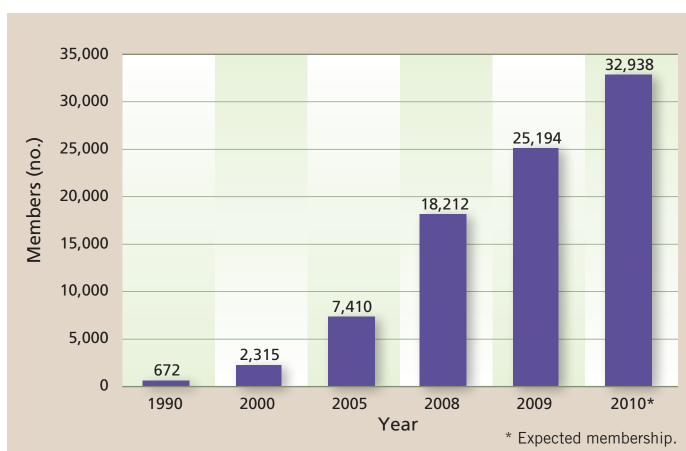


Fig. 3. CSA membership from 1990 to 2010 of all farms in study ($n = 46$).

Fig. 4. Changes in CSA farm membership, 1990–2009 (*n* = 36; includes only surveyed farms in existence in 2008).

and flexible, and different CSA operations are using it to address different challenges. The motivations of farmers for creating CSAs are diverse; ideological predispositions vary greatly, as do farmer attitudes around CSAs as a business and their practices for paying themselves. The diversity of CSA types, and the loose adherence to many of the features of the original concept of CSA, brings into question whether the original model met the needs of the California population. Expanding market opportunities for CSA farmers could involve further adaptations to reach consumers not commonly involved, such as participants in USDA's nutritional assistance programs, including the Special Supplemental Nutrition Program for Women, Infants and Children (WIC) (see page 15).

Despite the diversity of types we identified, CSAs in our study retained a number of core characteristics. Namely, the vast majority of CSA farmers in the Central Valley cultivated high levels of agrobiodiversity, were committed to agroecological practices and embodied an ethic of reducing off-farm resource use. CSA farmers in our study were also dedicated to enhancing the environment on and off their farms and to providing healthy food to their communities. Our study also revealed that CSAs in the Central Valley and surrounding foothills share characteristics with CSAs nationwide: Smaller-scale CSA farmers are more dependent upon the CSA as a market outlet; CSAs are less dependent upon off-farm work than U.S. agriculture generally; CSA farmers are younger, less diverse ethnically, more likely to be women and more formally educated than the general farming population; and CSA farming practices demonstrate strong commitments to environmental ethics (Anderson-Wilk 2007; DeLind and Ferguson 1999; Lass et al. 2003).

CSAs are an increasingly important form of direct marketing, crucial for smaller farms. The gross sales per acre of CSAs were considerably higher in our study than of almost all other agricultural endeavors, even in California where gross sales per acre are high. Although most CSAs are profitable, CSAs are like other forms of U.S. farming in often requiring farm partners to work off farm. Even though a CSA is hard work, farmers tend to find it rewarding. The vast majority were happy with their work and continued to view the CSA as a viable option for small- and medium-scale farmers.

Overall, CSAs provide an increasingly important marketing option for Central Valley and foothill farmers. However, the extent to which existing and new CSAs will be able to expand the movement and collectively increase their market share, rather than increasingly compete with one another for a limited number of members, remains to be seen. With the numerous economic, social and environmental benefits of the CSA model and its growing popularity, it would seem wise to explore the creation of policy instruments, informational clearinghouses, and additional UC Cooperative Extension efforts to support the needs of CSA farmers and members.

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UC Cooperative Extension explores a farm-to-WIC program

by Lucia L. Kaiser, Cathi Lamp, Chutima Ganthavorn, Lucrecia Farfan-Ramirez, Tammy McMurdo, Marita Cantwell *and* Shermain Hardesty

To increase fruit and vegetable consumption, the federal Special Supplemental Nutrition Program for Women, Infants and Children (WIC) distributes cash vouchers to low-income women with children to buy fruits and vegetables. The program reaches almost half of the infants and one-quarter of children under 5 years old in the United States. UC Cooperative Extension (UCCE) conducted a survey of produce preferences and buying habits among WIC participants in Tulare, Alameda and Riverside counties in 2010 to guide the development of a farm-to-WIC program that would connect small local growers to the WIC market. Based on the results, the UCCE team developed a list of 19 produce items to promote in a possible new farm-to-WIC program.


Elizabeth Thomsen/http://www.flickr.com/photos/ethomsen

Participants in the Special Supplemental Nutrition Program for Women, Infants and Children (WIC) can now purchase fresh produce monthly at participating farmers markets or WIC stores.

As interest in sustainable food systems has increased, farm-to-school and farm-to-institution partnerships have evolved to bring locally grown food to nearby communities. Changes in the federal Special Supplemental Nutrition Program for Women, Infants and Children (WIC) are now opening the door for new partnerships between local growers and WIC food outlets. Monthly cash-value vouchers allow participants to choose a wide variety of fruits and vegetables. To inform the possible development of a farm-to-WIC program by UC Cooperative Extension (UCCE), we surveyed WIC participants on their produce preferences and buying habits.

WIC provides supplemental foods to low-income pregnant, breastfeeding, nonbreastfeeding postpartum women, and infants and children up to 5 years old who are at nutritional risk; the program also provides nutrition education and referrals to social and health services. In California, which has the nation's largest WIC program, 82 local agencies serve about 1.43 million participants at 623 local centers. WIC participants redeem vouchers each month at 4,000 grocery stores statewide. About 40% shop at WIC-only stores, which stock and sell only WIC-authorized foods.

All authorized vendors, including the WIC-only stores, are required to stock all WIC foods (see box, page 17). Before 2009, the only produce item in WIC food packages — the particular foods and amounts that may be purchased with the vouchers each month — was fresh carrots. Now, under the new federal guidelines, all stores participating in WIC (both regular grocery and WIC-only stores) must provide a minimum number of fruits and vegetables.

Healthy fruits and vegetables

The U.S. Dietary Guidelines published in 2010 continue to emphasize the importance of consuming more fruits and vegetables to optimize health (USDHHS/USDA 2011). A diet rich in fruits and vegetables has been associated with reduced risks of chronic illnesses such as heart disease, stroke and cancer (Liu 2003). A national longitudinal cohort study that followed participants for 19 years found an association between higher intakes of fruits and vegetables and lower incidence of and mortality from cardiovascular disease (Bazzano et al. 2002). In a recent systematic review, greater intake of green leafy vegetables was associated with the reduced risk of type 2 diabetes (Carter et al. 2010).

Fruits and vegetables are rich in vitamins and minerals, as well as other phytochemicals that may protect against diseases. They also provide potassium and dietary fiber and tend to be less energy dense (lower in calories) than foods with added sugars and solid fats. National studies have found associations between low fruit and vegetable consumption and greater abdominal fat in adolescent boys (Bradlee et al. 2009) and obesity in adults (Ledikwe et al. 2006). Increasing the consumption of fruits and vegetables can be an effective strategy for weight management in combination with other strategies such as caloric restriction and physical activity (Ledoux et al. 2011).

Online: http://californiaagriculture.ucanr.org/landingpage.cfm?article=ca.v066n01p15&fulltext=yes

DOI: 10.3733/ca.v066n01p15

Reaching almost half of infants and one-quarter of U.S. children under 5 years old, the WIC program provides an unparalleled opportunity to increase fruit and vegetable consumption.

Low consumption nationally

California is a major producer of fruits and vegetables in the United States, but these foods are underconsumed in California and other states (Backman et al. 2007). In 2009, only 40% of California adults consumed fruit two or more times per day, and only 27% consumed vegetables three or more times per day (CDC 2010). In a national sample, only 50% of 2- to 5-year-olds surveyed from 1999 to 2002 met the MyPyramid fruit intake recommendation and only 22% met the vegetable intake recommendation; in older age groups, these percentages were even lower (Lorson et al. 2009).

Low-income households, in particular, face barriers to consuming more fruits and vegetables (Dubowitz et al. 2008; Morland and Filomena 2007; Yeh et al. 2008). UCCE research among low-income Latino families in California found that food insecurity — defined as the lack of access of all people at all times to enough food for an active, healthy life — is associated with lower household supplies and consumption of fruits and vegetables (Kaiser et al. 2003, 2004). In addition to household financial constraints, the limited availability of fruits and vegetables in low-income neighborhoods also appears to account for some of the disparities in intake across ethnic groups and socioeconomic levels (Morland and Filomena 2007). Domestic food assistance programs can provide financial incentives for people to buy more fruits and vegetables, and greater demand could ultimately improve local availability. However, small stores in low-income urban and rural neighborhoods find it challenging to supply a variety of high-quality produce at affordable prices.

In 2009, more than 9.1 million low-income women, infants and children received WIC nutrition education and supplementary foods and services, at a cost of $6.5 billion (USDA 2011). Reaching almost half of infants and one-quarter of U.S. children under 5 years old, the WIC program provides an unparalleled opportunity to increase fruit and vegetable consumption (Oliveira and Frazao 2009).

Fresh produce in WIC programs

Historically, the only produce item allowed by federal regulations in the standard WIC food package was fresh carrots, and this food was only available to women who were exclusively breastfeeding their infants (not receiving WIC formula). In 1992, a limited Farmers' Market Nutrition Program began providing vouchers worth about $10 to $30 per year to each WIC recipient to purchase fresh, locally grown fruits and vegetables. In 2007, only about 2.3 million WIC participants received this benefit.

In a demonstration project conducted in 2001, the Public Health Foundation in Los Angeles examined the impact of expanding this WIC benefit by providing $40 per month to postpartum WIC participants for the purchase of fruits and vegetables in either the usual WIC-authorized grocery stores or farmers markets (Herman et al. 2008). Compared to a control group, who received diapers, the intervention group increased their intake of fruits and vegetables and sustained higher consumption levels 6 months after the subsidy ended. Regardless of whether women were allowed to use their vouchers at a supermarket or farmers market, the redemption rate — which reflects the extent to which participants exchanged the vouchers for food — was about 90%. Moreover, participants purchased a wide variety of both fruits and vegetables (Herman et al. 2006).

In 2006, the U.S. Institute of Medicine published recommendations to change the WIC food packages, calling for the distribution of a wide variety of fruits and vegetables (IOM 2005). In October 2009, California WIC implemented a major overhaul of the state's WIC food packages and began distributing cash vouchers worth $6 to $10 per month per recipient (ages 12 months and older) for fruits and vegetables, to be redeemed at any authorized vendor.

New WIC strategies

The U.S. Department of Agriculture's Economic Research Service estimates that the revised WIC food packages will generate $4.6 billion nationwide in annual food retail sales after rebates (Hanson and Oliveira 2009). Of that amount, about $1.3 billion in farm revenues may be linked to WIC foods. (WIC also provides milk, cheese, eggs, beans, cereals and juice.) However, since WIC participants may in part be using vouchers to pay for food they had previously bought with their own funds, a conservative estimate is that the monthly WIC vouchers increase food expenditures by 26%, translating into a net addition to farm revenues of $331 million nationwide.

Achieving both the health and economic benefits of this policy change — the expanded distribution of fruits and vegetables to WIC participants — may require new strategies to improve WIC participants' access to and use of fruits and vegetables. These strategies must consider the special needs of low-income participants with limited access to transportation and of stores with small profit margins within their communities.

Furthermore, the WIC population is ethnically diverse. In California, the majority of participants (78%) are Latino, then white (8%), black (5.5%), Asian (5%) and Native American (0.9%) (California WIC Branch, unpublished data, 2008).

UC Cooperative Extension has developed fact sheets to help WIC participants purchase and prepare fresh produce.

WIC serves a vulnerable group, including pregnant and nursing mothers, and young children who are developing preferences for new foods.

Our working hypothesis was that a farm-to-WIC program, coupled with education on produce stocking for vendors and point-of-purchase information for WIC clients, could help increase the local availability of culturally preferred foods, the redemption of vouchers and, ultimately, the consumption of fresh fruits and vegetables.

UCCE explores farm-to-WIC program

In spring 2010, UCCE conducted a survey among WIC participants in Tulare, Alameda and Riverside counties to guide the development of a farm-to-WIC program that would connect small local growers to the WIC market through local grocery stores and farmers markets. We wanted to determine interest among WIC clients in purchasing locally produced foods and the factors influencing their shopping decisions. The Institutional Review Board at UC Davis approved the study protocol under exempt status.

We pilot-tested the wording and format with 20 English- and Spanish-speaking WIC participants in Yolo County and modified the survey accordingly. The final version contained 21 questions related to WIC shopping practices and educational needs, including client satisfaction with the quality and variety of produce in WIC stores, produce items purchased with WIC vouchers, factors underlying produce choices and information needed to make better use of the vouchers.

In each county, a UCCE staff member and supervisor attended a Web-based training on administering the survey. Then, UCCE staff members interviewed participants in WIC clinics in the three counties while they waited for their mandatory appointments. Criteria for inclusion in the survey were (1) ability to speak English or Spanish well enough to respond to questions, (2) receipt of WIC cash-value vouchers for fruits and vegetables since the rollout in October 2009 and (3) purchaser of most of WIC foods in their household. Our intent was to interview 300 WIC participants (100 from each county) between April and May 2010. Each interview lasted about 10 minutes. Of the 300 WIC clients approached, only 12 did not complete the survey, mainly because they were called for their WIC appointments and did not return to the waiting area.

Two UCCE staff members entered the data in an Excel spreadsheet, which was uploaded and analyzed in SAS version 9.2 (Cary, NC). Basic descriptive statistics included means and frequencies. Chi-square and Wilcoxon rank sum tests were used to examine differences in demographic variables and shopping practices among the three sites.

Shopping practices

Educational level, language preference and ethnicity differed among the three sites (table 1). The participants reported using their WIC fruit and vegetable

WIC foods

WIC food packages include infant jarred fruit and vegetables; milk (mostly lower-fat cow's milk), soy milk and tofu; cheese; eggs; whole grains, including whole wheat bread, brown rice and oatmeal; cold or hot breakfast cereal; peanut butter; beans, peas or lentils (dry or canned); juice, 100% as concentrate or bottled; and fresh, frozen or canned fruits and vegetables.

Although states can limit WIC foods, the California WIC program allows a wide variety of fruits and vegetables. Some specific produce items are not allowed, including any potatoes other than yams or sweet potatoes, *left*; any food or product from a salad bar or deli; party trays; fruit baskets; decorative vegetables and fruits, such as chilies or garlic on a string or painted pumpkins; nuts or fruit-nut mixtures; edible blossoms, such as squash blossoms; bagged salad, vegetable or fruit kits; and dried fruits and vegetables.

Photo: Oliver Hoffmann/iStockphoto.com

California allowable and unallowable WIC foods are listed at:

www.cdph.ca.gov/programs/wicworks/WIC%20Foods/WICAuthorizedFoodListShoppingGuide-4-2010.pdf.

TABLE 1: Demographics of WIC survey participants, 2010

	Alameda (*n* = 88)	Riverside (*n* = 101)	Tulare (*n* = 100)
Age (mean ± SD)*	28.1 ± 6.9	27.6 ± 7.1	28.2 ± 8.0
Education (%)†			
0–2 years	1.1	0.0	3.0
3–6 years	7.8	7.9	18.8
7–11 years	38.9	27.7	25.7
High school/GED	38.9	46.5	40.6
College	13.3	17.8	11.9
Language (%)‡			
English only	40.2	18.8	26.5
Spanish only	32.0	30.7	36.3
English/Spanish	26.8	50.5	33.3
English and other (Hmong)	1.0	0.0	2.0
Spanish/other (Mixtec)	0.0	0.0	1.0
Ethnicity (%)§			
White	1.1	7.9	9.0
Latino	64.0	90.1	86.0
Black	25.8	1.0	1.0
Asian	4.5	0.0	1.0
Native American	0.0	0.0	1.0
Other	1.1	1.0	2.0
Black and Native American	1.1	0.0	0.0
Latino and Black	2.3	0.0	0.0

* Means + standard deviation (SD) not significant (NS) using Wilcoxon rank sum.
† $P < 0.06$, using chi-square analyses.
‡ $P < 0.01$, using chi-square analyses.
§ $P < 0.0001$, using chi-square analyses.

vouchers at a variety of stores (table 2). More of the Alameda (76.3%) and Tulare (45%) county participants reported using the WIC-only stores (either alone or along with a supermarket) than did the Riverside County participants (15.8%).

Stocking produce is relatively new to WIC-only stores; before rollout of the new WIC food packages in October 2009, these stores were only required to stock limited amounts of fresh carrots. Whereas most WIC participants (58.0% to 72.3%) responded that their preferred stores offered many choices, fewer participants (18.5% to 41.0%) rated the produce quality as "excellent." Key factors determining purchase decisions were produce quality and freshness, and nutrient value (vitamins and minerals). Cost seemed relatively less important, possibly because WIC participants were procuring produce with the vouchers.

Among those not using WIC-only stores (n = 73), the main reason for not doing so was inconvenience (45.5%, 41.7% and 19.2% in Alameda, Riverside and Tulare counties, respectively [data not shown]). Low quality and lack of variety of produce in the WIC-only stores were also factors (18.2%, 19.4% and 15.3% in Alameda, Riverside and Tulare counties, respectively).

Using input from UCCE farm advisors in the three counties regarding which crops could be locally grown and the list

TABLE 2. WIC participants' choice of store, satisfaction level and decision-making factors, 2010

Survey question	Alameda (n = 88)	Riverside (n = 101)	Tulare (n = 100)
	.... %		
Where do you shop for fruits and vegetables with your WIC vouchers?*			
Supermarket	21.7	83.2†	40.0
WIC-only store	45.4	8.9	31.0
Supermarket and WIC-only store	30.9	6.9	14.0
Small grocery store	0.0	0.0	4.9
All other and combination	2.1	1.0	10.8
What is the quality of the fruits and vegetables sold at the store where you prefer to use your WIC vouchers?‡			
Unacceptable	0.0	0.0	0.0
Poor	1.1	1.0	0.0
Fair	9.2	11.0	4.0
Good	71.1	59.0	55.0
Excellent	18.5	29.0	41.0
What is the variety of fruits and vegetables sold at the store where you prefer to use your WIC vouchers?§			
No choices	0.0	0.0	0.0
Very few choices	0.0	2.0	1.0
Few choices	8.0	6.9	10.8
Some choices	29.4	18.8	30.9
Many choices	60.8	72.3	58.0
How important are the following reasons when choosing which fresh fruits and vegetables to buy (data for "very important" responses shown):			
I like the taste (NS)	88.5	92.1	88.2
My family likes the taste ($P < 0.02$)	84.5	98.0	85.3
They are on sale ($P < 0.004$)	67.0	73.3	52.0
They are available where I shop ($P < 0.002$)	83.5	95.1	75.5
They are fresh and good quality (NS)	93.8	99.0	96.1
I need them for a recipe or meal (NS)	50.0	63.4	58.8
They have lots of vitamins/minerals (NS)	93.8	99.0	96.1

* $P < 0.0001$, using chi-square analyses.
† Red indicates highest responses for each question.
‡ $P < 0.02$, using chi-square analyses.
§ Not significant, using Wilcoxon rank sum.

TABLE 3. Self-reported fruit and vegetable purchases of WIC participants, 2010*

Item	Alameda (n = 88) Bought	Alameda Would buy	Riverside (n = 101) Bought	Riverside Would buy	Tulare (n = 100) Bought	Tulare Would buy
	.... %					
Fruits						
Blueberries	8.0	42.1	12.9	18.8	7.0	38.0
Cactus fruit	3.4	28.4	4.0	13.9	4.0	28.0
Cantaloupe†	45.5	64.8	57.4	30.7	63.0	79.0
Grapes	83.0	70.5	55.5	41.6	41.0	71.0
Guava	6.8	48.9	6.9	16.8	9.0	53.0
Honeydew melon	9.1	44.3	36.6	27.7	23.0	46.0
Strawberries	77.3	62.5	76.2	42.6	73.0	81.0
Watermelon	34.1	77.3	28.7	29.7	53.0	83.0
Vegetables						
Bell pepper	22.7	51.1	26.7	17.8	33.0	51.0
Bok choi	6.8	15.9	0.0	2.0	4.0	7.0
Broccoli	73.9	69.3	69.3	38.6	77.0	86.0
Cabbage	26.1	58.0	29.7	16.8	48.0	56.0
Cabbage (Napa)	10.2	23.9	7.9	7.9	7.0	27.0
Carrot	59.1	55.7	67.3	25.7	75.0	70.0
Cauliflower	27.3	53.4	32.7	16.8	46.0	58.0
Chard	3.4	27.3	5.0	6.9	7.0	18.0
Chili pepper	15.9	34.1	23.8	19.8	42.0	51.0
Collards	6.8	31.8	4.0	5.0	5.0	9.0
Corn	48.9	71.6	47.5	32.7	56.0	79.0
Daikon	2.3	11.4	1.0	4.0	3.0	5.0
Eggplant	5.7	27.3	6.9	13.9	4.0	17.0
Gai lan	1.1	12.5	1.0	2.0	1.0	6.0
Green beans	29.6	53.4	31.7	16.8	43.0	55.0
Jicama	11.4	40.9	25.7	16.8	31.0	59.0
Lettuce	48.9	69.3	54.5	25.7	60.0	62.0
Long beans	5.7	18.2	1.0	4.0	9.0	23.0
Mustard greens	11.4	31.8	2.0	3.0	3.0	13.0
Nopales (cactus pads)	9.1	31.8	9.9	18.8	25.0	44.0
Onion	54.6	60.2	49.5	26.7	61.0	74.0
Radish	8.0	42.1	12.9	12.9	34.0	56.0
Spinach	25.0	53.4	31.7	16.8	29.0	47.0
Summer squash	20.5	37.5	22.8	17.8	44.0	51.0
Sweet potato	40.9	50.0	26.7	20.8	32.0	47.0
Tomatillo	20.5	42.1	26.7	13.9	45.0	53.0
Tomato	70.5	69.3	79.2	33.7	85.0	75.0
Winter squash	3.4	19.3	8.9	8.9	8.0	23.0

* WIC participants circled pictures of items they had bought with WIC vouchers and items they would buy if available in their preferred stores.
† Red indicates produce identified in the survey as candidates for a California farm-to-WIC program.

of WIC-allowable foods (see box, page 17), we included survey questions about participants' use of WIC vouchers in the past 6 months to purchase 36 different produce items. The survey asked whether the item had been purchased (bought) and whether they would be interested in buying it in the future (would buy) if it were available in their preferred store. More than 30% of participants in all locations reported having bought or having a future interest in buying most items, except for bok choi, cactus fruit, chard, daikon, eggplant, gai lan, long beans, Napa cabbage and winter squash (table 3). In addition, the survey allowed participants to write in other commonly purchased items. The most common responses (in rank order) were banana, apple, orange, mango, avocado and pineapple.

In a joint meeting, UCCE farm and nutrition advisors from the three counties reviewed the survey results and generated a shorter list of fresh fruits and vegetables as a starting point for discussions with growers and WIC vendors. Key considerations included (1) crop grown in the local area, (2) demand from WIC participants (greater than 30% purchased or expressed an interest in purchasing), (3) postharvest handling manageable for growers and stores and (4) appropriate for the WIC population of pregnant women, infants, toddlers and young children, including nutritional benefits and taste acceptability to young children.

Weighing the considerations equally, the UCCE team identified 19 candidate produce items: bell pepper, broccoli, cabbage, cantaloupe, carrot, collards, corn, grapes, green beans, lettuce, mustard greens, nopales (cactus pads), spinach, strawberries, sweet potato, tomatillo, tomato and watermelon (table 3). Although mustard greens and collards were not popular across all sites, the advisors gauged a potential market in Alameda County, so these were retained. Based on write-in responses, oranges were added.

Next steps

The survey showed that WIC participants were interested in purchasing fresh produce with better quality and more variety. Some WIC participants that we surveyed said they avoided shopping at WIC-only stores in part because these interests were not met. The survey helped to generate a list of 19 produce items to explore in a possible farm-to-WIC program.

The UCCE team met with growers and local WIC vendors to explore these marketing opportunities. The nutrition advisors and staff have developed and pilot-tested fact sheets for a limited-literacy audience (see page 16). Each one features a single fruit or vegetable, with tips on easy and appealing ways to prepare and serve them to young children. Along with training on safe and careful handling of fresh produce, stores involved in the project (rather than farmers markets) will receive these point-of-purchase materials to stimulate increased sales of fresh produce.

The study and these subsequent activities provide an opportunity for us to further examine the feasibility of a UCCE-led farm-to-WIC program. The purpose of such a program would be to increase the consumption of a wide variety of fresh produce, with a focus on locally grown produce when available. They also provide insights into UC's role in benefiting farmers and improving access of low-income communities to a wide variety of healthy, fresh produce.

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Crop rotation and genetic resistance reduce risk of damage from Fusarium wilt in lettuce

by Jeness C. Scott, Thomas R. Gordon, Sharon C. Kirkpatrick, Steven T. Koike, Michael E. Matheron, Oswaldo E. Ochoa, Maria J. Truco *and* Richard W. Michelmore

Fusarium wilt of lettuce, caused by the soilborne fungus* Fusarium oxysporum *f. sp.* lactucae*, affects all major lettuce production areas in California and Arizona. In trials at UC Davis, we found that lettuce cultivars differ significantly in susceptibility to the disease, with some leaf and romaine types highly resistant under all test conditions. For more susceptible cultivars, disease severity is strongly influenced by inoculum levels and ambient temperature. Management of Fusarium wilt requires an integrated approach that includes crop rotation to reduce soil inoculum levels and the use of resistant cultivars during the warmest planting windows.

Lettuce cultivars have varying susceptibility to Fusarium wilt, a fungal disease. When grown in infested soils, Caesar was highly disease resistant. *Inset, top*, Grand Max and, *middle and bottom*, Early Queen were progressively less resistant.

Lettuce is the fifth most valuable agricultural commodity in California, with a farm-gate value of over $1.7 billion in 2009. Successful production requires effectively managing diseases that reduce yield, lower quality and generate control costs. Lettuce (*Lactuca sativa*) is subject to diseases such as downy mildew, caused by *Bremia lactucae*, and lettuce drop, caused by *Sclerotinia* spp. (both resident in California for many years), as well as a more recent problem, Fusarium wilt.

Fusarium wilt was discovered in California in 1990, when plants with symptoms that ranged from mild stunting to complete collapse were observed in two fields near Huron, in the San Joaquin Valley. Diseased plants had severely rotted taproots, from which a fungus identified as *Fusarium oxysporum* was isolated (Hubbard and Gerik 1993). *F. oxysporum* is widespread in agricultural soils throughout the world and is commonly isolated from the roots of healthy plants. Most strains are weak parasites that grow only in the root cortex and cause no visible damage to their host plant. However, some strains invade the water-conducting tissue (xylem) and restrict the flow of water and cause wilting.

The isolate of *F. oxysporum* recovered from the diseased California plants was pathogenic only on lettuce, not on any other crops tested (Hubbard and Gerik 1993). Host-specific, disease-causing strains of *F. oxysporum* are referred to as formae speciales (f. sp.) to distinguish them from nonpathogenic strains. The host-specific strain causing disease on lettuce is known as *F. oxysporum* f. sp. *lactucae*.

The origin of the pathogenic strain causing Fusarium wilt in California lettuce is unknown, but it may have been introduced from overseas. The same pathogen has been affecting lettuce in Japan since 1955 (Matuo and Motohashi 1967). It may have been transported on lettuce seed, which can be contaminated with *F. oxysporum* f. sp. *lactucae*; for example, the pathogen has been recovered from commercial lettuce seed lots in Italy (Garibaldi et al. 2004). Fusarium wilt has recently appeared in many countries, including Iran, Taiwan, Italy, Portugal and Brazil.

When a lettuce plant affected by Fusarium wilt dies, the pathogen can produce survival structures (chlamydospores) within diseased tissue. Chlamydospores are incorporated into soil with crop residues, and they may survive there for one to several years, infecting the roots of any susceptible crop that is planted. Initially, California lettuce growers could avoid Fusarium wilt by not returning to affected fields. However, avoidance became increasingly difficult as *F. oxysporum* f. sp. *lactucae* spread in the San Joaquin Valley, probably in soil moved around on farming equipment. Soil transportation may have been how the pathogen became established in

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Arizona and coastal California, where Fusarium wilt was recognized in 2001 and 2002, respectively.

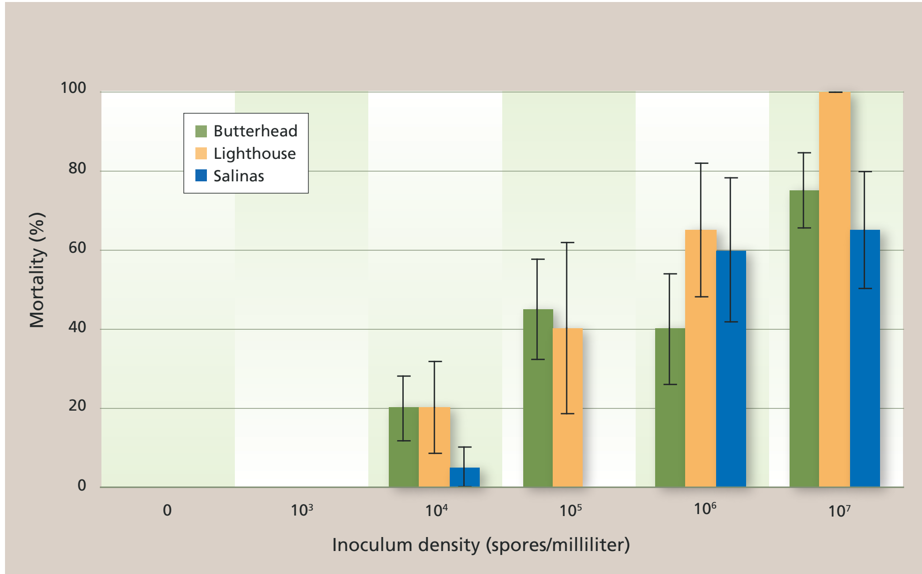

Fig. 1. Mortality resulting from inoculations of lettuce seedlings with water (inoculum density = 0) or one of five inoculum densities of the Fusarium wilt pathogen.

Survival in soil

If the Fusarium wilt pathogen is established in a field, it may be possible to eradicate it through soil fumigation; the chances are best when the affected area is limited in size and can be treated thoroughly. Without intervention, an infestation will expand as infective propagules (spores or mycelium of the pathogen) are moved with soil during cultivation. Continued production of lettuce in an infested field requires careful management to minimize losses. Even if the pathogen can be eradicated, reintroduction remains a risk, and routine preplant fumigation is generally not an option because of costs and regulatory restrictions. Consequently, growers must rely on the attrition of inoculum that occurs naturally when nonsusceptible crops are grown instead of lettuce (i.e., crop rotation).

To estimate the longevity of pathogen propagules, we transported soil from a naturally infested commercial lettuce field in Arizona to establish microplots at the University of Arizona's Yuma Agricultural Center. Plots were maintained in a fallow condition (weed-free), and soil samples were taken at intervals over 34 months. Soil dilution plating was used to enumerate colony-forming units (CFUs) of *F. oxysporum* f. sp. *lactucae*, based on the pathogen's distinctive appearance on a selective growth medium (Scott, Gordon, et al. 2010). After 6 and 12 months, the inoculum density (number of CFUs per unit weight of soil) had declined by 71% and 86%, respectively. The decline in viability continued at a slower rate; after 34 months, *F. oxysporum* f. sp. *lactucae* was detectable at 482 CFUs per ounce (17 CFUs per gram), representing 0.5% of the starting population. We estimated the half-life (the time interval required for inoculum to decline to 50% of the original level) of the fungal population in soil to be 5.9 ± 0.7 months.

These results imply that keeping a field free of a susceptible crop for a year should dramatically reduce the density of pathogen inoculum — provided there is no significant reproduction on weeds or a rotation crop — but that the pathogen will likely persist at a low level for at least several years. The inoculum density that constitutes a threshold below which economic damage will not occur depends on other factors, particularly the inherent susceptibility of the crop and the level of inoculum to which it is exposed.

Effect of inoculum density

We tested the effect of inoculum density on the susceptibility of three lettuce cultivars using root-dip inoculations in a greenhouse trial. Seedling roots of the cultivars Butterhead, Lighthouse and Salinas were submerged in a suspension of pathogen spores at each of five different inoculum densities: 10^3, 10^4, 10^5, 10^6 and 10^7 spores per milliliter. Pathogen spores were obtained from a known virulent strain originally isolated from a diseased lettuce plant in California (Hubbard and Gerik 1993).

Inoculated seedlings of all three cultivars developed symptoms of Fusarium wilt, even at the lowest dose of 10^3 spores per milliliter, although no mortality was observed at this level (fig. 1). No disease symptoms were observed in seedlings that were dipped in water rather than a spore suspension. Based on logistic regression, increasing the inoculum density significantly elevated the likelihood of mortality ($P < 0.001$). The cultivar Salinas appeared more resistant than the other two cultivars at both 10^4 and 10^5 spores per milliliter, but this difference was less evident at 10^6 and 10^7 spores per milliliter (fig. 1).

These results suggest that screening for resistance at 10^5 spores per milliliter

In trials conducted at UC Davis, crisphead, romaine and leaf lettuce were evaluated on a 4-point scale for susceptibility to Fusarium wilt. *Above*, co-authors Thomas Gordon (left) and Maria Truco.

may provide better resolution of differences in susceptibility than higher inoculum levels. Most important is that such differences are predictive of how cultivars will respond under field conditions. If inoculation with 10^5 spores per milliliter understates the disease pressure to which plants would likely be subjected in a naturally infested field, differences apparent at this inoculum level may be misleading. Conversely, higher inoculum levels may overstate natural disease pressures and therefore fail to detect useful levels of disease resistance.

Predicting susceptibility

To assess the relationship between cultivar response to seedling inoculations and susceptibility under field conditions, we established an infested plot on the Department of Plant Pathology research farm at UC Davis. Lab-reared inoculum of *F. oxysporum* f. sp. *lactucae* was incorporated into the soil in 2002, and successive crops of susceptible lettuce cultivars were grown for 3 years in order to ensure high levels of inoculum throughout the field. In 2006, seedlings of cultivars that differed in susceptibility to root-dip inoculations were transplanted into the infested field. The trial was replicated three times during the season. In each replication, plants were rated for disease severity on a scale of 1 to 4, with 1 for no symptoms, 2 for mild stunting, 3 for severe stunting and some leaf yellowing or necrosis, and 4 for plant mortality.

Final disease severity ratings, taken 6 weeks after planting, were compared to ratings recorded for the same set of cultivars subjected to seedling root-dip inoculations at 10^5 and 10^6 spores per milliliter, using correlation analysis. The results showed the ranking of cultivars based on a root-dip assay to be highly and significantly correlated with rankings based on field trials. For root-dip assays using 10^5 and 10^6 spores per milliliter, Pearson correlation coefficients ranged from 0.844 to 0.893, and from 0.792 to 0.826, respectively, for three replications of the field trial. These findings indicate that correlations with susceptibility under field conditions were somewhat stronger when seedlings were inoculated with 10^5 as opposed to 10^6 spores per milliliter, but also that inoculations at either inoculum level reliably indicated differences in susceptibility to Fusarium wilt.

Cultivar field trials

Field trials revealed significant differences between cultivars in susceptibility to Fusarium wilt. At 3 weeks after planting, two leaf lettuce cultivars (Lolla Rossa and Red Rossa) and three romaine cultivars (Caesar, Green Forest and King Henry) had low disease-severity ratings and appeared resistant. Two crisphead lettuce cultivars (Beacon and Early Queen) were highly susceptible, and three other crisphead cultivars (Grand Max, Kahuna and Salinas) were intermediate between these extremes (fig. 2). Salinas was the most resistant of the crisphead lettuce cultivars tested by Hubbard and Gerik (1993) and suffered limited mortality from Fusarium wilt in a field trial in Arizona (Matheron et al. 2005).

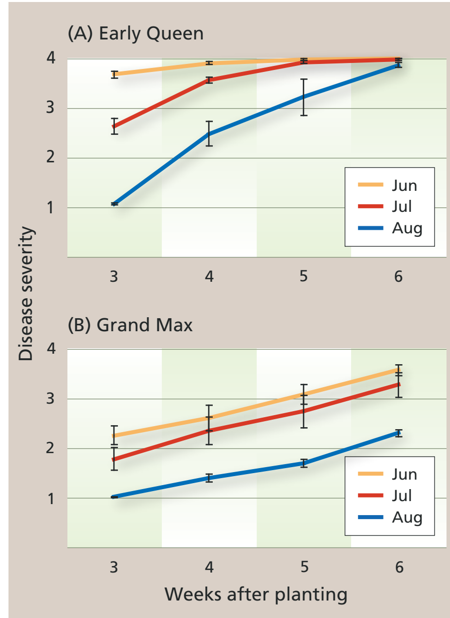

Fig. 3. Disease severity over time in three plantings (established in June, July and August) of crisphead lettuce cultivars (A) Early Queen and (B) Grand Max. Disease severity: 1 = no symptoms, 2 = mild stunting, 3 = severe stunting, some leaf yellowing or necrosis, 4 = plant mortality.

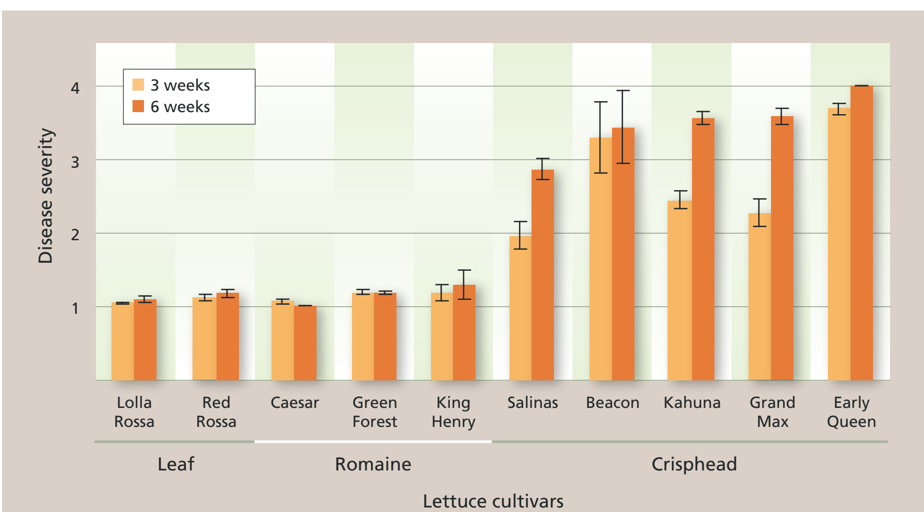

Fig. 2. Severity of symptoms of Fusarium wilt in two leaf lettuce cultivars, three romaine cultivars and five crisphead lettuce cultivars, 3 and 6 weeks after transplanting into a field infested with Fusarium wilt pathogen. Disease severity: 1 = no symptoms, 2 = mild stunting, 3 = severe stunting, some leaf yellowing or necrosis, 4 = plant mortality.

By the final rating, 6 weeks after planting, differences among the crisphead lettuce cultivars had largely disappeared (fig. 2). Although Salinas and Grand Max are more resistant to Fusarium wilt than other crisphead lettuce cultivars, their level of resistance may be insufficient to prevent severe damage. On the other hand, leaf and romaine cultivars retained low severity ratings until the end of the season. However, Scott, Kirkpatrick, et al. (2010) found that some leaf and romaine cultivars tested under greenhouse conditions were severely damaged by Fusarium wilt, so there was not a consistent association between cultivar type and susceptibility.

Effects of temperature

In the field trials at UC Davis, disease developed more rapidly in the first (June) trial than in the second (July) and third (August) trials. This is apparent from a comparison of the rate at which disease severity increased in the susceptible cultivar Early Queen. In the June trial, mean disease severity for Early Queen was 3.7 (on a scale of 1 to 4) at 3 weeks after planting, compared to 2.6 and 1.1 at the same interval in the July and August plantings, respectively (fig. 3A). Disease severity was lower in the August trial throughout the evaluation period, until the final rating at 6 weeks after planting, when mortality was 100%, or nearly so, regardless of planting date. On the other hand, for the Grand Max cultivar the differences between trials remained apparent even at the end of the season (fig. 3B).

Differences in disease severity corresponded to differences in temperatures, Air temperatures were highest during the June planting, with a mean daily high/low of 99°F/59°F (37°C/15°C). They were progressively lower during trials in July, 95°F/55°F (35°C/13°C), and August, 90°F/52°F (32°C/11°C). These findings suggest that higher temperatures may render lettuce more prone to damage from Fusarium wilt.

To look more directly at the effects of temperature on disease development, we conducted tests in controlled environment chambers set to a 14-hour photoperiod and one of three temperature regimes: cool, day/night temperatures of 73°F/64°F (23°C/18°C); moderate, 82°F/68°F (28°C/20°C); or warm, 91°F/73°F (33°C/23°C). Seed was sown into potting mix infested with the Fusarium wilt pathogen at 141,751 CFUs per ounce (5×10^3 CFUs per gram) (Scott, Gordon, et al. 2010).

One month after seeding, plants were rated for disease severity. The results confirmed a significant effect of temperature on the development of Fusarium wilt, with disease being most severe at the highest temperatures. Under cool conditions, even the susceptible cultivar Early Queen suffered relatively little damage, whereas it showed maximal disease severity at the highest temperature (fig. 4). A similar trend was evident for the cultivar Grand Max, although it was less severely affected than Early Queen at all tested temperatures. In contrast, the highly resistant cultivar Lolla Rossa remained healthy regardless of the temperature regime (fig. 4).

Observations in California's coastal lettuce-growing districts support the importance of temperature as a factor affecting development of Fusarium wilt. Fields in the Pajaro Valley and King City area have become infested with *F. oxysporum* f. sp. *lactucae*, and Fusarium wilt of lettuce has occurred in both areas. Whereas Fusarium wilt in the Pajaro Valley has remained insignificant, the incidence and severity of disease has increased in the King City area. In the Pajaro Valley, mean daily high temperatures during the main lettuce-growing season (May through October) remain below 73°F (23°C); corresponding temperatures in the King City area are 77°F (25°C) or above, reaching a high of 84°F (29°C) for a 3-month period (July through September) (table 1). Higher temperatures may help to explain the greater incidence and severity of Fusarium wilt in the King City area.

The effect of temperature on Fusarium wilt has important implications for disease management. Lettuce is grown throughout the year in California and Arizona, and the risk of damage from Fusarium wilt is highest during the warmest periods. Field trials conducted by Matheron et al. (2005) in Arizona showed a significant effect of planting date on the incidence of Fusarium wilt. The highest incidence (88%) occurred in September plantings, which corresponded to a mean soil temperature of 79°F (26°C), whereas the lowest disease incidence (1%) was in December plantings, when mean soil temperature was 57°F (14°C). These findings indicate that losses to Fusarium wilt may be greatly reduced by not using susceptible cultivars during warm growing periods.

The effect of temperature on disease severity also has relevance to screening for resistance to Fusarium wilt. For example, when grown under cool conditions, many lettuce cultivars were essentially indistinguishable, whereas clear differences in susceptibility were apparent under warm conditions (Scott, Gordon, et al. 2010). Better resolution of differences in susceptibility should facilitate the process of identifying sources of resistance and transferring the determinants of resistance into other genetic backgrounds.

Genetic improvements

A continuing objective of our research is to understand the genetic basis of resistance and to elevate the resistance of

Lettuce is grown throughout the year in California and Arizona, and the risk of damage from Fusarium wilt is highest during the warmest periods.

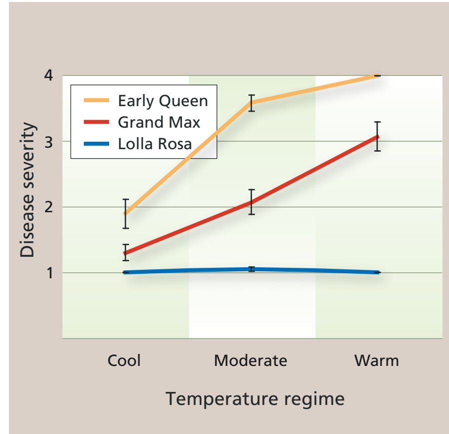

Fig. 4. Severity of Fusarium wilt symptoms in a leaf lettuce cultivar (Lolla Rossa) and two crisphead lettuce cultivars (Grand Max and Early Queen) maintained under three temperature regimes. Disease severity: 1 = no symptoms, 2 = mild stunting, 3 = severe stunting, some leaf yellowing or necrosis, 4 = plant mortality.

TABLE 1. Mean daily temperatures in coastal growing areas affected by Fusarium wilt

Location		Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
		°F (°C)							
King City*	High	67 (19.4)	72 (22.2)	77 (25.0)	81 (27.2)	84 (28.9)	84 (28.9)	84 (28.9)	78 (25.5)
	Low	38 (3.3)	40 (4.4)	45 (7.2)	48 (8.9)	50 (10.0)	51 (10.5)	48 (8.9)	44 (6.7)
Pajaro Valley†	High	62 (16.7)	68 (20.0)	69 (20.5)	71 (21.6)	72 (22.2)	72 (22.2)	73 (22.8)	72 (22.2)
	Low	41 (5.0)	43 (6.1)	48 (8.9)	50 (10.0)	52 (11.1)	52 (11.1)	50.9 (10.5)	49 (9.4)

* Source: US Department of State 2008.
† Citydata.com 2011.

crisphead lettuce cultivars to Fusarium wilt. To this end, we analyzed recombinant inbred lines (RILs) developed from a cross between the crisphead lettuce cultivar Salinas, which has moderate resistance to Fusarium wilt, and Valmaine, a highly resistant romaine cultivar.

RILs are populations derived from a cross between two inbred lines to produce an F_1 hybrid that is subsequently self-pollinated for several generations to capture and immortalize the variation segregating in the cross. A total of 147 RILs were tested for susceptibility in the infested plot at UC Davis during the summers of 2007 and 2008.

To analyze the genetics of resistance, we determined the segregation of 76 polymorphic Illumina GoldenGate SNP markers (Michelmore Laboratory 2011) to genetically characterize each RIL. SNP (single nucleotide polymorphism) markers are differences in the chromosomal DNA sequence that occur frequently in many genomes. Such markers allow the inheritance of each chromosomal region to be analyzed and correlated with segregating traits (e.g., disease resistance). Some traits are determined by and therefore inherited as single genes. However, many are determined by several genes that are located in multiple positions in the genome. These are known as quantitative trait loci (QTLs). Alternative versions of each QTL are referred to as alleles.

Analysis of the segregation of resistance relative to each SNP marker identified three QTLs for resistance to Fusarium wilt on chromosomal linkage groups (LGs) 1, 2 and 7. For the QTLs on LG1 and LG2, the Valmaine allele conferred resistance; on LG7, the Salinas allele was responsible for resistance. Although Valmaine has a high level of resistance compared to Salinas, our findings indicate that Salinas has a gene conferring a low level of resistance that is distinct from those in Valmaine, and that combining these positive alleles from both parents provides higher levels of resistance than is conferred by either parent. The more extreme resistance and susceptibility in some RILs — resulting from the combining of alleles from both parents such that some RILs manifest either greater susceptibility than Salinas or greater resistance than Valmaine — is known as transgressive segregation (fig. 5).

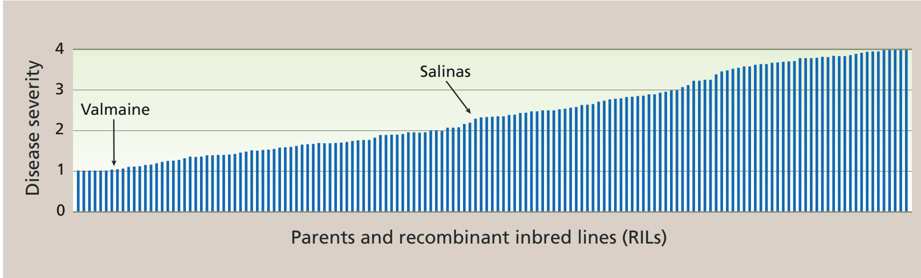

Fig. 5. Distribution of disease severity scores. Recombinant inbred lines with transgressive segregation for resistance were more resistant than Valmaine cultivar and lines with transgressive segregation for susceptibility showed more severe disease symptoms than Salinas cultuvar. Disease severity: 1 = no symptoms, 2 = mild stunting, 3 = severe stunting, some leaf yellowing or necrosis, 4 = plant mortality.

We have identified other resistant romaine and red leaf cultivars and started developing populations to determine the genetic basis of their resistance. Breeding is under way to transfer the resistance genes from Valmaine to crisphead types that will be aided by molecular markers linked to the QTL. The process is time consuming, so it will be several years before highly resistant crisphead cultivars are available.

Reducing lettuce damage

Damage from Fusarium wilt can be avoided by not growing a susceptible cultivar in a field with a history of the disease. Where the pathogen is present, disease severity is influenced by three factors: cultivar susceptibility, the abundance of pathogen inoculum and ambient temperatures during the growing season. Highly resistant cultivars appear to remain healthy under all conditions, but for most cultivars — including all crisphead types that have been tested — disease severity increases with higher soil inoculum densities and warmer weather.

The risk of severe Fusarium wilt damage may be reduced by crop rotation to allow for the attrition of pathogen propagules in the soil, and by not growing susceptible cultivars during the warmest planting windows. In the future, highly resistant cultivars of multiple types will be available for vulnerable production areas and warm periods of the season.

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RESEARCH ARTICLE ABSTRACT

Citrus growers vary in their adoption of biological control

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

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

Jack Kelly Clark/UC Statewide IPM Program

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

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

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

Natural enemies of citrus pests

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

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

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(Editor's note: Full text also includes findings on citrus red mite, citrus thrips and cottony cushion scale.)

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DOI: 10.3733/ca.E.v066n01p29

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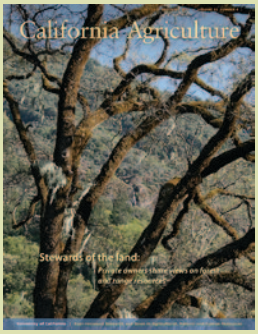

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RESEARCH ARTICLE

Totally impermeable film retains fumigants, allowing lower application rates in strawberry

by Steven A. Fennimore *and* Husein A. Ajwa

The California strawberry industry is highly dependent on soil fumigation to control soil pests and maintain high productivity. Plastic films are used to hold fumigants in the soil at the doses needed to control pests and to prevent the loss of fumigant. Totally impermeable film (TIF) was compared to standard film (STD) for the retention of soil fumigants. 1,3-dichloropropene plus chloropicrin concentrations under TIF were 46% to 54% higher than under standard film, and higher fumigant concentrations under TIF were correlated with higher strawberry fruit yields and better weed control. The results suggest that to achieve fruit yield and weed control similar to methyl bromide and chloropicrin, 33% less 1,3-dichloropropene plus chloropicrin is needed under TIF than standard films.

About 80% of California strawberry fields, such as these in Santa Maria, are treated with soil fumigants prior to planting. Plastic tarps are applied to prevent leakage of the fumigants.

The California strawberry industry produces about 85% of the strawberries grown in the United States, on 37,000 acres, with a value of $1.5 billion in 2008 (ERS 2009). To control soilborne diseases and weeds, California strawberry fields have long been fumigated with methyl bromide (MB) plus chloropicrin (Pic). However, methyl bromide is being phased out as an ozone-depleting substance under the Montreal Protocol (USDS 2009), an international treaty. Currently, some California strawberries can still be treated with methyl bromide under a critical-use exemption, subject to annual review by parties to the Montreal Protocol.

Alternative fumigants permitted for use in California strawberries are 1,3-dichloropropene (1,3-D), chloropicrin and, as of December 2010, methyl iodide. About 81% of California strawberries are grown in soils that were previously treated with chloropicrin (Pic), while 30% are also fumigated with 1,3-D and 43% with methyl bromide (CDPR 2008).

Since soil treatments began in the 1960s, entire fields have been covered with polyethylene film to hold in the fumigant at concentrations needed to kill soil pests (called "flat fumigation") (Wilhelm and Paulus 1980). More recently, a sizable portion (45% to 55%) of strawberry acreage has been treated with fumigants applied to beds via the drip irrigation system (Ajwa et al. 2002; USDS 2009).

The major alternatives to methyl bromide, 1,3-D and chloropicrin, are heavily regulated. The transition away from methyl bromide to alternatives has been complicated by regulations aimed at protecting workers and others from exposure to fumigants. In California, 1,3-D use per 36-square-mile township is limited to 90,250 pounds, called a "township cap," which severely limits its availability in key strawberry production areas (Carpenter et al. 2001). The recent critical-use nomination for strawberry (allowing methyl bromide use) indicates that "township caps currently limit the use of 1,3-D on 40% to 62% of total strawberry land" (USDS 2009). In other words, methyl bromide use continues in California because restrictions on alternative fumigants leave few options.

Among the reasons that fumigants are so heavily regulated in California is that they are classified as volatile organic compounds (VOCs). Alternative fumigants such as 1,3-D are released into the air and, after reacting with nitrogen oxides, can convert to form ground-level ozone — a harmful air pollutant (Gao 2009; Segawa 2008). Regulations have been developed to reduce the contribution of fumigants to ozone formation, which, for example, has seriously affected the use of fumigants in Ventura County, a key strawberry production area.

Fumigants and barrier films

Gas-impermeable films can minimize fumigant emissions, increase their retention over time and reduce the amount of fumigant needed for effective pest control (Gamliel et al. 1998; Minuto et al. 1999; Wang et al. 1999). The use of virtually

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impermeable film (VIF) can greatly reduce fumigant emissions and enhance their distribution in soil, in comparison with conventional polyethylene films or uncovered soil (Chellemi and Mirusso 2002; Nelson et al. 2001). VIF differs from traditional high-density polyethylene tarps in that it has additional gas-impermeable layers, such as nylon or polyaminides, between the polyethylene layers (Wang et al. 1997).

Fumigant concentrations of 1,3-D and chloropicrin were higher under VIF than low-density polyethylene (LDPE) tarp, 1 to 4 days after drip fumigation (Desaeger and Csinos 2005). The improved retention of fumigants under VIF also provides more opportunity for them to degrade in the soil rather than be released into the atmosphere (Wang and Yates 1998). A number of researchers have found that VIF as a tarp can reduce the amount of 1,3-D plus chloropicrin needed for effective soil disinfestations by 50% (De Cal et al. 2004; Medina et al. 2006; Porter et al. 2006). Santos et al. (2005, 2007) found that reducing methyl bromide plus chloropicrin rates by one-half under VIF controlled nutsedge similarly to the full-rate of 350 pounds per acre applied under standard films.

A relatively new barrier, totally impermeable film (TIF), has been shown to apply easily and retain fumigant better than VIF (Ajwa 2008; Chow 2008). TIF is a five-layer film with two thin ethylene vinyl alcohol layers embedded in three layers of standard polyethylene film (Chow 2008).

Our studies evaluated the compatibility of TIF and standard films with the two major fumigant application methods for strawberry, broadcast fumigation and chemigation. The primary objective was to compare fumigant retention under TIF and standard film. Secondary objectives were to measure the effects on strawberry fruit yield and weed control.

TIF field evaluations

Broadcast fumigation trial (2007). We compared the retention of methyl bromide plus chloropicrin under TIF and standard films at a commercial farm near Salinas in 2007. The soil was a Chualar sandy loam. Methyl bromide 57% plus chloropicrin 43% (weight per weight [w/w]) and 1,3-D 61% plus chloropicrin 35% (w/w) (trade name Telone C35), both at 350 pounds per acre, were applied by a commercial applicator (TriCal, Hollister, CA) on Oct. 15, 2007. As the fumigant was applied, it was immediately tarped by 13-foot-wide standard film (STD) (TriCal, 1-mil-thick [1 mil = 1/1000th inch] high-density polyethylene) or 13-foot-wide TIF (Raven, Sioux Falls, SD; 1.4-mil thickness).

A meter was used to measure volatile organic compounds (VOCs), which can react with nitrogen oxides to form air pollutants.

The plots were 280 feet long and 33 feet wide to allow for three passes, each 11 feet wide, of the application tractor. The films were 13 feet wide overall with 1 foot on the leading edge used to anchor the film in the soil and 1 foot on the trailing edge used to glue to the leading edge of the previous pass, creating a 1-foot overlap. Hence, the applied film is like rows of overlapped roofing shingles. The proprietary glue used by the commercial applicator adhered to the TIF film and held it in place without incident.

Each treatment was replicated two times and arranged in a randomized complete block design. Fumigant concentrations under the tarp were monitored with a MiniRae VOC meter (Rae Systems, San Jose, CA) at 3, 27, 51, 76, 97, 120 and 166 hours after application. The MiniRae VOC meter uses a photo ionization detector to measure the concentrations of volatile compounds such as fumigants. Fumigant samples were taken from airspace between the soil surface and the tarp at three random locations near the center of the plots. The film was cut and removed 192 hours after application.

The field was then prepared for strawberry planting by the installation of 52-inch-wide raised beds with two drip irrigation lines per bed. 'Albion' strawberry was transplanted on Nov. 11, 2007. Strawberry fruit were harvested from two 40-plant sample stations per plot from April 18 to Sept. 1, 2008, and fruit were sorted into marketable and cull fruit by a trained crew. Weeds were sampled from two 125-square-foot sample areas on Feb. 15, April 28 and July 8, 2008.

Chemigation trial (2008). In 2008, we evaluated TIF at the USDA Agricultural Research Service farm on Spence Road near Salinas. The soil was a Chualar sandy loam. We injected 1,3-D 35% plus chloropicrin 60% plus an emulsifier 5% (w/w) (trade name Pic-Clor 60) through the drip irrigation system (chemigation) on Oct. 21, 2008, at 50, 100, 200, 300 and 400 pounds per acre, under both standard (TriCal, 1 mil) and TIF (Raven, Sioux Falls, SD; 1.4 mil) film (Ajwa et al. 2002).

Briefly, the fumigants were injected in a closed system directly from nitrogen-pressurized cylinders and metered into irrigation water with a flow meter (Key Instruments, Trevose, PA; McMaster-Carr Supply, Los Angeles, CA). A static mixing device (TAH Industries, Robbinsville, NJ) was installed at the point of injection to mix fumigants with irrigation water before distribution via the drip irrigation system. A backflow prevention device (Amiad Filtration Systems, Oxnard, CA) was used to prevent contamination of the water source. An emulsifiable formulation of methyl bromide 57% plus chloropicrin 43% (w/w) was applied on Oct. 29, 2008, at 350 pounds per acre, also through the drip irrigation system.

Each treatment was replicated four times, and the trial was arranged in a randomized complete block design. Plot sizes were a single 52-inch-wide by 75-foot-long bed. Fumigant concentrations under the tarp were sampled at one location near the plot center with a MiniRae VOC meter as described above, at 3, 8, 24, 48, 72, 96, 144, 192, 240 and 336 hours after application. The MiniRae meter was calibrated with known concentrations of 1,3-D and chloropicrin prior to each sampling.

The plastic films were left on the beds for the length of the strawberry season. Before transplanting strawberries, planting holes were punched in the bed, and 'Albion' strawberry was transplanted by hand into all plots on Nov. 24, 2008. Visual crop injury was estimated on Jan. 6, 2009, using a scale of 0 = safe to 10 = dead. On

March 10, 2009, diameters were measured on 20 plants per plot. Fruit were harvested from 50 sample stations in each plot once or twice weekly as needed from March 30 until Oct. 30, 2009. Fruit were graded as described in the 2007 trial.

Weed measurements. Weed densities were measured in 2007 and 2008. In 2008, nylon bags containing yellow nutsedge tubers and weed seeds (common chickweed, prostrate knotweed, little mallow and common purslane) were buried in each plot before the fumigant application, at a depth of 6 inches. These species were evaluated because they represent a range of susceptibility to fumigants from difficult (nutsedge and little mallow), to intermediate (knotweed), to easy (chickweed and purslane). Little mallow and chickweed are common in strawberry.

Weed seeds were retrieved 2 weeks after the methyl bromide plus chloropicrin application, and their viability was determined. The yellow nutsedge was planted in potting soil and placed in an illuminated growth chamber at 85°F for 4 weeks. Weed seed viability was determined using tetrazolium assays. Weed density ratings were measured in 125-square-foot sample areas on the bed tops, on Feb. 15, April 28 and July 8, 2008 (2007 trial), and Dec. 11, 2008, and Feb. 3 and March 17, 2009 (2008 trial).

Statistical analysis. The data was subjected to analysis of variance in SAS v. 9.1 (SAS Institute, Cary, NC), and Duncan's multiple range test was used for mean separation for all data at the 5% significance level. Weed seed and yellow nutsedge tuber survival data were analyzed to evaluate the effects of fumigant rate, film, and the interaction between rate and film. Linear contrasts were used to compare weed seed survival under the TIF and standard films using SAS PROC GLM. To determine if there was any correlation between strawberry fruit yield and fumigant concentrations, the 2008 data was tested using the SAS PROC CORR routine. Fumigant concentration and weed density data (Salinas 2008 only) were subjected to nonlinear regression analysis using Sigma Plot v. 11 (SPSS, Chicago, IL).

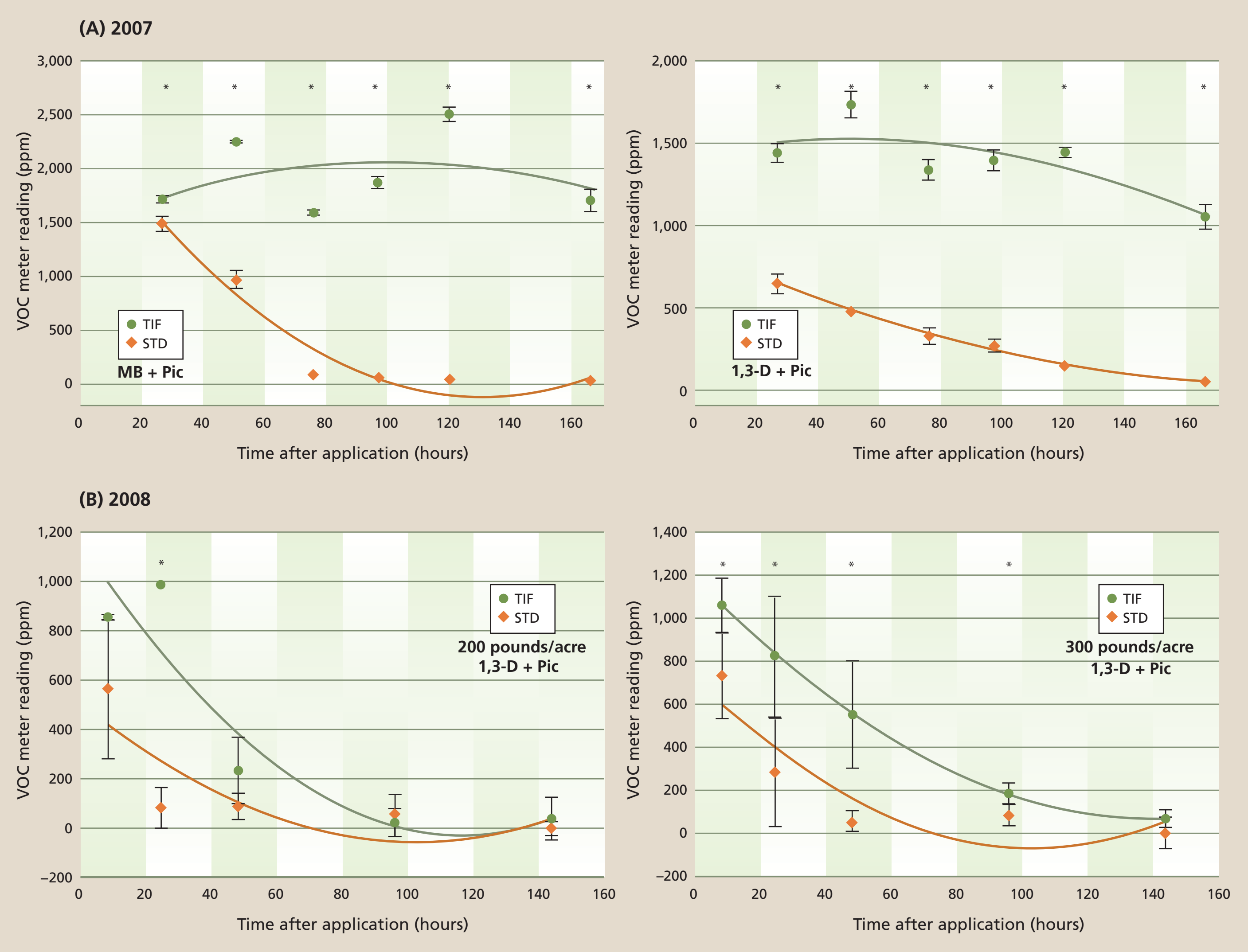

Fig. 1. (A) Methyl bromide plus chloropicrin (MB + Pic) (left) and 1,3-D plus chloropicrin (Pic) (right) VOC meter readings under totally impermeable (TIF) and standard (STD) films at 27, 51, 76, 97, 120 and 166 hours after application, Salinas, 2007; and (B) VOC meter readings for 1,3-D plus chloropicrin under TIF and STD films at 200 pounds (left) and 300 pounds (right) per acre at 8, 24, 48, 96 and 144 hours after application, Salinas, 2008. Lines are predicted values of nonlinear regression analysis using the polynomial function. Asterisks indicate significantly higher fumigant dose under TIF than STD according to Duncan's multiple range test at *P* = 0.05. Error bars are standard error of the mean.

Film effectiveness

2007 trial. At Salinas in 2007, methyl bromide plus chloropicrin and 1,3-D plus chloropicrin were both retained for 0 to 166 hours at significantly higher concentrations under TIF than under standard film (fig. 1A). Average strawberry fruit yields for 1,3-D plus chloropicrin were 0.77 (TIF) and 0.71 (STD) pounds per plant, and did not differ significantly. Average fruit yields for methyl bromide plus chloropicrin were 305 (TIF) and 295 (STD) grams per plant, and did not differ significantly. Weed densities were not different between the films at the rates tested (data not shown).

2008 trial. Because application rates tested in 2007 were normal, the rates were sufficiently high to suppress most pathogens and weeds regardless of the film permeability. For this reason, in 2008 we chose to compare fumigant retention under the two films at a range of rates from low to high, to determine if TIF would improve retention and efficacy across that range.

At Salinas in 2008, 1,3-D plus chloropicrin concentrations in the 200-pound-per-acre treatment were higher 24 hours post-application under TIF than under standard film (fig. 1B). The 1,3-D plus chloropicrin concentrations in the 300-pound-per-acre treatment were higher under TIF than under standard film at 8, 24, 48 and 96 hours after application. No injury to strawberry was observed when transplanted 4 weeks after fumigation (data not shown). Generally, there were no tarp effects on plant diameters except at the 1,3-D plus chloropicrin rate of 100 pounds per acre; TIF plants were 9.4 inches compared with 8.3 inches for standard-film plants ($P < 0.0001$).

Marketable fruit yields were higher with TIF than with standard film. The differences were significant in the 1,3-D plus chloropicrin treatments at 100 and 200 pounds per acre (fig. 2). There was a positive correlation between the 8-hour 1,3-D plus chloropicrin concentration and full-season fruit yields for each film (standard [$r^2 = 0.49$, $P = 0.0001$] and TIF [$r^2 = 0.55$, $P = 0.0001$]). The 8-hour fumigant concentration accounted for 49% to 55% of yield variability in the standard and TIF treatments, respectively.

Weed densities were higher under standard film than under TIF. At 100 pounds per acre, 1,3-D plus chloropicrin applied under TIF had significantly fewer weeds than the same rate under standard film (fig. 3). The interaction between fumigant rate and film was significant for common chickweed ($P = 0.0011$) and common purslane ($P = 0.0032$), meaning that the survival of each of these two weeds was different under the two films. The interaction of yellow nutsedge rate by film was not significant ($P = 0.20$), indicating that nutsedge survival was similar under both films. However, we sought to describe the performance of TIF, therefore we evaluated nutsedge separately under both films. Yellow nutsedge tuber survival was less under TIF than standard film at 100 pounds per acre 1,3-D plus chloropicrin, but not at the other rates. Common purslane and common chickweed seed survival were lower under TIF than standard film at 50 pounds per acre 1,3-D plus chloropicrin (table 1). Little mallow and knotweed viability were similar under both films (data not shown).

Differences in weed control due to film type were only observed at the lower fumigant doses of 50 and 100 pounds per acre. This is likely due to the fact that TIF retained more fumigant than standard film, which resulted in a higher dose and lower weed seed survival under TIF than standard film (fig. 3). At application rates above 100 pounds per acre, the fumigant concentrations under both TIF and standard films were sufficiently high to kill weeds, so no differences were found between the films.

TABLE 1. Effect of totally impermeable (TIF) or standard (STD) film and 1,3-D plus chloropicrin (Pic) rate on survival of weeds in strawberry, 2008

Treatment (pounds/acre)	TIF	STD	TIF vs. STD†
Yellow nutsedge			
Control (0)	73.8	69.4	ns
1,3-D + Pic (50)	45.0	41.3	ns
1,3-D + Pic (100)	12.5	28.1	*
1,3-D + Pic (200)	0.6	2.5	ns
1,3-D + Pic (300)	0.0	6.9	ns
Methyl bromide + Pic (350)	0.6	3.1	ns
Common purslane			
Control (0)	47.8	53.3	ns
1,3-D + Pic (50)	22.8	53.0	***
1,3-D + Pic (100)	1.0	1.5	ns
1,3-D + Pic (200)	1.5	1.0	ns
1,3-D + Pic (300)	0.0	0.0	ns
Methyl bromide + Pic (350)	0.3	0.0	ns
Common chickweed			
Control (0)	37.8	47.8	ns
1,3-D + Pic (50)	11.3	22.8	***
1,3-D + Pic (100)	0.3	1.0	ns
1,3-D + Pic (200)	0.3	1.5	ns
1,3-D + Pic (300)	0.0	0.0	ns
Methyl bromide + Pic (350)	0.0	0.0	ns

† * = significant at $P = 0.05$; *** = significant at $P = < 0.001$; ns = not significantly different at $P = 0.05$. Asterisks show significant difference in weed survival between TIF and STD films within rows.

Lower application rates

Results of two trials conducted over 2 years indicate that TIF consistently held methyl bromide plus chloropicrin and 1,3-D plus chloropicrin (Telone C35 and Pic-Clor 60) at higher concentrations than standard film (fig. 1). At fumigant rates of 100 and 200 pounds per acre, strawberry fruit yields were higher and weed control was more complete where TIF was used, compared to standard film (figs. 2 and 3). This is likely due to the higher fumigant concentrations being held for a longer time under the TIF than under the more-permeable standard film, so that weeds and possibly soil pathogens (not measured) were more thoroughly controlled.

Drip-applied 1,3-D plus chloropicrin under standard film required at least 300 pounds per acre to provide fruit yields

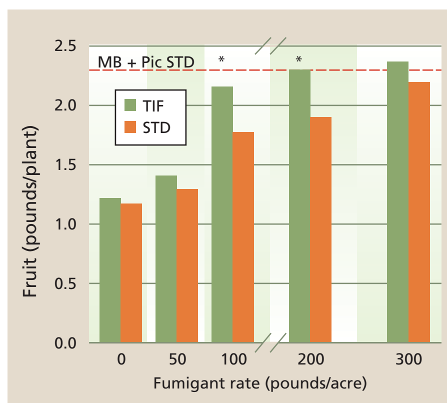

Fig. 2. Strawberry fruit yield per plant from March 30 to Oct. 30, 2009, in plots fumigated with 1,3-D plus chloropicrin using totally impermeable (TIF) or standard (STD) films. Reference standard yield is methyl bromide plus chloropicrin (MB + Pic) at 350 pounds per acre under STD, shown by the reference line at 2.31 pounds fruit per plant. Asterisks indicate that yield under TIF was significantly higher than under STD according to Duncan's multiple range test at $P = 0.05$.

comparable to methyl bromide plus chloropicrin (fig. 2). In contrast, 1,3-D plus-chloropicrin drip-applied under TIF at 200 pounds per acre had fruit yields and weed control similar to methyl bromide plus chloropicrin, a 33% reduction in 1,3-D plus chloropicrin rate compared to standard film. Similarly, Ajwa et al. (2005) found that the rates of drip-applied chloropicrin required to produce strawberry yields similar to methyl bromide plus chloropicrin were 294 and 198 pounds per acre under standard and VIF, respectively, a 48% reduction in chloropicrin.

The recent registration of methyl iodide as a soil fumigant by the California Department of Pesticide Registration (CDPR) requires the use of impermeable films (CDPR 2010). Methyl iodide must be used with impermeable films as approved by CDPR, and TIF (Vaporsafe) is on the list of approved films (CDPR 2011). The results presented here further validate that TIF is effective at increasing fumigant retention and may ease some of the burdens of fumigant regulations on end-users, as well as ease concerns of the general public about exposure to fumigants.

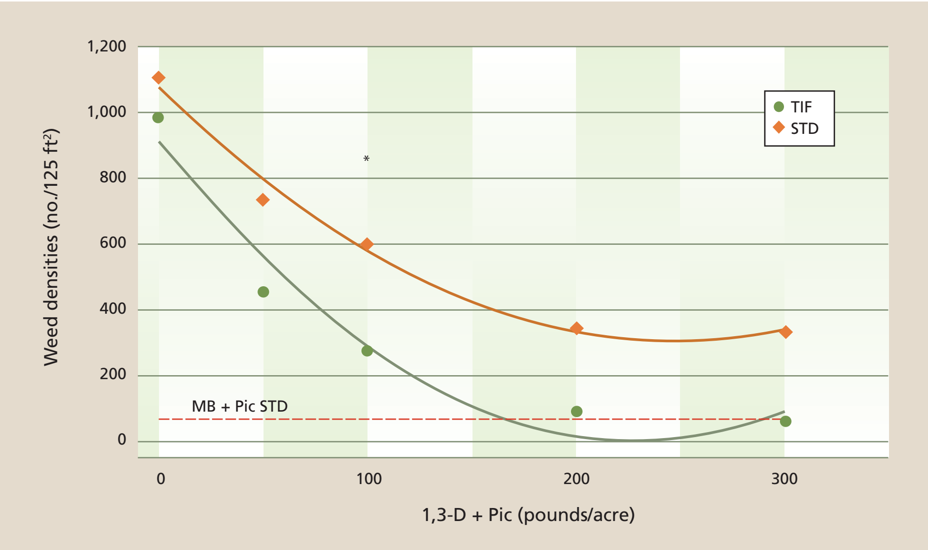

Fig. 3. Season-long weed densities per 125-square-foot sample area in plots previously fumigated with 1,3-D plus chloropicrin (Pic) using totally impermeable (TIF) or standard (STD) films. Lines are predicted values of nonlinear regression analysis using exponential decay function. The reference for weed control is methyl bromide plus chloropicrin under STD, shown by the reference line at 69.3 weeds per 125 square feet. Asterisk indicates that weed densities with TIF were significantly lower than with STD according to a Duncan's multiple range test at *P* = 0.05.

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