Agricultural and Resource Economics
ARE UPDATE

Giannini Foundation of Agricultural Economics, University of California Vol. 21, No. 3 Jan/Feb 2018

ALSO IN THIS ISSUE

Can Micro-Climate Engineering Save California Pistachios?

Itai Trilnick, Benjamin Gordon, and David Zilberman

Pistachio orchards in the San Joaquin Valley are threatened by warming winters. Researchers found a way to lower tree temperatures during the winter, a solution concept we term "Micro-Climate Engineering." We assess the economic gains from this innovation at $1-4 billion yearly in 2030. We believe this type of solution will play a major role in climate change adaptation.

Climate Change and Climate Bottlenecks

The focus of empirical research in climate change economics has recently shifted from exploring the effects of mean temperatures on various outcomes to the analysis of more subtle traits, such as the effects of extreme weather events. Abnormally warm days are the classic example, as the negative, non-linear effects of hot days on staple crop yields are by now a well-known result, replicated in various studies around the globe. This kind of extreme weather phenomena, harming yields over a short period of time, are bottlenecks that can bring a demise of a crop, even if the average climatic conditions are suitable for it. There is a reason to believe that much of the climate change damage to agriculture, at least by changes in temperatures, would be brought by an increase in the frequency of such extreme weather events, i.e., tightening of the climate bottlenecks.

If bottlenecks are a problem, the solution needs not be one that alters climate year round. What if we could just alter the temperatures in fields and orchards for a few hours every year, and just enough to prevent most of the damage? As opposed to Geo-Engineering, a set of proposals to intervene in global climate and revert climate change, this is a very local and temporary intervention. We term this adaptation technique "Micro-Climate Engineering" (MCE), and think it could be very useful for some of California's most profitable crops. Specifically, we look into the potential gains from this approach in pistachios, which are sensitive to changes from current climate. Rising daytime temperatures in winter are forming a bottleneck, which is predicted to hurt pistachio yields quite soon.

Before we proceed to our study, let us point out that MCE practices are already in use, and arguably have been used for millennia. Growers have always faced climate bottlenecks. It is the use of MCE as a climate change-adaptation technique that is new. For an existing MCE example, take an infamous temperature bottleneck on the cold side: frost. A frost lasts a few hours but causes great damages. Driving through Northern California's vineyards, one can witness an MCE solution already in use: big fans, sometimes augmented with propane tanks, circulate air around the precious plants on frost nights.

MCE often implements existing technologies to overcome a challenge, in ways many growers would find natural or familiar. While other researchers figure out more MCE solutions for growers, we are left with the task of assessing their potential gains.

California Pistachios and Climate Change

Introduced to California more than 80 years ago, and grown commercially since the mid-1970s, pistachios (*Pistachia vera*) were the state's ninth leading agricultural product in gross value in 2014, generating a total revenue of $1.65 billion. California produces virtually all the pistachio crop in the U.S., and competes internationally with Iran and Turkey (two-thirds of revenues are from export). In 2014, five California

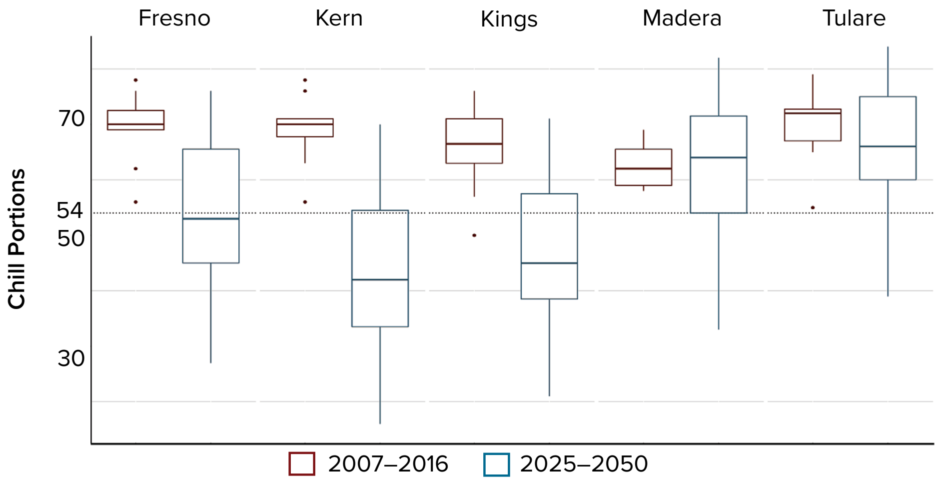

Figure 1. Winter Chill Portion Distributions

Note: 2016–2017 distributions are processed from CIMIS data. The 2025–2050 distributions are processed from our calibrated climate model climate predictions by CEDA. Boxes encompass 25th–75th percentiles of observations. Middle line in each box plot indicates the median.

counties had 96% of the state's pistachio acreage: Kern (24%), Fresno (23%), Tulare (22%), Madera (17%), and Kings (8%).

Pistachios have seen a spectacular acreage growth. Since 2000, total harvested acres in these counties have been increasing by roughly 10% yearly. Since 2010, average yearly growth has been 13.5%. Each increase represents a six to seven-year-old investment decision, as trees need to mature before commercial harvest.

Like many other fruit and nut trees, pistachios require minimal input of winter chill, a temperature metric measured in portions. Many fruit and nut trees "hibernate" during winter and "wake up" in spring. Agronomists stipulate that for optimal bud break scheduling, tree buds "count" chill portions and measure day lengths until reaching both threshold levels. Only then will the buds break and the tree will start blooming. Failure to attain a threshold chill count, varying between crops and varieties, leads to low and non-uniform breaking of buds, and low yields at harvest. Thus, chill accumulation is critical for growers, especially in warmer areas where the chill constraint might be binding.

Agronomists estimate the minimum requirement for the common pistachio cultivars in California at 54–58 portions. Compared to other popular fruit and nut crops in the state, this is a high threshold, putting pistachios on the verge of not attaining its chill requirements in some California counties. In fact, there is evidence of low chill already hurting yields. Thus, winter chill can be seen as a bottleneck: a slight decrease in chill portions could mean a great drop in yields.

Chill in Southern California is predicted to decline in the next decades. Climate literature suggests chill will be declining in the whole San Joaquin Valley. We ran our own calculations, not because we don't trust climatologists, but to get a separate estimate for each of our pistachio-growing counties. Using climate predictions in a "business as usual" Representative Concentration Pathways (RCP) 8.5 scenario (one with high carbon emissions from human sources) from the Centre for Environmental Data Analysis, and calibrating with observed data from the California Irrigation Management Information System (CIMIS), we get a distribution of present and (predicted) future chill-portion distribution in Figure 1. By 2025–2050, three out of our five counties (Fresno, Kern, and Kings) are predicted to get less than sufficient chill in most years.

Scientists at the University of California Cooperative Extension have been experimenting with potential solutions for the threat of low chill. One solution tested successfully in small-scale experiments involves spraying a non-toxic chemical mix, based on kaolin clay, on the dormant pistachio trees. Acting as a de-facto shading device, this creates a special micro-climate for the chill-counting tree buds. Shaded from winter sunlight, they now experience lower effective daytime temperatures, which raises their count of chill portions.

In experiments, the chill-portion count on treated trees was higher than on untreated trees; and the treated trees produced more pistachio clusters. Kaolin itself is already used for other purposes in agriculture, and research continues on the potential of other commonly used reflecting substances for shading. With relatively cheap application costs, this technique can help raise the chill counts in orchards, and at times save harvests. But what would be the gains from this technology?

Modeling Pistachios Market with MCE

To assess the potential gains from the MCE technique in pistachios, we model the market in the year 2030. Starting with an individual, decision-making grower, for whom we maximize profits by setting the level of MCE and traditional inputs, we aggregate on the county level, for which we have past production data as well as the climate predictions. Supply is modeled as the aggregate supply of our five counties, each one with a different (but correlated) climate realization and acreage. Each county serves as the representative of its growers, setting an optimal MCE level given the weather realization and the other counties' choices. Closing the model with a demand function, the solution is a market price and five MCE levels (implying five county supplies).

The benchmark used to assess the gains from MCE is an identical simulation run where the MCE levels are forced to zero. Thus, a "good" year with sufficient chill in all counties has zero gains from MCE. When the chill realization is low, in some or all counties, the benchmark price and quantities in the no-MCE run are different than in the MCE run. This allows us to calculate the gains in grower profits, consumer benefits, and total welfare—their sum.

We calibrate our model with 2014 price and county outputs to get some realistic values. We do not consider additional storage as a no-MCE benchmark, for two main reasons. First, storage is already in extensive use to deal with the alternate-bearing patterns of pistachios. The loss predictions in low-chill years are quite high, meaning that most of the output would have to be stored in any given year, which we find unlikely. Second, pistachio storage time is limited, usually up to a year. Thus, a multi-year storage strategy to deal with insufficient chill is unrealistic.

Besides the climate distribution, we define ranges and distributions for other parameters such as the price sensitivity of demand (elastic—more sensitive to price) and supply (inelastic—less sensitive to price), market power both on the grower side (about half of California pistachios are marketed by one firm) and downstream side (large processing plants or exporters), and estimated cost of kaolin application per acre (courtesy of UCANR's Agricultural Issues Center). Drawing randomly from these distributions, we run our market model many times to obtain gain distributions reported below.

One more decision, external to the model, needs to be made: the growth in acreage and its distribution in 2030. Taking past acreage growth, we create a ***High Scenario*** (acreage grows 5.11 times from current) and ***Low Scenario*** (2.74 times). Demand is modeled to grow at the same rate as the total

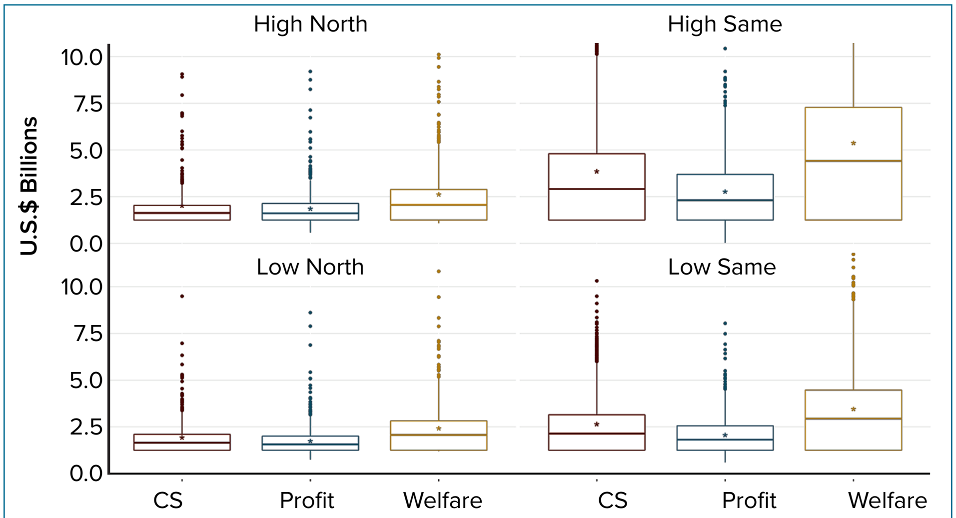

Figure 2. Total Gains Distribution by Scenario

Note: Boxes encompass 25th–75th percentiles of observations. Middle line in each box plot indicates the median, the asterisk is the average.

acreage growth. As growers might take future chill predictions into consideration, we also have a ***North Scenario***, in which all new growth happens in Madera and Tulare counties, where chill is not predicted to decline below critical levels (Tulare isn't really to the north, but it is colder); and a ***Same Scenario***, where the county acreage shares remain the same as present ones.

Together, we have four scenarios: ***High North, High Same, Low North,*** and ***Low Same***. As expected, we later see that gains from MCE are greater when acreage growth is high rather than low, and the distribution is same rather than north. This scenario range excludes the possibility of shifting existing orchards to the north, as this is very expensive and potentially unnecessary with MCE. On the other hand, this also assumes conservatively that the growth rate does not increase in the more damage-prone counties, at the expense of the cooler ones, as a result of MCE technology being available to growers.

Note that the ***North Scenario***, where new acreage is very unlikely to be hit by insufficient chill due to its geographic location, is analogous to planting heat-tolerant pistachio varieties in new acreage in general. This means we also exclude switching varieties in currently harvested acres. It seems reasonable, given the high start-up costs (net costs of $16,137 per acre in the first six years, according to the latest UC Cooperative Extension's cost estimates that do not include uprooting the old orchard), foregone income in the years of establishing orchards with new varieties, and uncertainty on the success of new varieties in California conditions.

Simulation Results

The model is run 1,000 times, solving numerically for price and county MCE levels. We do not include parameters resulting in a grower/consumer price ratio above six, generated by some combinations of market powers and elasticities, leaving us with 942 results for each scenario. These simulations include "good" year realizations where chill is sufficient around the state. Thus, we interpret average simulated gains as expected gains. The mean effect of MCE is a 32–88% quantity increase (scenario depending).

Given California's big market share in production, this increase translates to a 13–31% drop in market price. For the gains in terms of profits, consumer benefits, and total welfare, see simulated distributions in Figure 2. They are virtually all positive. This could be expected with consumer gains, because of their higher price sensitivity. However, for profit gains, as there is some measure of market power in each

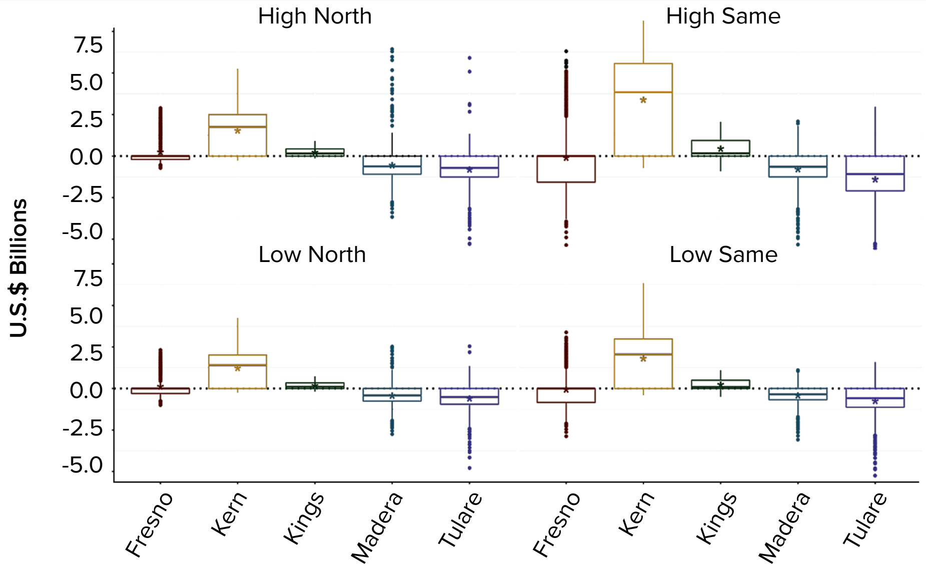

Figure 3. Profit Gains from MCE by County

Note: Boxes encompass 25th–75th percentiles of observations. Middle line in each box plot indicates the median, the asterisk is the average.

simulation, this was not an obvious result.

In total, the average profit gain is \$0.49–\$1.52 billion; the average consumer surplus gain is \$0.68–\$2.60 billion; and the average total welfare gain is \$1.17–\$4.12 billion. The scope of these ranges is mostly the product of our different scenarios: the lower values correspond to the ***Low North Scenario***, while the higher values are from the ***High Same Scenario***. In reality, some combination of these scenarios, and resulting average gains, is possible.

One interesting finding, driven by our county-specific modeling, is the difference in profit gains between counties. In the benchmark setting, i.e., no-MCE, the cooler counties are the obvious winners from climate change, at the expense of the warmer counties. Thus the gains from MCE, while positive in total, vary greatly among counties.

Figure 3 shows the profit-gain distribution by county. Kern County, the largest pistachio producer at present, and also the most threatened by climate change in terms of chill portions, is the big winner from MCE. On the other hand, Tulare and Madera see mostly losses from the new technology.

This insight is relevant to adaptation techniques in general. Besides the baseline climate heterogeneity, not all areas affected by climate change have the research resources available in California, nor are the capital investments required for MCE implementation available around the world.

Another insight from simulation results is that gains are positively correlated with market power. This correlation points in two potential directions for future research. First, the relatively unexplored intersection of market power, agriculture, and climate change. As gains in our model are basically the recovery from a bottleneck, this reflects a positive correlation between climate-change damages and market power.

The second point is about public investment in R&D for MCE solutions. In some cases, market power serves as an extra incentive for investment in R&D, where simple profits are deemed insufficient. This is sometimes said about investment in the pharma industry. Here, consumer gains from MCE increase with market power. A large share of these gains is enjoyed by domestic consumers. Therefore, public investment in research for MCE solutions might be beneficial for taxpayers as well.

Conclusions

Many climate change effects on agriculture could be the result of tightening climate bottlenecks, rather than a drastic change in mean climatic conditions. Where feasible, both physically and economically, MCE technologies could help growers adapt to climate change, delaying eventual crop transitions for decades. We document a new technology to help California pistachio growers overcome low-chill years, and model the market to assess its potential gains in the year 2030. They are in the low-billion dollars for a crop of secondary importance in California agriculture, indicating a great potential for MCE as an adaptation concept in general. We believe we will witness more such MCE solutions in future years.

Suggested Citation:

Trilnick, Itai, Benjamin Gordon, and David Zilberman. "Can Micro-Climate Engineering Save California Pistachios?" *ARE Update* 21(3) (2018): 1–4. University of California Giannini Foundation of Agricultural Economics.

Authors' Bios

Itai Trilnick and Benjamin Gordon are Ph.D students and David Zilberman is professor and Robinson Chair, all in the Department of Agricultural and Resource Economics at UC Berkeley. Itai can be contacted at itai.trilnick@berkeley.edu.

For additional information, the authors recommend:

Beede, B. and Doll, D. 2016. "Sun Reflecting Products for Increased Winter Chill?" http://thealmonddoctor.com/2016/12/14/sun-reflecting-products-for-increased-winter-chill

Trilnick, I., Gordon, B., and Zilberman, D. 2018. "Micro-Climate Engineering for Climate Change Adaptation in Agriculture." Working paper. https://escholarship.org/uc/item/3fw1q06n

Who Owns California's Cropland?

Luke Macaulay and Van Butsic

Analyses of cropland ownership patterns and planted crop mixes can help researchers prioritize outreach efforts and tailor research to stakeholders' needs.

Information about the property-size distribution and use of agricultural land at the property level is useful in assessing technology adoption, fragmentation of land, pesticide applications, wildlife connectivity, and many other issues. Data on agricultural land-ownership patterns can also help answer a host of important questions such as the characteristics of properties planted with a particular crop; variation in ownership patterns across counties; and cropping combinations. Finally, ownership information also can be useful for organizations providing technical and conservation support on a landscape scale.

Improvements in satellite-based imagery (remote sensing) technologies have allowed for increasingly accurate maps that specify where farmers plant crops. Advances in geographic information systems processing capacity allows for owner-level analysis of agricultural land use. This study presents a novel analysis to elucidate cropland ownership in California that draws on publicly available satellite-based cropland data and a spatially explicit land-ownership database.

The authors created an ownership map of California from compiling individual county parcel maps across multiple years, with 49 counties from 2011 to 2015 and nine counties from 2005 to 2010. For this analysis, cropland area less than 5 acres, or less than 5% of a property's area, was excluded from the analysis.

This analysis supplements existing data by providing information at the property level, which we define as all parcels owned by a given landowner. This method allows the generation of ownership summary statistics, measures of inequality by county and by crop, and new information on crop mixes by property.

California Cropland Ownership Characteristics

Approximately 96% of California cropland is privately owned, followed by 1.4% federal, 0.9% state, 0.8% local, and 0.6% special districts (e.g., irrigation districts). Of the government-owned land, 50% is fallow, 16% is alfalfa or hay, and 14% is grain crops, with all other crops making up less than 5% of the total.

In 2013 there were approximately 7.87 million acres of private cropland in California greater than 5 acres or 5% of an owner's property, made up by approximately 68,699 owners. The largest 1% of cropland properties (the 687 properties larger than 1,277 acres) accounted for 26.5% of California's cropland. The largest 5% of properties (3,435 properties that are larger than 477 acres) accounted for just over half (50.6%) of California's cropland (Table 1).

The remaining 95% of properties (65,370 properties) comprised the remainder (49.4%) of the state's cropland. The 25% of California cropland

Table 1. Frequency Table of Ownership of California Cropland Based on Size Class

Size Category (in acres)	Total Acres	Percent of Total Acres	Cumulative Sum of Acres	Number of Owners	Percent of Total Owners	Cumulative Sum of Owners
5-10	97,056	1.2%	97,056	13,327	19.4%	13,327
10-25	301,931	3.6%	398,988	18,413	26.8%	31,740
25-50	423,983	5.1%	822,970	11,853	17.3%	43,593
50-75	347,432	4.2%	1,170,402	5,573	8.1%	49,166
75-100	305,583	3.7%	1,475,985	3,572	5.2%	52,738
100-250	1,391,963	16.8%	2,867,948	8,875	12.9%	61,613
250-500	1,367,857	16.5%	4,235,805	3,934	5.7%	65,547
1,000	1,459,906	17.6%	5,695,711	2,106	3.1%	67,653
5,000	1,695,154	20.4%	7,390,865	975	1.4%	68,628
10,000	348,303	4.2%	7,739,168	51	0.1%	68,679
> 10,000	558,856	6.7%	8,298,024	20	0.03%	68,699

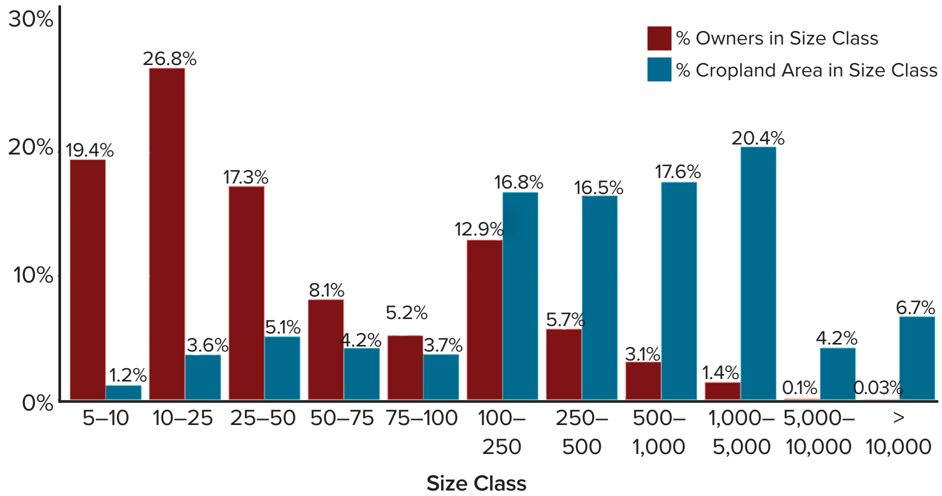

Figure 1. Distribution of Number of Owners and Percent of Private Cropland Ownership Greater than 5 Acres in Particular Size Classes of Ownership.

Source: Author's statewide ownership map

comprised of the smallest properties is made up of 57,490 properties, 84% of all owners, and these properties are smaller than 152 acres. This leads to a distribution of ownership where the bulk of land falls into larger size classes between 100 to 5,000 acres, while the bulk of the owners fall into categories of less than 50 acres (Figure 1). The median acreage of properties was 29.8 acres and mean acreage was 120.7 acres.

County Cropland Ownership

We calculated metrics of cropland ownership on a county basis, including an analysis of equality of ownership, represented by the Gini coefficient. The Gini coefficient is a measure of statistical dispersion that is commonly used as a measure of inequality, where a value of zero expresses perfect equality with all values the same and a value of one expresses maximal inequality among values.

Notably, private cropland dominated the land area of Sutter and Kings Counties, making up over 64% of their land area. Yolo and San Joaquin counties had the next highest amount at 46%. The rural corners of California generally had the largest median size of cropland property, with the highest values in Imperial and Modoc counties (> 80 acres). More urban and tourism-focused counties (Los Angeles, Lake, and Sonoma counties) tended to have lower median property size.

Equality of cropland ownership, however, was not well-predicted by whether a county is rural or urban; rather, it tended to be most associated with the size and number of the largest landowners in the county or regulations implementing a minimum parcel size. Kings County had the most unequal cropland ownership, followed by Kern and Contra Costa counties. Santa Clara, Napa, and Mendocino counties had the most equal cropland ownership (of counties with > 5,000 acres of private cropland).

Crop Types

Many crops had similar ownership characteristics with a few exceptions. Rice and cotton had large average acreages planted, while fruit trees, walnut trees, and other tree crops had small average size plantings (Figure 2). Among properties growing rice, the average acres planted to rice were far larger (214 acres) than the average acreages grown in all other crop categories. There were also few properties that planted small areas of rice; the 25th percentile of rice acres planted was 40 acres, more than six times larger than the equivalent measure for any other crop type.

Properties planted with cotton in 2013 had the second highest average (117 acres), but the median acreage of cotton properties was similar to other crops. The metric that tends to set cotton apart from rice is its much higher maximum acres grown on a single property (~56,600 acres). Rice and cotton had comparatively few properties planted, ranking 13th and 14th in number of owners across 14 crop categories, yet they ranked 6th and 10th in acres planted out of the crop categories.

The crop categories of fruit trees, walnuts, and other tree crops were notable for their comparatively small ownerships. Mean ownership was between 27 and 35 acres, and median values were below 8.45 acres. While two other crop types, almonds and fallow land, had median values around 8 acres, their average values were comparatively larger.

The year 2013 was the second year of the recent and ongoing drought in California, and approximately 25,265 owners had over 1 million acres left fallow, with 45 acres being the average area left fallow. Nearly 60,000 of those acres were left fallow by a single property owner in Kings, Kern, and Tulare counties, an area where crops are highly dependent on irrigation.

Land planted with rice, which had the highest-average acreage planted, also had the most equal distribution of land, in part because there were relatively few small properties. The most unequal ownership came in the other tree crops category, which is composed of 82% pistachios, 1% pecans, and 17% all other tree crops.

In the other tree crops category, a single ownership of pistachios acreage accounted for 7% of that crop category's area. This, combined with an abundance of small owners (evidenced by the lowest median ownership size of all crop categories), led to a high inequality measure. This measure of 7% in the largest ownership allows for separate corporate owners that may be controlled by a single entity. Using a more inclusive measure of what constitutes a single owner, this category shows that a single entity likely accounts for approximately 11.4% of all ownership in the other tree crop category.

Crop Mixes

Many landowners or their tenants plant multiple crops, either in rotation or as market demands shift. We used our database to calculate typologies of properties based on the similarities of crops planted together. The analysis identified seven crop clusters that yield interesting insights into how farmers specialize or mix crops. Three clusters tended to mix crops or orchards, with no single category composing more than half of the property area, while four clusters tended to specialize in a particular crop type, with more than 79% planted in a single crop type (Table 2).

Many grape, rice, almond, and alfalfa/hay producers tended to focus the majority of their plantings in their primary crop. Of the three clusters that mixed crops, one was mixtures of fruit trees, almonds, and walnuts; the second was dominated by fallow land and a mixture of other crops; the third group was very diverse, and tended towards a comparatively even mixture of grain crops, tomatoes, alfalfa/hay, and fallow land. Of the farmers who specialized in single crops, those who grew grapes had the strongest specialization, followed by rice, alfalfa/hay, and almonds.

Implications for Research and Extension

Agricultural statistics are crucial to decision-making, improving agricultural efficiency, and protecting the environment. Improvements in remote-sensing technologies, along with the availability of parcel data, allow researchers to present agricultural statistics in new ways. We do that here and show, to our knowledge for the first time, how land ownership is distributed for multiple crops throughout the state. We do not comment here on whether this ownership arrangement is efficient, just, or fair.

From the perspective of resource agencies and Cooperative Extension, these ownership patterns present opportunities for tailoring research and extension programs to their desired audience. For example, knowledge of the average size and distribution of cropland ownership in a particular type of crop can assist researchers developing more efficient harvest methods geared towards a particular-sized parcel, or in prioritizing outreach activities and methods of communication.

In terms of outreach, natural resource professionals seeking to increase adoption of best practices in particular counties or for certain crop types can benefit from this knowledge. For example, in crop types dominated by a few large properties, individual

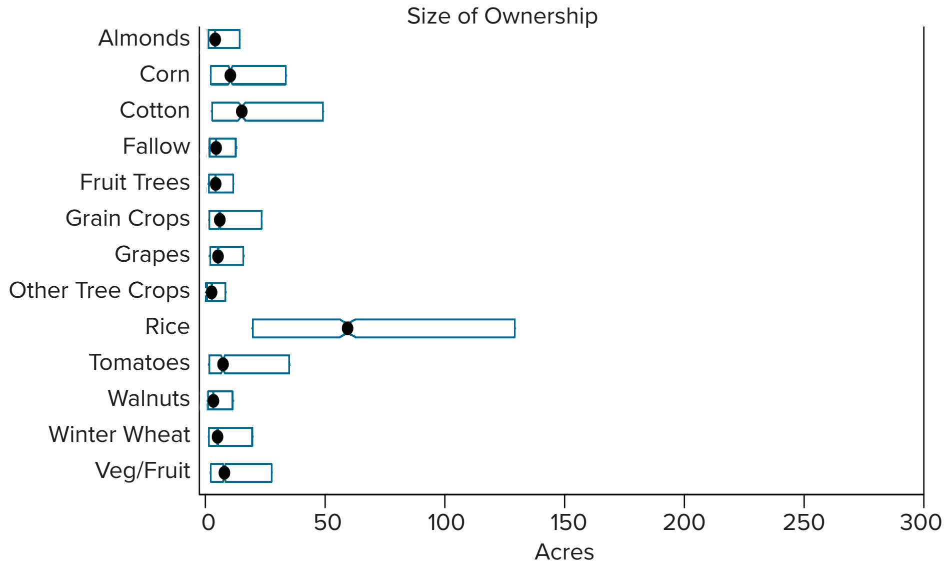

Figure 2. Measures of Acres Planted by Individual Owners by Crop Type.

Median represented by black dot, first and third quartile value at outer edge of boxes.

Table 2. Average Percentage of Crop Category Grown for Each Owner, by Cluster

Crop Cluster/ % of Cropland	Crop Type	Percent
1/ 9.5%	Grapes	85.2%
	Almonds	5.2%
	Other (12 types)	9.6%
2/ 24.5%	Grain Crops	30.0%
	Winter Wheat	20.4%
	Alfalfa & Hay	10.1%
	Fallow	9.5%
	Tomatoes	8.6%
	Corn	8.5%
	Other (8 types)	12.8%
3/ 10.9%	Fruit Trees	43.8%
	Walnuts	27.2%
	Almonds	11.2%
	Other (11 types)	17.7%
4/ 29.3%	Fallow	48.7%
	Vegs & Fruits	9.2%
	Other Tree Crops	8.3%
	Alfalfa & Hay	6.5%
	Almonds	6.4%
	Other (9 types)	21.0%
5/ 7.5%	Almonds	87.5%
	Other (13 types)	12.5%
6/ 10.4%	Alfalfa & Hay	79.1%
	Almonds	6.4%
	Other (12 types)	14.5%
7/ 7.9%	Rice	83.0%
	Fallow	6.8%
	Other (12 types)	10.3%

outreach may be an appropriate method of extension given the disproportionate area of cropland affected. Alternatively, crops dominated by many small properties like fruit trees or walnuts will likely require efforts utilizing mass communication tools that can reach thousands of owners.

The largest 1% of cropland properties accounted for 26.5% of California's cropland. The largest 5% of properties account for just over half of California's cropland.

For crops with comparatively low variation in ownership size (rice and tomatoes), outreach agencies may be able to reach a broad audience by focusing on challenges facing an average-sized farm. Crops with wide variation in property size (e.g., almonds, other tree crops, and properties with fallow land) may require an approach that reaches owners of small, medium, and large properties. While the vegetables/fruit category exhibits low variation in property size owned, it contains the widest variation of crop types, requiring a large diversity of subject-matter experts who can be devoted to relatively similar-sized properties.

The analysis of crop mixes yields insights into guiding research and extension approaches, as well as information for equipment or seed sellers. Knowing that grapes, rice, alfalfa/hay, and almonds all tended towards specialization suggests that specialized outreach may be most effective. Conversely, researchers and advisors working on crop categories that are commonly mixed may benefit by collaborating with others to uncover potential synergies in mixed-planting systems. The characteristics of the clusters can also help these collaborators to know their audience; for example, properties with mixed crops from clusters 2 and 4 were larger than the average farm, while the tree crop mix (cluster 3) was composed of smaller properties than average.

Many factors such as the suitability of land for particular crops, historical settlement patterns, whether economies of scale are present for particular crops, and local land-use ordinances likely influence the differences in distribution of ownership by different crop types and in different counties. Walnuts had small median and mean area planted, which is likely driven by their requirements for high-quality alluvial soils that occur along rivers flowing out of the Sierra Nevada. These lands have generally coincided with historic small towns that have been farmed for longer periods of time, leading to greater fragmentation as generations turn over and land holdings are split among family members.

Much of the state's rice is grown on soils that have such a high clay content that no other crops can be productively grown on them, possibly reducing small-farm demand and subdivision for this type of land. The consolidation of cotton plantings occurred historically and likely is impacted by a variety of factors, including the relative difficulty in growing cotton, its greater ability to grow in saline soils, and economies of scale in producing sufficient cotton to sustain a ginning operation.

Historical settlement and homesteading patterns, where the farm size was limited by the amount of labor available (usually the immediate family), may have made aggregations of land more difficult in some places, potentially driving the relative equality of ownership in Santa Clara, Mendocino, and Napa County. Additionally, Napa County enacted the Agricultural Preserve Act and Measure P, which implement minimum-parcel-size regulations and zones agricultural use as the best use in many areas of Napa County. These factors have led to comparatively few dominant landowners in these coastal agricultural areas, and in the case of Napa, fewer smallholders, which limits the measure of inequality.

These results provide useful information for Cooperative Extension efforts seeking to target growers by particular crop varieties or by various localities. This assessment can provide help in prioritizing outreach activities and methods of communication, as well as in tailoring research efforts to stakeholders' needs. They may also prove useful in allocating resources regionally, depending on the area of cropland, type of crop, and number of people served. Continuing to track the relationship between ownership patterns and crop patterns in the future will be a valuable way to analyze the ever-changing landscape of agriculture in California.

Suggested Citation:

Macaulay, Luke and Van Butsic. "Who Owns California's Cropland?" *ARE Update* 21(3) (2018): 5–8. University of California Giannini Foundation of Agricultural Economics.

Authors' Bios

Luke Macaulay and Van Butsic are Assistant UC Cooperative Extension Specialists in the Department of Environmental Science, Policy, and Management at UC Berkeley. Luke can be contacted at luke.macaulay@berkeley.edu. The authors thank the UC Berkeley Earth Sciences & Map Library and UC Agriculture and Natural Resources for funding to support this research.

The Cost to Manage Invasive Aquatic Weeds in the California Bay-Delta

Karen M. Jetter and Kjersti Nes

Invasive aquatic weeds have become an increasing problem in the California Bay-Delta, with Brazilian waterweed and water hyacinth being particular problems. In 2014 and 2015, large mats of water hyacinth began to choke Delta waterways, increasing control costs of a variety of public agencies and marinas. Between 2013 and 2016, these groups spent about $46 million to manage all invasive aquatic weeds.

The California Bay-Delta (Delta) is an inland delta system at the confluence of the Sacramento and San Joaquin rivers. It supports a complex ecosystem with diverse economic activities. About two-thirds of California salmon move through the Delta and the endangered Delta smelt calls it home. Agricultural crops grown on Delta islands have a value added of over $1 billion. Water from the Delta is pumped south and used for agriculture in the San Joaquin Valley, valued at $33.4 billion in 2015, and for millions of other urban and rural users in Californian homes and businesses.

Over the past decade, there has been a growing problem with invasive aquatic weeds in the Delta. Invasive weeds can either be floating aquatic weeds, where the plant floats on the surface and roots dangle in the water; or submerged aquatic weeds, where the plant roots at the bottom of the water body and grows from there. Two weeds of particular ecological and economic concern in the mid-2010s were Brazilian waterweed (*Egeria densa*) and water hyacinth (*Eichhornia crassipes*). Brazilian waterweed is a shallow, water-submerged weed with foliage floating on the surface of the water. Water hyacinth is a floating weed with broad, shiny, green leaves, purple flowers, and bulbous stalks with feathery, free hanging roots. Water hyacinth prefers lakes and slow-running water. As a result, water hyacinth spread and grew rapidly into dense mats throughout the Delta during the drought years in 2014 and 2015. These mats shaded out Brazilian waterweed and other submerged plants, reducing their impact on the environment, but threatened the viability of different activities on the Delta.

Widespread invasions of aquatic weeds may cause significant damage to fish habitat by lowering the level of oxygen in the water; displacing or shading out submerged native habitat upon which native aquatic species thrive; interrupting commercial shipping and recreational boating; endangering the ability of federal and state agencies to pump water to the California aqueduct system; and increasing the costs to manage mosquito populations to reduce the risk of the spread of West Nile Virus.

To prevent these effects, several public agencies control aquatic weeds, including the California Division of Boating and Waterways, the U.S. Bureau of Reclamation, the Port of Stockton, county weed control districts, and private marinas. Following are the budgetary costs for managing all invasive weeds provided by these agencies and marinas. Marina owners or harbor masters were interviewed. Each interview included questions on whether there was a problem with invasive weeds at their facility; if they had a problem with weeds, did they manage it, and if they managed weeds, how did they manage them—including materials, labor and costs.

The Division of Boating and Waterways (DBW)

The public agency responsible for area-wide management of invasive weeds is the California Division of Boating and Waterways (DBW). This agency is part of the California Department of Parks and Recreation. It is the only agency that can legally treat infestations using chemical controls such as herbicides, or mechanical controls such as harvesters. However, under special circumstances, the DBW can authorize another agency to complete weed management.

Area-wide management of invasive weeds must adhere to a rigorous set of environmental criteria, including limits on the months when herbicides can be applied in different treatment zones. There are four zones on the Delta. In three of the zones, treatments cannot begin until March 1. In the fourth zone, treatments cannot begin until June 1. These environmental restrictions (due to fish movements and breeding periods) allow weeds to grow until they can be treated with herbicides.

In 2015, DBW began using harvesting equipment for early-season treatments in select areas to keep the growth and spread of invasive weeds low until more effective herbicide treatments could occur. Frequently, these were "nursery" sites—those sites which are a particular source of infestation for other sites. This helps to keep the weeds from spreading, infesting other areas, and increasing the costs of control several months later when herbicides are available for use.

Budgetary costs to manage invasive aquatic weeds increased from $7.124 million in 2013, to $7.625 million in 2014, and $13.718 million in 2015 (Table 1). In particular, 2015 saw very large infestations early on due to the mild winter. Typically, the large mats of water hyacinth will die off over the winter. Not everything will die off, so there will still be some plant material, especially in Delta nursery sites. However, the winter of 2015 was milder and dryer than most.

Table 1. Cost of Invasive Weed Control: California Bay Delta (in $1000)

	2013	2014	2015	2016	Total
	--------------------------dollars--------------------------				
CA Division of Boating and Waterways	7,124	7,625	13,718	12,545	41,012
Bureau of Reclamation	343	833	921	658	2,755
Marinas	169	576	943	310	1,999
Port of Stockton	51	306	168	0	524
Weed Control District - San Joaquin County	223	73	37	155	488
Weed Control District - Contra Costa	74	0	0	0	74
Total	**7,984**	**9,413**	**15,787**	**13,668**	**46,852**

More plant material was seen earlier than previous years. With early control constrained by environmental regulations on the timing of herbicide applications, water hyacinth mats increased exponentially, causing control costs to increase rapidly. In 2016 budgetary costs fell to $12.545 million.

During this time, DBW also began a collaborative project with the Delta Regional Areawide Aquatic Weed Project (DRAAWP) to improve management of invasive aquatic weeds, such as the use of satellite images of weed infestations. This reduced plant material, along with a colder and rainier winter, and lower infestation of water hyacinth. With improved management and better climatic conditions in 2016, the water hyacinth crisis abated and budgetary costs fell.

The U.S. Bureau of Reclamation

The U.S. Bureau of Reclamation (BOR) is one of the agencies responsible for operating a facility that pumps water from the Delta into the California aqueduct system. Before that water can be pumped, debris, weeds, and fish must be removed. This is done at the Tracy Fish Collection Facility. A series of screens and diversions are used to remove the objects and capture the fish.

With no control, large mats of water hyacinth will accumulate and "dam" the screens. A mechanical arm is used to sweep the weeds into an area where a crane then removes the weeds, puts them into a truck, and the truck disposes them on BOR property to dry out and decompose.

At the height of the drought in 2014 and 2015 when water hyacinth infestations were greatest, multiple cranes were needed and operations were being completed around the clock. Since then, with better area-wide weed management, more rain, and stronger currents, infestations of water hyacinth have declined. Extra efforts are still required during the fall when weed mats break up, but fewer cranes are needed to clear out the debris and keep water flowing.

Costs by the BOR associated with changes in aquatic weed management increased from $343,085 in 2013, to $832,803 in 2014, and $921,000 in 2015 (Table 1). In 2016 costs fell to $657,664.

Marinas

Over 88 active marinas are found up and down the rivers of the Delta that allow for recreational activities such as boating and fishing. Without control, floating aquatic weeds gather around docks, grow, and will eventually shut down access to slips. Submerged aquatic weeds can block the entrance to marinas and get tangled up in ships' rudders, motors, etc., causing damage.

Marina owners and managers cannot spray herbicides to treat weeds or use harvesters, but can use a variety of other means to keep weeds managed. For small infestations of floating weeds, marinas will have people physically remove plants from the water. For larger infestations, small boats will be used to push the weeds out into the main channel of the river. In some cases, and with permission from the Army Corps of Engineers, booms can be placed across a marina opening to prevent floating weeds from entering. For submerged aquatic weeds, divers can pull weeds out of the riverbed. However, pulling weeds causes plants to break and spreads the infestation.

Marinas incur costs to remove weeds, and lose slip fees if infestations grow large enough to block boat slips. In 2014 invasive weeds cost marinas $170,500 in Brazilian waterweed control and lost business, and $405,676 for water hyacinth control and lost business. In 2015 the total costs due to the presence of Brazilian waterweed fell to $103,218, but increased to $198,670 in 2016. Conversely, the costs to marinas due to the presence of water hyacinth increased to $840,109 in 2015, but fell to $111,821 in 2016. Large mats of water hyacinth shade the plants underneath them, including Brazilian waterweed, and affect their growth. As populations of water hyacinth declined in 2016, costs to treat it also declined. The decline in water hyacinth growth; however, caused Brazilian waterweed populations to increase, along with marinas' costs to manage it.

Weed Control Districts

The still water in water hyacinth mats provide enough habitat for mosquitoes to breed. When on-going disease-monitoring activities by local mosquito control districts show that West Nile Virus is a threat to human health, mosquitoes will need to be treated in water hyacinth as part of an area-wide mosquito management program.

Mosquito control costs in water hyacinth mats were highest in 2013 at $233,000, and 2016 at $155,000. During years when infestations of water hyacinth were greatest, mosquito control costs were lowest—$73,000 in 2014 and $37,000 in 2015. This is probably due to the drier, drought conditions in 2014 and 2015, which kept overall mosquito populations low, even though there was more weed habitat in the Delta.

The Port of Stockton and Daylight-Only Navigation on the Delta

Deep water channels in the Delta from Oakland to Sacramento and Stockton allow commercial shipping through the Delta on container ships. The Port of Stockton is responsible for keeping public docks open to ships. Large mats of water hyacinth can prevent container ships from docking and unloading their cargo.

To keep the Port of Stockton clear, the port authority, under an agreement with DBW, will remove weeds using a harvester and truck them to a nearby disposal location. Costs incurred by the Port of Stockton to manage water hyacinth were $51,000 in 2013 (Table 1). This increased to $306,000 in 2014 and then decreased to $168,000 in 2015. In 2016 the Port of Stockton did not need to do any supplemental treatments.

In addition, large mats of water hyacinth can interfere with commercial shipping by shutting down night time navigation on the deep-water channel between Oakland and Stockton. The San Francisco Bar Pilots association determines when weed infestations are so dense that they interfere with a pilot's ability to navigate the river.

When a container ship arrives at the Port of Oakland, a local pilot goes on board to navigate the ship up the river. When traveling the deep-water channel at night, these pilots rely on navigation pylons that ping when the radar hits them. When weed mats are so dense that they obscure the pylons from radar, the pilots are unable to safely determine where the river turns and where banks are. At that point, they shift to a "Daylight-Only Transfer" (DOT) protocol when pilots can visually see where the pylons are. Once a DOT is established, it remains in effect until weed mats have broken up and dissipated. To date, DOT protocols due to invasive weeds have occurred between Oct. 26, 2014, and Jan. 30, 2015, as well as between Oct. 20, 2015, and Feb. 19, 2016.

Table 2. Costs Incurred by Marinas Due to the Presence of an Invasive Aquatic Weed (IAW)

	2014		2015		2016	
	Brazilian Water Weed	Water Hyacinth	Brazilian Water weed	Water Hyacinth	Brazilian Water Weed	Water Hyacinth
Number of marinas surveyed	58	58	50	50	57	57
Percent of marinas that managed an IAW	22%	65%	22%	50%	14%	42%
Management expenditures	$145,500	$353,245	$50,218	$534,199	$193,420	$80,821
Average cost per marina that managed an IAW	$12,125	$9,812	$4,565	$21,368	$21,491	$3,368
Marinas that reported lost business due to an IAW	1	7	4	9	1	2
Total cost of lost business	$25,000	$52,431	$53,000	$305,910	$5,250	$31,000
Total costs	**$170,500**	**$405,676**	**$103,218**	**$840,109**	**$198,670**	**$111,821**

No costs occurred due to DOT protocols because most of the costs to ship are fixed, such as the boat leasing, crew costs, etc. Losses would occur only if the closures prevented the ship from making its next pickup, and no evidence suggests that the five to six hours during which ships cannot navigate the deep-water channel at night resulted in a ship missing the next cargo pickup.

Total Costs of Managing Invasive Aquatic Weeds

Total costs to treat invasive weeds by all agencies and marinas were $7.984 million in 2013, $9.413 million in 2014, and $15.787 million in 2015. In 2016 costs declined, equaling $13.668 million. Total costs over all four years were $46.852 million. DBW had the largest expenditures, followed by BOR, then the marinas (Table 1).

Costs to treat invasive weeds peaked in 2015 due to the peak infestations of water hyacinth in 2014 and 2015. While budgetary costs for DBW were relatively higher in 2015 and 2016 compared to previous years, the increased control of water hyacinth resulted in lower costs of control for other agencies, especially the Port of Stockton and marinas. By keeping infestations down in key areas and increasing management in others, there was less material for other players to manage. Furthermore, with better control throughout the year, there was less plant material available the following year. This, combined with better climatic conditions, resulted in lower costs in 2016.

During 2014–2015, the severe drought caused water hyacinth populations to grow rapidly in the relatively slow current. With better management practices and more rain, populations of water hyacinth have not reached the heights of that time. With the decline in water hyacinth mats, different invasive aquatic weeds are now threatening Delta ecological and economic systems. Pennywort (*Hydrocotyle ranunculoides*), in particular, is spreading into areas once dominated by water hyacinth. In addition, the lack of water hyacinth mats in the river allowed more sunlight to pass through the water, causing increased growth of Brazilian waterweed.

Suggested Citation:

Jetter, K.M., and K. Nes. "The Cost to Manage Invasive Aquatic Weeds in the California Bay-Delta." *ARE Update* 21(3) (2018): 9–11. UC Giannini Foundation of Agricultural Economics.

Authors' Bios

Karen Jetter is an associate project scientist at the UC Agricultural Issues Center. She can be reached at kmjetter@ucdavis.edu. Kjersti Nes is a Ph.D. candidate in the ARE department at UC Davis.

Agricultural and Resource Economics
ARE UPDATE
Giannini Foundation of Agricultural Economics, University of California

Department of Agricultural and Resource Economics
UC Davis
One Shields Avenue
Davis CA 95616
GPBS

ARE UPDATE is published six times per year by the Giannini Foundation of Agricultural Economics, University of California.

Domestic subscriptions are available free of charge to interested parties. To subscribe to **ARE UPDATE** by mail contact:

Julie McNamara, Communications Director
Giannini Foundation of Agricultural Economics
Department of Agricultural and Resource Economics
University of California
One Shields Avenue, Davis, CA 95616
E-mail: julie@primal.ucdavis.edu
Phone: 530-752-5346

To receive notification when new issues of the **ARE UPDATE** are available online, submit an e-mail request to join our list to julie@primal.ucdavis.edu.

ARE UPDATE is available online at:
http://giannini.ucop.edu/publications/are-update/