Topics in Subtropics Newsletter

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News from the Subtropical Tree Crop Farm Advisors in California

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Progress in Developing Mechanical Harvesting for California Black Ripe 'Manzanillo' Table Olives

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Introduction and Earlier Research:

Harvesting is among the major inputs for many crops including olive. The current inability to mechanically harvest California's traditionally trained 'Manzanillo' table olives trees, 96 trees per acre, (Fig 1) will eventually result in these older, traditionally widely spaced orchards being pulled out, and potentially, the California table olive industry, now 14,000 acres and declining, dying due to the cost of hand harvest.

Fig. 1. Traditional California 'Manzanillo' table olive tree and traditional ladder, bucket, and glove harvest.

Mechanical harvesting of table olives was started in California in the 1940s, not adopted, and resumed in the 1990s . The goal both times was to develop a cost-effective technique to harvest table olives .

From 1996 through 2014 The California Olive Committee funded Krueger, Fichtner, Castro-Garcia, Rosa, Miles and Ferguson to develop mechanical harvesting for 'Manzanillo' California Black Ripe table olives (Ferguson et al. (2010, 2014). They produced a prototype canopy contact shaker (Fig. 2) and evaluated the current pistachio trunk shakers (Fig. 3) for harvesting efficiency in existing orchards, 96-139 trees per acre, modified with mechanical + hand pruning, (Figs. 4 and 5) and in newly planted hedgerow orchards (Fig 6).

Fig. 2. A canopy contact harvester adapted from a jatropha harvester. Canopy contact harvesters have higher potential efficiencies with hedgerow orchards that can present a hedgerowed vertical fruiting wall to the harvester head. These orchards can be developed from existing orchards at, 96 -139 tree per acre, with mechanical pruning or developed as a hedgerow at higher densities, 202 trees per acre.

Fig. 3. Double sided trunk shaking pistachio harvester that can be used in existing orchards, 96 - 139 tree per acre, modified with mechanical pruning or hedgerow orchards at higher densities, 180-202 trees per acre.

Collectively, the 11 years of mechanical harvesting research from 1996 – 2014, interrupted by appearance of the Olive Fly that diverted all research funds to that problem from 1999 to 2007, produced the following results. Two effective harvesting technologies, trunk shaking with existing pistachio harvesters and canopy contact shaking as an experimental prototype, were developed. The limiting factors of fruit and tree damage were mitigated sufficiently with harvester and canopy modifications. Economically efficient mechanical harvesting, competitive with hand harvesting was achieved with both harvesters.

The prototype canopy contact harvester achieved an average 88 - 90% final harvester efficiency in both low-density modified traditional orchards, 96 trees per acre, and in newly developed moderate density hedgerow orchards, 202 trees per acre.

Similarly, trunk shakers achieved a final harvester efficiency of 77.5% in moderate density hedgerow orchards (180 trees per acre) modified with mechanical + hand pruning.

With both shaking technologies receiving station grades were statistically insignificantly different from those of hand harvested olives in the olives were not overripe. When processed as California Black Ripe table olives neither a trained sensory nor a consumer panel could distinguish hand from mechanically harvested olives (Ferguson et al. (2010, 2014).

Fig. 4: Traditional 26 x 26 feet orchard converted to a hedgerow by interplanting to 13 x 26 feet, 139 trees per acre, topped at 12 feet and double side hedged 6 feet from the trunk on alternate years. The hand-pruned trees produced an average of 4.84 tons per acre over the 7 experimental years versus 3.97 tons per acre for the mechanically pruned trees. At the 92% mechanical harvesting efficiency achieved in 2013 for this orchard the average harvestable yield would be 3.65 tons per acre. The hand-pruned trees produced an average of 4.84 tons per acre and were mechanically harvested with 82% efficiency for a net average annual yield of 3.96 tons per acre over the 7-year experimental period. This is a difference of 0.32 tons less per acre annually. This difference in net return would be more than compensated for by the difference in harvest costs between mechanical and hand harvesting.

When compared to hand pruned rows the mechanically pruned rows had a slightly lower but statistically insignificant 3.64 tons per acre average annual yield versus 4.84 tons per acre for hand pruned olives over the 7-year experimental period: 2008 - 2014. This difference of 0.32 tons per acre less annually was easily be compensated for by the lower cost and higher efficiency of mechanical harvesting. It is also important to note that, even with four crop failures in 7 years both pruning treatments produced moderate yields.

Figure 5. Young moderate density traditional orchard, 180 trees per acre, converted to a hedgerow with mechanical and hand pruning for harvesting with both a canopy contact head and trunk-shaking harvester.

Figure 6. Hedgerow orchard spaced at 12 x 18, 202 trees per acre. The objective was to produce

a tree that was 12 feet tall, 6 feet wide, and skirted at 3 feet to produce a 324 $ft.^3$ canopy volume. With these dimensions, volume and shape it can be harvested by either a canopy contact head or trunk-shaking harvester.

In spite of these promising results the olive industry's conversion to mechanical harvesting has been limited. The primary reasons are lack of commercially available canopy contact harvesters, reluctance to lose the 2 years of yield converting traditional orchards to mechanically harvestable orchards and reluctance to plant new moderate density hedgerow olive orchards when olive prices remain static and pistachios and almonds are so profitable.

A few olive growers are having limited success with trunk shakers in younger trees with small regularly shaped trunks, Fig. 3. Trunk shakers harvest the olives closest to the trunk and main scaffolds more efficiently; specifically the olives at the top of the canopy. However, the olive's willowy growth habit prevents effective transmission of vibrational energy from the trunk and through the main scaffolds to the small vertical distal branches where most of the fruit is located. To remove this fruit with a trunk shaker, requires a high energy and extended duration shake with potential for trunk damage. Because the crop remaining after trunk shaking is generally low in the canopy and can be harvested without ladders, a gleaning crew can harvest the remaining fruit if it is economically feasible; at least a ton per acre. However, this low hanging exterior fruit is easily harvested by canopy contact harvesters, particularly if the tree is pruned to present a fruiting wall to the canopy contact head. This suggests using both canopy contact and trunk shaking harvesters sequentially, or simultaneously, would be the best way to improve final mechanical harvesting efficiency.

To encourage planting of mechanically harvestable orchards Musco Olive Company is offering growers free trees and future contracts for establishing mechanically harvestable moderate density hedgerow orchards; https://www.olives.com/milliontrees/mechanical-harvesting/. However, until these new moderate density orchards mature the processors need olives, which means the traditional California olive orchards must be harvested. Therefore the California Olive Committee, https://calolive.org/, is supporting development of a more efficient mechanical harvester for traditional trees.

To achieve this goal we have developed an alternative harvester design that is 50% lighter than the UC Davis canopy contact harvester shown in Fig. 2. Shown in Fig. 7 this new shaker-based harvester prototype can accommodate larger trees, delivers the maximum shaking energy to the canopy, as opposed to the trunk, and therefore eliminates trunk damage. However, it is not continuous motion like the UC Davis harvester, and requires more time per tree.

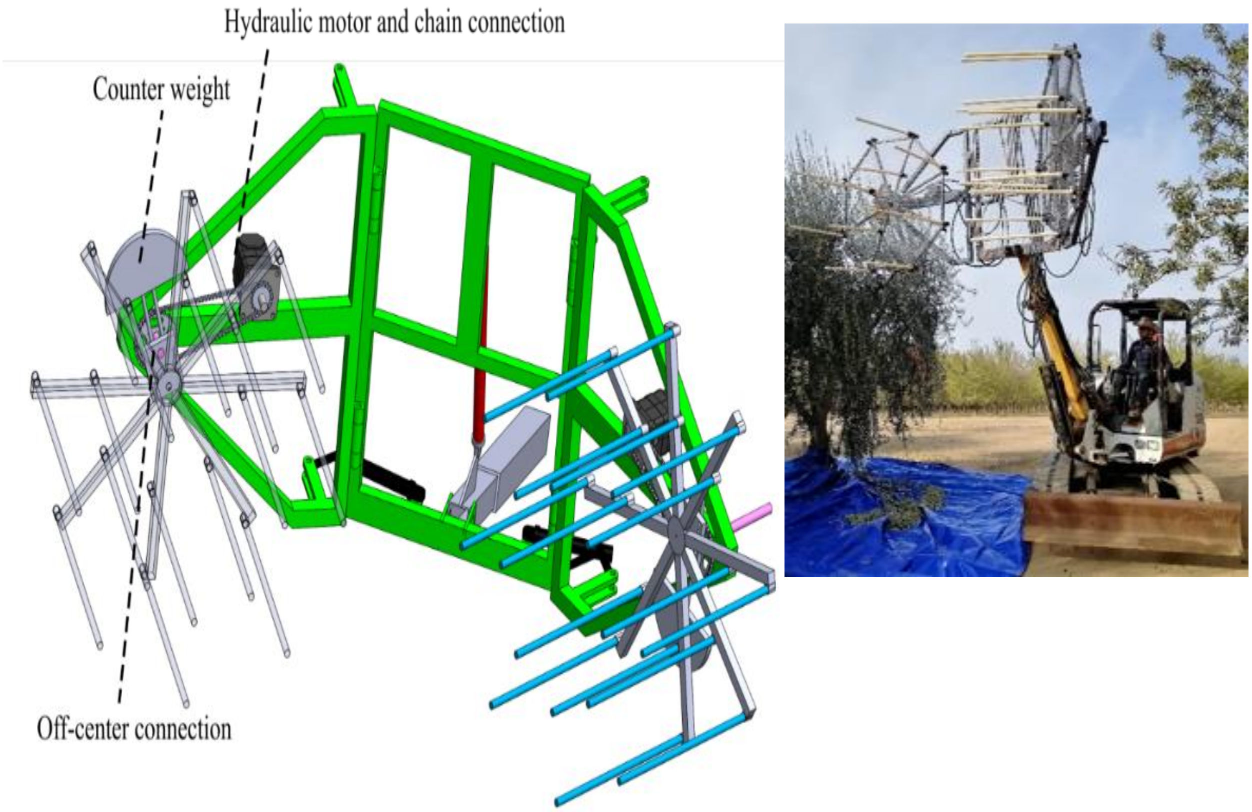

Fig. 7. UC Merced canopy contact harvester head.

In 2020 preliminary research demonstrated simultaneously combining trunk and canopy shaker technologies produced significantly higher harvest efficiencies compared to using either alone.

In 2021 we propose to build a new prototype harvester combining the trunk and canopy shaker in one machine and assess the best shaking parameters, amplitudes and frequencies. These parameters are needed for fine-tuning the machine to achieve the optimal machine capacity.

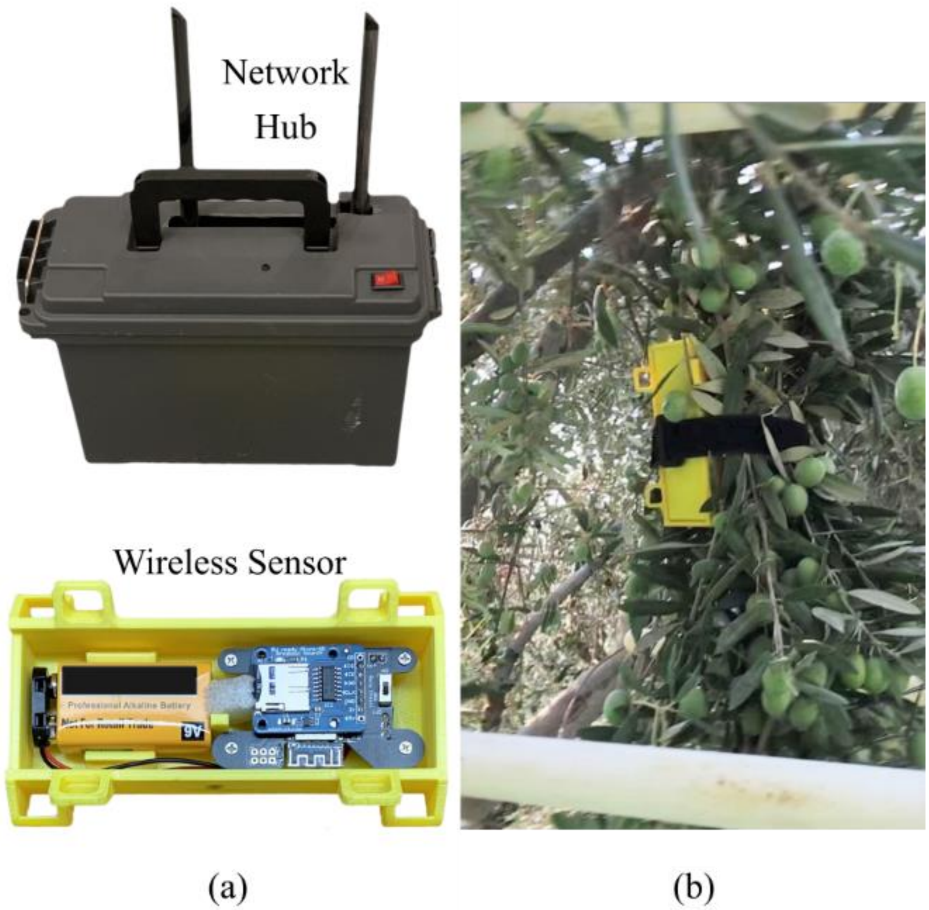

Fig. 8. Wireless sensor module and network hub (a) and wireless sensor module installed on olive branches for data collection (b).

<u>Progress with UC Merced Canopy Shaker:</u>
Figure 7 shows the UC Merced canopy shaker fruit removal system developed in Ehsani's lab. This canopy shaker was tested in 2018, 2019 and 2020. To measure and record vibration and force distribution throughout the canopy, a wireless sensor system consisting of a network hub and multiple sensing modules was developed. Each sensing module has a built-in 3D accelerometer, wireless module, battery, and storage unit. The network hub connects wirelessly to all the sensing modules and lets the operator trigger data recording via a smartphone app, Fig. 8. Three accelerometer sensors were attached to a tree to monitor tree vibration. One sensor was attached to the tree trunk, one to the main branch, and one to a second smaller branch. Using these sensors, we could compare the acceleration distribution throughout the tree canopy of both the UC Merced's canopy shaker and a trunk shaker harvester.

Figure 9 below shows the acceleration of each sensor for each of these harvesters when both were shaking a tree simultaneously. The data collected from the canopy shaker shows that the small-diameter branches, where the fruit is located, vibrate at a higher acceleration than the larger primary branches and trunk.

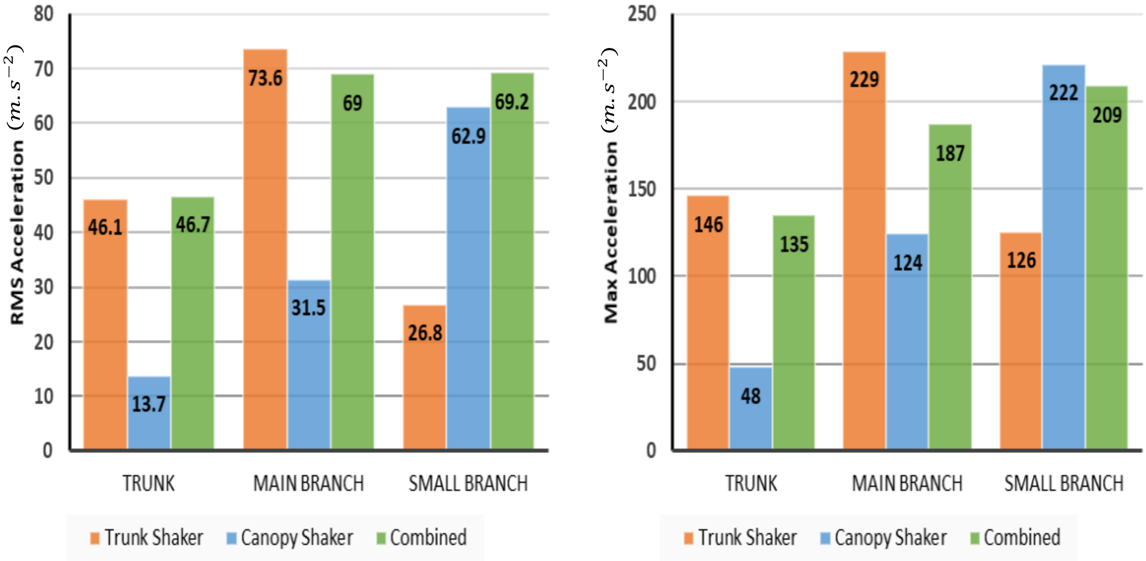

Figure 9. Root mean square or vibration at each part of the tree (left) and maximum acceleration produced by the two harvesters alone and together within each part of the tree (right).

Figure 10 B below shows the canopy shaker transmitted more energy to the small branches than to the tree trunk and root system, potentially producing less tree damage than a trunk shaker. Figure 10A shows the data collected for the trunk shaker. It shows there is much higher acceleration in the trunk than the small branches. Collectively, Figures 10A and B demonstrate the UC Merced canopy shaker applies most of the energy where the olives are located and, therefore, is more efficient. Compared to trunk shaking, the amount of acceleration (force) of the canopy shaker decreased by 70% at the tree trunk and 57% at the main branches and increased by 134% at the small branches. Figure 10 C shows the results of the test in which a tree was simultaneously shaken by the canopy and trunk shaker. While Figure 9 shows the root mean square and maximum amplitude of vibration recorded by the sensors on the tree Figure 10 demonstrates that a combination method of simultaneously shaking the trunk and canopy more effectively removes fruit in less time. It also shows a more uniform distribution of energy throughout the canopy.

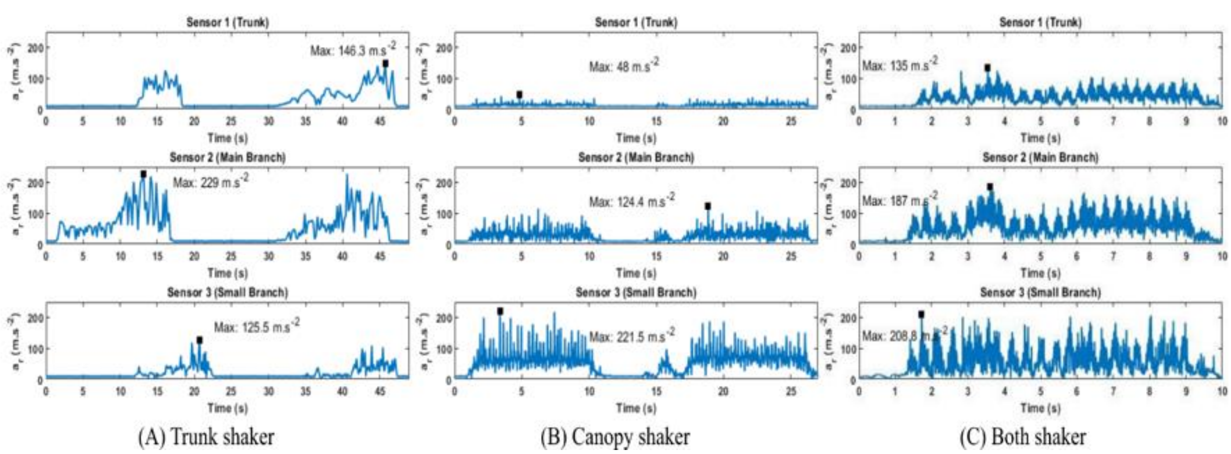

Figure 10. Vibration transmission through the tree using (A) trunk shaker, (B) UC Merced canopy shaker and (C) both shakers operating simultaneously.

Combined Shaker Experiment Results:

A combination trunk shaker and UC Merced canopy shaker were tested on 33 trees during the 2020 harvest season in Nickels Soils Laboratory orchard in Arbuckle, CA. An Orchard Machinery Corporation (OMC) the trunk shaker was used. For each shaker, trunk, and canopy, three different shaking frequencies were chosen. Eleven trials were conducted, including the nine combinations of shaking frequencies (Figure 11), and one trial each using the trunk shaker and UC Merced canopy shakers alone (Table 1). Each trial had three replicates (a total of 33 trees). The canopy shaker was set to a 2″ off-center distance, generating an oscillation with a 4″ amplitude. Rotational speed was set to 100, 150 and 200 rpm for the experiment. The trunk shaker intensity was set to low, medium and high. Shake duration was 15 seconds.

Figure 11. Trunk and canopy shaker simultaneously shaking an olive tree.

Table 1. Experimental design for selecting the optimal shaking frequencies; each replicated 3 times.

Trunk shaker intensity / Canopy shaker (rpm)	Low	Medium	High
100	Trial-1	Trial-2	Trial-3
150	Trial-4	Trial-5	Trial-6
200	Trial-7	Trial-8	Trial-9

Canopy shaker	Trial-10
Trunk shaker	Trial-11

The mechanically harvested fruit was collected on tarps for weighing. An experienced olive harvesting crew gleaned the remaining fruit for weighing. Harvest efficiency was calculated as given below:

$$Efficiency = \frac{Mechanically\ harvested\ (lb)}{Manually\ harvested\ (lb) + \ Mechanically\ harvested\ (lb)} \times 100$$

Harvest efficiency for each of the 11 trials is shown in Figure 12. Trial 1 through trial 9 used the UC Merced canopy and the OMC trunk shakers simultaneously. Trial 10 used the UCM canopy shaker alone and trial 11 used the OMC trunk shaker alone.

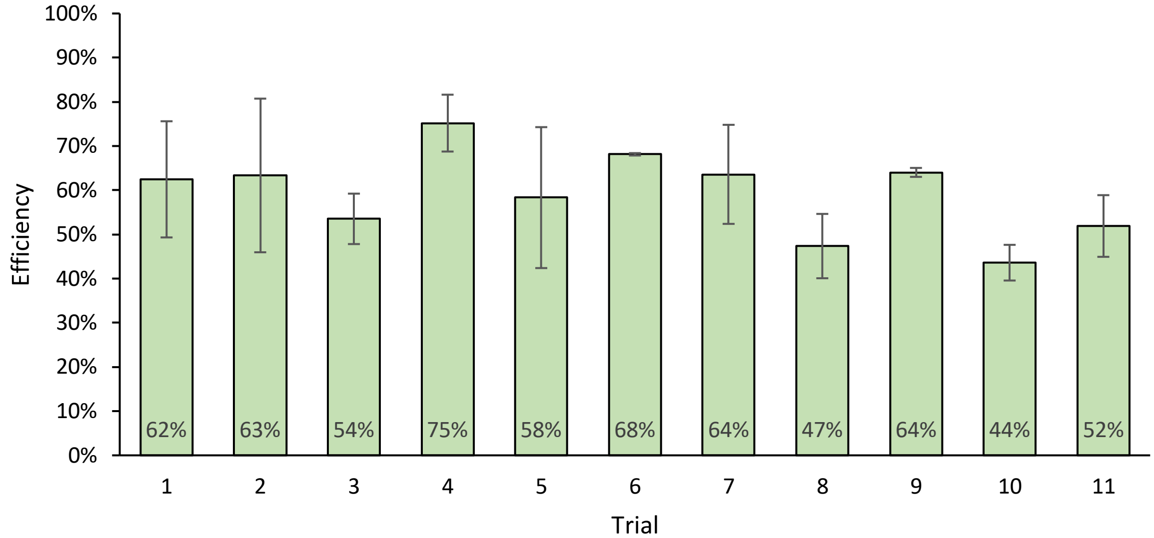

Fig. 12. Harvest efficiency for all 11 trial combinations. Trials 1-9 used the canopy contact and trunk shaker simultaneously. Trial 10 used the UC Merced Canopy shaker alone and trial 11 used the OMC trunk shaker alone.

As can be seen in Figure 12 above using both shakers simultaneously, except for trial 8, produced better harvest efficiency than using either shaker alone. Figure 13 below shows the average harvest efficiency for all three shaking methods. This figure shows the combined shaker method improved harvest efficiency by 41% and 19% compared to the canopy shaker and trunk shaker alone, respectively.

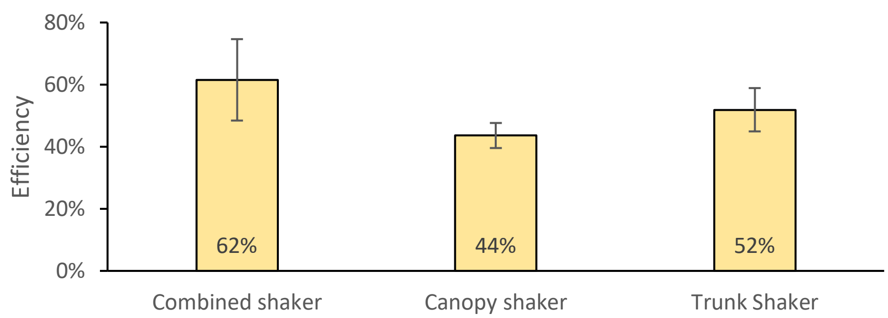

Fig. 13. Average harvest efficiency for three methods demonstrating the average higher efficiency when the trunk and canopy shaking are combined.

Collectively, these results demonstrate combining trunk and canopy contact shakers simultaneously will increase final olive harvest efficiency. Among the nine trials using both shakers, trials 4 and 6 had the highest harvest efficiencies, 75% and 68%, respectively. While this concept worked relatively well for small to medium-size trees, it is not suitable for larger mature trees because the shaking head is too small to effectively shake the tree canopy. Therefore, in 2021 we will be designing, building and testing a larger shaker head suitable for traditional mature olive trees, in combination with a trunk shaker, in a traditional orchard and a mechanically pruned orchard. Figure 14 below shows our proposed prototype. Note the Bobcat® or excavator could be rented and the harvest head side mounted.

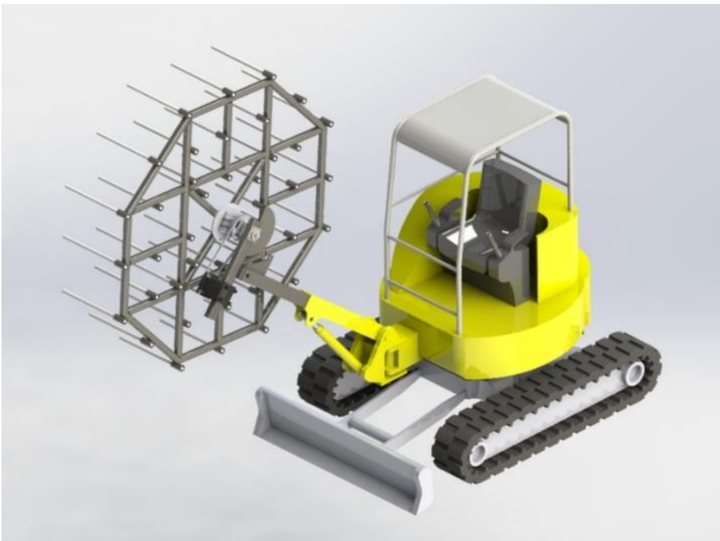

Figure 14. Proposed shaker design with a side-mounted canopy shaker.

<u>Specific Objectives for 2021</u>:

- Evaluate combined canopy and trunk shaker on larger traditional mechanically pruned olive trees.
- Determine the optimum shaking parameters; frequency, amplitude, duration, for the combined trunk and canopy shaker with large traditional trees

Our final proposed deliverable is a lightweight canopy shaker head that can be side mounted on a Bobcat® or excavator and in combination with existing trunk shakers efficiently shake large traditionally shaped table olive tree canopies. However, if the canopies are prepared with mechanical pruning it should be faster and more efficient. The side mount design will allow better mobility within the tree row and shaker head height adjustment at each tree.
While we will be testing this canopy harvester in combination with a trunk shaker on larger traditional trees, our earlier experimental results demonstrated canopy contact harvester heads can be highly efficient alone, or operated as a detached pair on opposite sides of the tree if the tree as are properly trained and pruned into a hedgerow with a fruiting wall. Future development objectives include developing a coordinated, though not necessarily attached, fruit collecting system, and continuous movement down a tree row.

Finally, our earlier results suggest canopy contact harvesting heads can be used as a harvester for young pistachio trees, before the stakes are removed and when the trunks are too small for a trunk shaking harvester. It could also be used as a mummy knocker for winter Navel Orangeworm (Amyelois transitella) sanitation.

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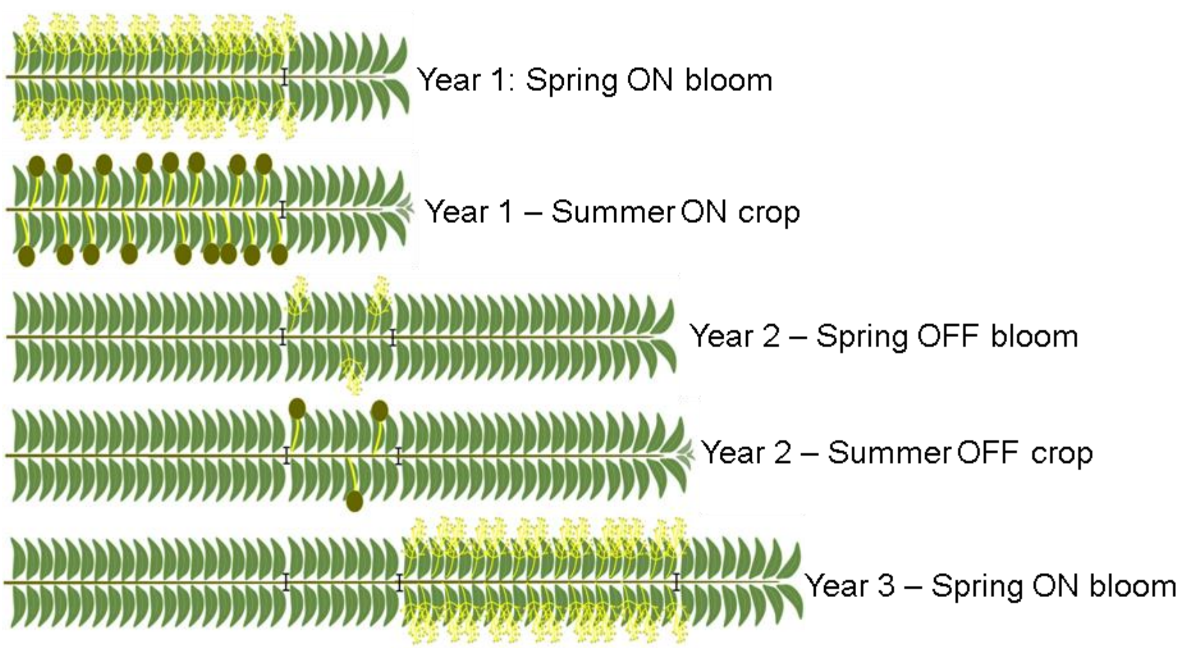
Developing a Nitrogen Fertilizer Plan for Olive Orchards

Elizabeth J. Fichtner, Farm Advisor, UCCE Kings and Tulare Counties

Nitrogen management plans (NMP) for California olive orchards are essential for the Irrigated Lands Regulatory Program and can increase net return. A good NMP has the potential to increase yield, improve oil quality and mitigate biotic and abiotic stresses while reducing nitrogen losses from the orchard.

Olives differ from other orchard crops in California in that they are both evergreen and alternate bearing. Individual leaves may persist on the tree for two to three years. Leaf abscission is somewhat seasonal, with most leaf drop occurring in late spring. Rapid shoot expansion occurs on non-bearing branches during the hottest part of the summer (July-August) on 'Manzanillo' olives in California. The fruit on bearing branches limits current season vegetative growth. Olives bear fruit on the prior year's growth, and the alternate bearing cycle is characterized by extensive vegetative growth in one year followed by reproductive growth the following year (Figure 1). With bloom occurring in late April to mid-May, fruit set can be estimated in early July, allowing for consideration of crop load while interpreting foliar nutritional analysis in late July-early August.

Figure 1. Illustrative model of the alternate bearing cycle of olive.



Model credit: C. Lovatt

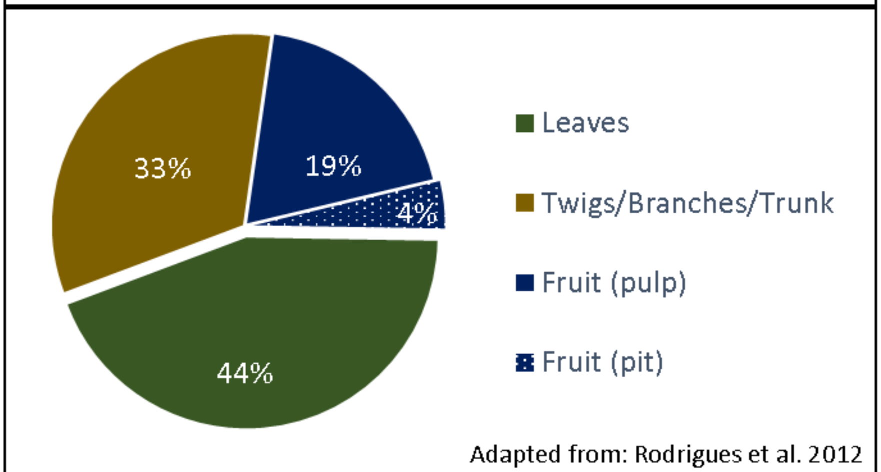
Critical Nitrogen Values. Foliar nitrogen content in July/August should range from approximately 1.3-1.7% to maintain adequate plant health. The symptoms of nitrogen deficiency manifest when foliar nitrogen content drops to 1.1% nitrogen. As leaves become increasingly nitrogen deficient, foliar chlorosis progresses from yellow/green to yellow. Leaf abscission is common at nitrogen levels below 0.9%. Nitrogen deficiency in olive is associated with a reduced number of flowers per inflorescence, low fruit set, and reduced yield.

Excess nitrogen (>1.7%) adversely affects oil quality. Oil with low polyphenol concentration is associated with orchards exhibiting excess nitrogen fertility. Since polyphenols are the main antioxidant in olive oil, reduced polyphenol levels are associated with reduced oxidative stability.

Nitrogen content may impact orchard susceptibility to biotic and abiotic stresses. For example, while excess nitrogen content has been associated with increased tolerance to frost prior to dormancy, in spring (post-dormancy) it is associated with sensitivity to low temperatures. High nitrogen content has also been associated with increased susceptibility to peacock spot, a foliar fungal disease on olive.

Foliar Sampling for Nitrogen Analysis. By convention, foliar nutrient analysis is conducted in late July-early August in California. Fully-expanded leaves are collected from the middle to basal region of the current year's growth at a height of about 5-8 feet from the ground. To capture a general estimate of the nitrogen status of the orchard, samples should be taken from 15-30 trees, with approximately 5-8 leaf samples collected per tree. Leaves for analysis should only be collected from non-bearing branches. Growers may find it beneficial to make note of the ON and OFF status in the historical records of each block. The orchard bearing status, combined with anticipated yield and foliar analysis will guide decisions for nitrogen applications the following year.

Figure 2. Approximate distribution of nitrogen in the aboveground portion of olive trees.



Distribution of nitrogen in the olive tree. Over 75% of the aboveground nitrogen in the olive tree is incorporated in the vegetative biomass (Figure 2). The twigs, secondary branches, main branches, and trunk account for approximately 33% of aboveground nitrogen (Figure 2). Twenty-three percent of the aboveground nitrogen is harbored in the fruit, with the majority in the pulp (19%) (Figure 2). Fruit is only an important nitrogen sink during the initial phase of growth. As fruit size increases, the N concentration decreases due to dilution.

Estimation of nitrogen removed from the orchard. The easiest component of orchard nitrogen loss to estimate is the nitrogen in the harvested fruit. A ton of harvested olives removes approximately 6-8 lbs of nitrogen from the orchard. The quantity of nitrogen in the fruit varies slightly between olive varieties (Table 1). Growers can use the Fruit Removal Nutrient Calculator for Olive on the California State University, Chico (CSU Chico) website to gain estimates of N removal by the three oil varieties (Arbequina, Arbosana, and Koroneiki), and the Manzanillo table olive. This tool was developed by Dr. Richard Rosecrance (Professor, CSU Chico) and Bill Krueger (Farm Advisor, UCCE). To access the Fruit Removal Nutrient Calculator for Olive, visit the following URL:

http://rrosecrance.yourweb.csuchico.edu/Model/OliveCalculator/OliveCalculator.html

Pruning may generate a second component of nitrogen loss from orchards. The best practice to mitigate nitrogen loss from pruning is to reincorporate the pruned material into the orchard floor by flail mowing. The nitrogen in this organic material will gradually become available to the trees through mineralization.

Table 1. The quantity of nitrogen removed per ton of fruit at harvest varies by variety.			
Variety	1 ton per acre crop (lbs Nitrogen)	5 ton per acre crop (lbs Nitrogen)	10 ton per acre crop (lbs Nitrogen)
Arbequina	6.81	34.07	68.14
Arbosana	6.39	31.97	63.94
Koroneiki	7.45	37.26	74.51
Manzanillo	8.04	40.22	80.44

Source: Total Fruit Nutrient Removal Calculator for Olive In California. B. Krueger (UCCE Glenn County) and R. Rosecrance (California State University, Chico).

In mature orchards, the wood removed by annually pruning is approximately equal to the annual vegetative growth. Consequently, the input and removal of nitrogen in vegetative growth is cyclic and almost equal in mature orchards. In young orchards, nitrogen inputs are utilized to support vegetative growth and little nitrogen is removed from the orchard in prunings or crop. During this time nitrogen must be supplied to meet the demand to support vegetative growth. It is estimated that approximately 2.5 lbs nitrogen is required to produce 1,000 lbs. fresh weight of tree growth.


Figure 3. Plant tissues pruned from the trees are typically flail mowed for reincorporation into the orchard floor. Nitrogen incorporated in this biomass will be released by mineralization.

Nitrogen Use Efficiency. Not all the nitrogen supplied to the orchard from fertilizer and other inputs (i.e. organic matter, irrigation water) is utilized for tree growth and crop production. A fraction of nitrogen is lost from the orchard ecosystem through processes such as runoff, leaching, and denitrification. Efficiency varies among orchards, with some orchard systems exhibiting higher nitrogen utilization rates than others. The efficiency generally varies from 60% - 90%. Higher values denote more efficient use of nitrogen inputs. To estimate the amount of nitrogen to supply an orchard, the demand is divided by the estimated efficiency. For example, if nitrogen demand is 50 lbs. per acre and efficiency is estimated at 0.8, then 62.5 lbs. of nitrogen per acre should be applied.

Summary. Nitrogen management plans are site-specific and designed to meet orchard and crop demand while reducing environmental losses. Nitrogen utilization is never 100% efficient. Nitrogen use efficiency can be maximized by minimizing losses from irrigation and fertilization practices while utilizing foliar analysis and knowledge of alternate bearing status to fine-tune applications.

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Should I Pay for Avocado Pollination Services?

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If you own or manage a commercial avocado orchard, you have likely debated at one point or another whether to seek out honey bee colonies to pollinate your orchard, and how much to pay the beekeeper for those pollination services. A recent academic paper published in the *Journal of Applied Entomology* summarizes findings regarding the role of insect pollination in avocado production, and I would encourage you to take a look, especially if you have not sought out honey bee colonies in the past (see Dymond et al., 2021 referenced at end of article). Dymond et al. conclude that "In 19 out of 23 studies, insect pollinators contributed significantly to pollination, fruit set and yield." And "In most situations, growers will benefit from an increased density of pollinators." However, they note that renting honey bee colonies may not make economic sense for every orchard. In this article, I'll touch on some factors that may influence a grower's decision to place honey bee colonies in avocado orchards for pollination services.

Are managed honey bee colonies needed in your orchard?
Given the conclusions of Dymond et al. (2021), if you are a grower who has not placed honey bee colonies in your avocado orchard in the past, this may be something to consider going forward. Though, doing so may not guarantee increases in yield because your orchard has likely been receiving pollination services from wild pollinators and/or honey bee colonies located nearby. If your orchard is located near natural pollinator habitat, you may receive sufficient wild pollinators to obtain significant fruit set, in which case additional bees may not be necessary. Foraging honey bees typically seek out the least competitive forage sources, so if your orchard without honey bee colonies is located near an orchard in which the grower paid for pollination services, it is likely you are "borrowing" bees from your neighbor's orchard. In that situation, bringing in managed honey bees may not make the most economic sense from your perspective, but it may make your neighbor happy!

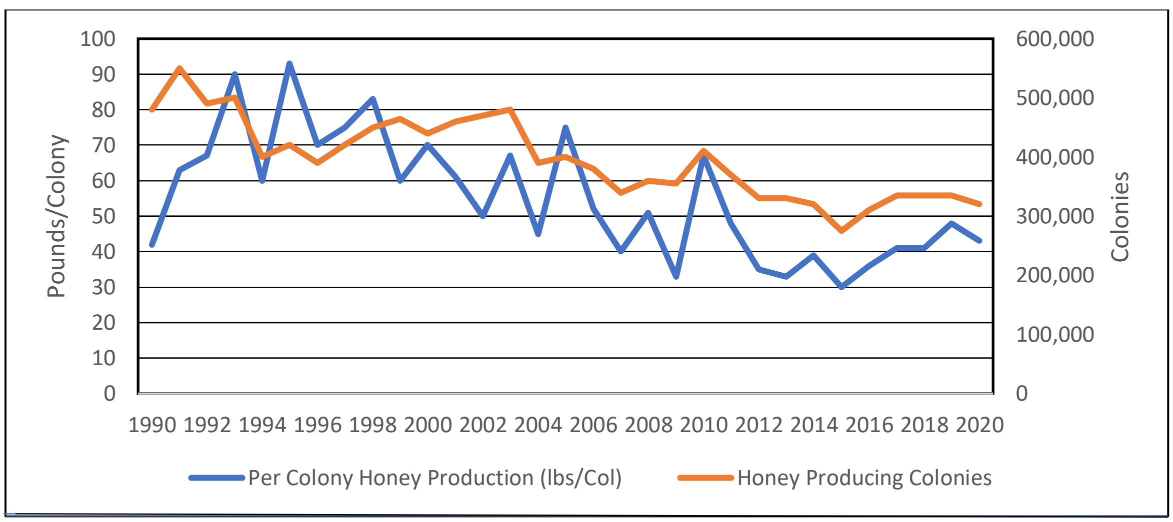
Supply of honey bee colonies
Depending on location, avocado bloom can begin in late March/early April and last through May/June (Bender, 2013). One important factor in the availability of honey bee colonies for pollination services for avocado bloom is the number of colonies in California at the end of almond bloom. In 2020, roughly 2.4 million colonies were required to pollinate California's almond orchards, far exceeding the number of colonies that remain in California year-round. This means roughly 2 million colonies were shipped in to California to meet this demand. This number makes up approximately 88% of the total number of colonies in the U.S., so beekeepers bring colonies from as far as New York and Florida to meet these needs (Goodrich and Durant, 2020; Goodrich, 2019).

For avocado growers, this means at the very beginning of avocado bloom, there may still be a surplus of bees left in California. Beekeepers from northern states, e.g., North Dakota, South Dakota, and Montana, can't transport colonies back right away given there may still be snow on the ground and little blooming for the bees to forage on. However, as spring progresses throughout the rest of the U.S., the number of bees in California begins to decrease substantially.

Looking at the U.S. Department of Agriculture (USDA) Honey Bee Colonies Report, on April 1, 2018, there were 1.1 million colonies in California and by July 1, 2018 the number of colonies was nearly half that at 590,000.

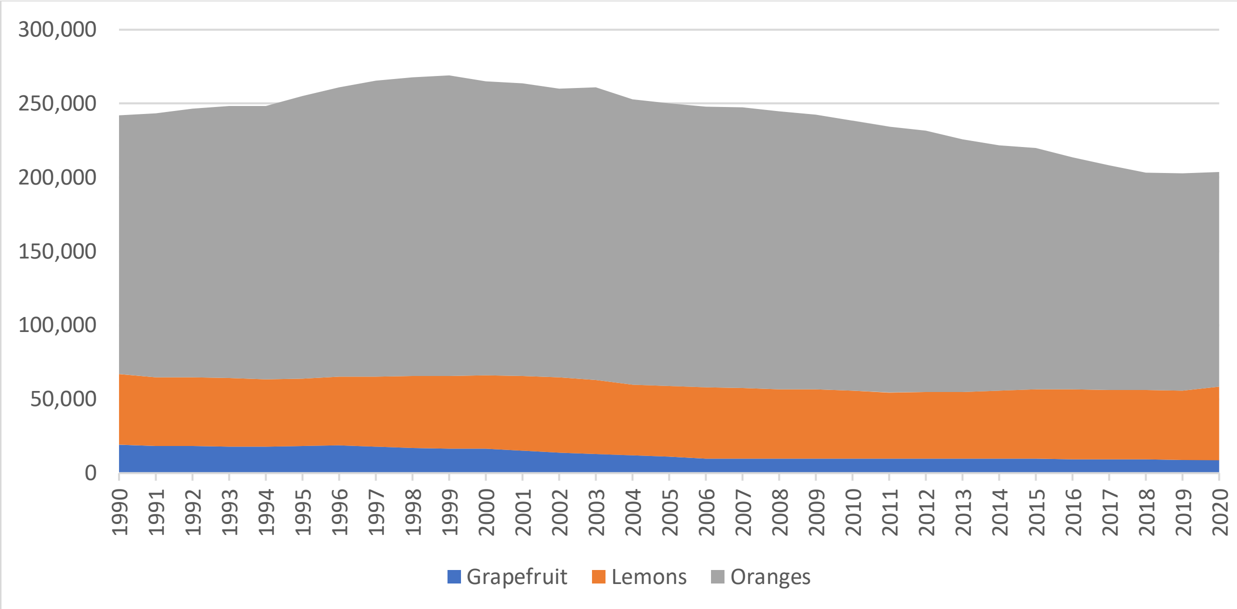
Traditionally, California beekeepers would place colonies in or near citrus orchards for honey production after almond bloom (Champetier, 2010). In addition to being good for bees (and their keepers), this practice has benefitted growers of nearby crops that require pollination services. For example, a beekeeper might place colonies for no charge in an avocado orchard that needs pollination services simply to gain access to the prime honey-producing location. However, given the surplus of colonies remaining in California after almond bloom, I suspect (notably without any direct empirical evidence) these locations are not as prime as they once were. Supporting evidence for my theory is shown in Figures 1 and 2. Figure 1 displays a fairly prominent downward trend in total honey-producing colonies in California since 1990, and over the same time period, the average amount of honey produced per colony in California has trended downward as well. If the essential inputs to honey production, i.e., floral nectar and pollen sources, were roughly equivalent over this time period, one would expect for honey production per colony to increase as the number of colonies decreases given the lower competition over floral sources. Figure 2 shows bearing citrus acreage over this time period. Citrus acreage has decreased since the late 1990s, which might partially explain lower honey production per colony in recent years. However, the decreasing trend in honey production per colony occurred even in the late 1990s when citrus acreage in California was increasing. These trends suggest that the influx of bee colonies due to almond pollination requirements have encroached on forage resources previously utilized by California beekeepers, lowering their potential for honey production. Again, I caveat the previous suggestion with the fact that I have not yet directly tested this hypothesis, so these relationships could be coincidental.

Figure 1: California Honey Producing Colonies and Per-Colony Honey Production, 1990-2020



Source: USDA NASS *Honey* report

Figure 2: California Bearing Citrus Acreage, 1990-2020



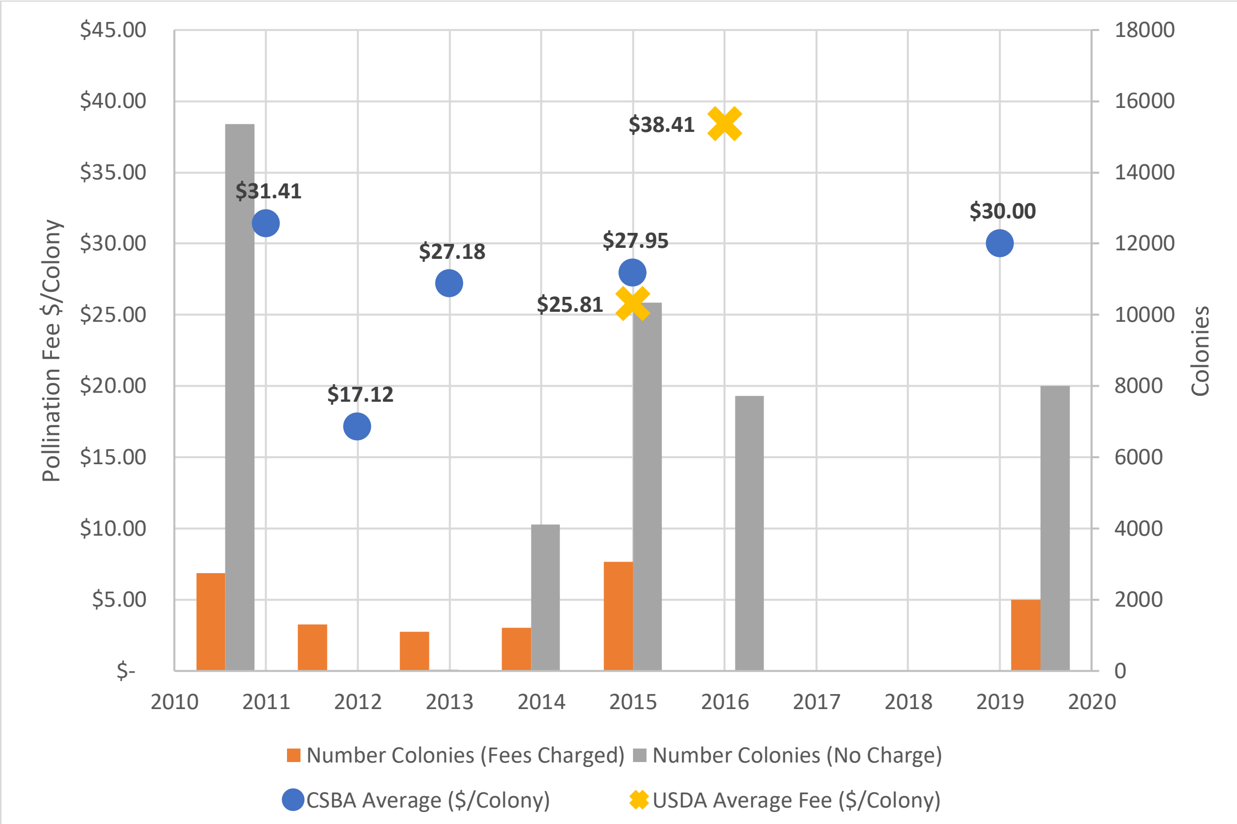
Source: USDA NASS

The surplus of colonies due to almond pollination may have two potential implications for the availability and cost of pollination services for avocado production. The first impact being that if my previous hypothesis holds merit, citrus resources are not as valuable to California beekeepers as they once were, and beekeepers may be less likely to place colonies in avocado orchards for no charge. The second implication is that the surplus of honey bee colonies in California (at least at the beginning of avocado bloom) puts downward pressure on the pollination rental fee because after almond bloom beekeepers must find some forage source for their colonies or feed them sugar syrup. Nectar and pollen from avocado trees is healthier for the bees than sugar syrup (and doesn't cost the beekeeper money). These two implications are offsetting to some extent, so it is unclear what net impact will be on avocado pollination fees going forward.

Avocado pollination fees (or lack thereof)

Few sources exist that track pollination fees that help inform growers on how much they should be paying for pollination services. USDA began a Cost of Pollination survey that lasted two years, but unfortunately they discontinued it. The California State Beekeeper's Association surveys their beekeepers annually on the pollination fees collected, and provides some guidance on pollination fees, though the response rate for this survey has diminished over the years, so it's difficult to know how representative it is. Figure 3 shows the CSBA and USDA annual average fees (in 2019 dollars) for avocado pollination (colonies that were placed in avocados for no charge were not included in these averages). The figure also shows along the secondary axis, the total number of colonies rented out for payment and at no charge for avocado pollination by the CSBA respondents each year. Over the 2010 to 2019 time period, beekeepers that collected fees for avocado pollination were paid on average $27 per colony. There was variation above and below this number, but it seems to have stayed fairly constant over time. When beekeepers reported the number of colonies that were placed at no charge for avocado pollination, the amount of colonies far exceeded those that were placed for a rental fee, however again due to low response rates, it's hard to say how representative this is.

Figure 3: Average Avocado Pollination Fees (2019 dollars), Total Colonies Rented, and Total Colonies Placed for No Charge, 2010-2019



Sources: California State Beekeeper's Association Pollination Fee Surveys, USDA NASS *Cost of Pollination* report

Notes: Fees are adjusted to 2019 dollars using the Bureau of Economic Analysis GDP Price Deflator. No CSBA respondents reported placing colonies in avocados (either for a fee or no charge) in years 2017 and 2018

At the average rental fee of $27 per hive, if an avocado grower rented two hives per acre, he/she would need approximately $54 per acre in increased value for renting the hives to make economic sense. Assuming a price of $1.40/lb., the break-even yield increase to justify paying for pollination services is roughly 39 additional pounds per acre. At five hives per acre, the break-even yield increase would be 96 lbs per acre. This simplified analysis of course leaves out other costs that might increase with increased yields, however I think it displays that the potential benefits associated with pollination rentals might easily exceed the costs.

Beekeeper costs of pollination services

Many growers likely wonder: why should I pay a beekeeper for pollination services when they are receiving pollen and nectar from the avocado (and potentially nearby citrus) orchards? Most beekeepers who perform pollination services are commercial operations that depend on profitability to sustain their business. These operations must consider many costs when determining whether or not to do pollination services, and compare those costs with the revenues from pollination fees and/or honey production. Below I outline some of the primary considerations, though there may be others depending on the specific beekeeping operation.

- **Transportation costs**

  One of the most obvious costs to beekeeping operations is the cost associated with transporting colonies to and from the avocado orchard. Transportation and corresponding labor costs will vary depending on the distance between their bee holding yard and the orchard.

- **Costs of pesticide exposure**

  Another potential cost that is obvious to beekeepers, but not always growers, is that anytime a beekeeper places their colonies in or near agricultural production areas, they risk their colonies being exposed to pesticides. Pesticide exposure can kill the colony entirely, or have sublethal impacts on the colony, affecting its development for weeks or months. Lost or weakened colonies decrease future revenues, and increase the cost of production for the beekeeper. I suspect the threat of pesticide exposure near citrus orchards has grown larger in recent years given the necessary treatment of Asian Citrus Psyllid with insecticides to prevent the spread of Huanglongbing disease.

- **Other revenue opportunities**

  Beekeepers must consider their opportunity costs of placing bees in avocado orchards. If they can produce honey elsewhere, the pollination profits (fees collected and/or honey produced less costs) would have to be greater than the expected profits from foregone honey production in order for it to make economic sense. Similarly, if the beekeeper can get paid to pollinate another crop that overlaps in bloom with avocados, e.g., apples or sweet cherries, the profits from avocado pollination would have to be equal to or larger than the profits from pollinating the other crop in order for the beekeeper to choose to pollinate avocados.

Concluding thoughts

So, to answer the question posed by the title, should you be paying for avocado pollination services? Unfortunately, there is no "one size fits all" answer in my opinion. The answer will depend highly on the location of your orchard (specifically proximity to wild pollinators, managed honey bee colonies, and citrus orchards). If you decide to bring in managed honey bee colonies, it's important to keep in mind the beekeeper's costs and potential foregone revenues when negotiating a fair pollination fee.

Need to find a beekeeper? You can search for pollination services by county in the Almond Board of California's Industry Directory: https://www.almonds.com/tools-and-resources/industry-directory

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Collaboration is Key to Saving Kern County Citrus

Judy Zaninovich, Kern County ACP/HLB Grower Liaison

It has been 8 years since the Asian Citrus Psyllid (ACP) was first detected in Kern County in 2013. At that time many experts predicted it was the "beginning of the end" for the local citrus industry. ACP and the disease it can spread, Huanglongbing (HLB), are the citrus industry's biggest threat to date…HLB is a death sentence for an infected citrus tree. It was widely thought that once this disease vector arrived, we would follow the path of rapid disease spread, severe fruit decline, and tree death, which has historically occurred in other states and countries.

The threat is real, to which Florida and Texas citrus industries can attest as they continue to fight for survival against high levels of HLB infections. So far in California, nearly 2,300 HLB-positive trees have been found in Los Angeles, Orange, Riverside, and San Bernardino counties – all residential trees, none detected in commercial citrus yet. However, Kern County growers are understandably very concerned since the HLB detections were found in counties just to the south of Kern and any confirmed detection of HLB will cause critical regulatory changes that may affect everyone.

And, although there have been seasonal increases of detections in some years since ACP was first detected in Kern County, psyllids have not yet become widely established as originally predicted and no HLB-positive trees have been found here yet.

Why? Well, there are several possible reasons for this.

First: Multi-agency Cooperation.
The California citrus industry watched closely and learned from other HLB-affected states and countries what had or had not worked for them in their battle against HLB. In response, the California citrus industry developed an aggressive multi-disciplinary and cooperative program, the Citrus Pest & Disease Prevention Division (Division) – a division of the California Department of Food and Agriculture. The Division works in close partnership with other county, state, and federal agencies and citrus industry groups. Locally, the Division along with the Kern County Agricultural

Commissioner's office have boots on the ground in Kern County and are working tirelessly to survey for ACP and HLB, trap and test psyllids found, treat residential citrus when ACP are detected, and are prepared to quickly remove confirmed HLB-positive trees if discovered.

Second: Central Valley climate.

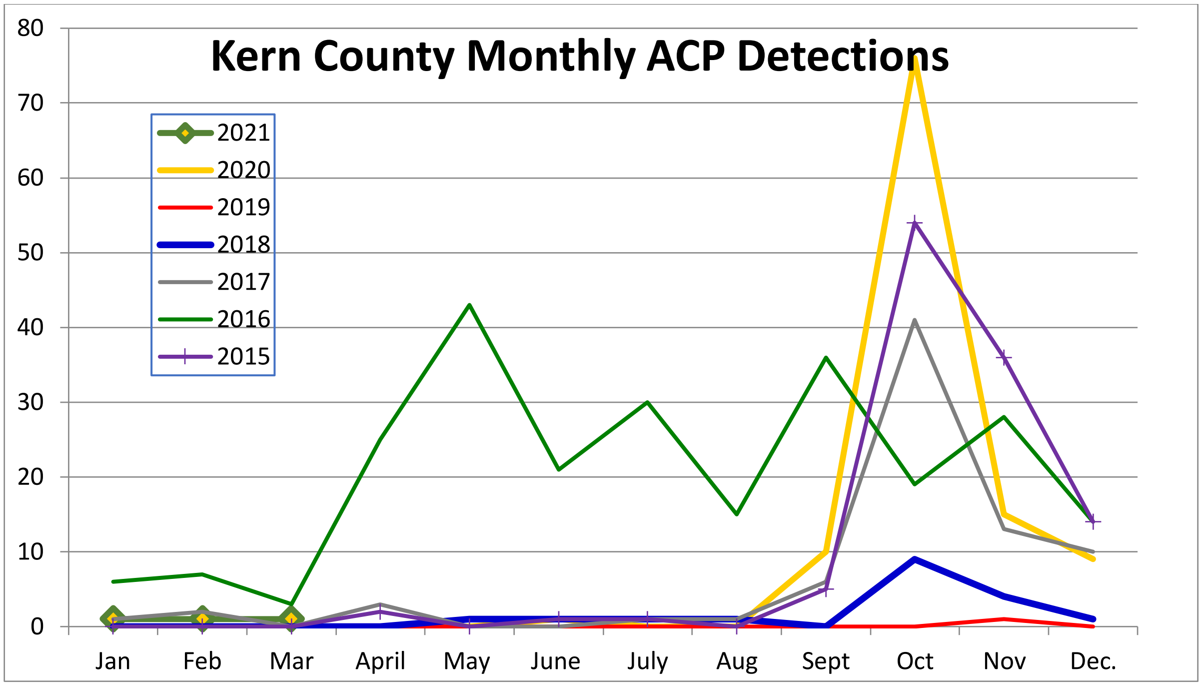
Hot summers/cold winters and distinct foliar flushing periods in the valley are less than optimum for psyllid population development compared to the milder weather along the coast. Psyllids need young tender leaves to continue to build a population. Although the weather here is not optimum and populations haven't been extremely high to date (which can occur in coastal areas), concerning levels of ACP have been occasionally found here, mostly in untreated trees.

Third: Protecting with regulations.

The California Department of Food and Agriculture has implemented regulations to protect the citrus industry that assist in keeping the ACP populations from spreading. One example is the regulation which growers ensure harvested fruit is free from psyllids when moving the fruit to another ACP quarantine region (by using field cleaning machines, grate cleaning, or the application of ACP treatments) along with tarping truckloads of harvested citrus. Data analysis from the industry's Data Analysis and Tactical Operations Center (DATOC) has shown these actions have reduced the spread of ACP in California.

Finally, and most importantly: Grower/resident cooperation.

When ACP has been detected in Kern County, a very high percentage of commercial citrus growers and homeowners continue to cooperate by making/allowing timely treatments to knock down psyllids. For example, in 2015-16 a serious outbreak of ACP occurred in both residential and commercial citrus in Bakersfield and rural areas south and east of the city. Both trap detections and live breeding populations were discovered by Division survey crews. However, with strong support from both residents and growers with ACP treatments, the psyllid population was successfully controlled to very low levels for a few years – see graph.



Then again in the fall of 2020, Kern County citrus was challenged with another outbreak of ACP – nearly 100 trap detections along with several live breeding populations were found. But again, the cooperation from property owners was excellent regarding treatments to their citrus to control ACP. To further aid in continued psyllid suppression, it is recommended that Kern County growers add an ACP-effective material to their spring treatments to insure that possible undetected ACP aren't left to build on the spring foliar flush.

So, what has been the main reasons for the prevention of the establishment of ACP and the possible transmission of HLB to Kern County citrus so far? Collaboration, vigilance, cooperation, and a bit of luck. Experts are now hopeful that with continued diligence, ACP populations may be able to be suppressed to very low levels in the valley most years with only the occasional ACP outbreak. Alternatively, a widely established ACP population not only increases the threat for HLB but will also cause the need for additional insecticide treatments to try to suppress the population. **The best defense we have against HLB is to continue to keep psyllid populations as low as possible.** Partnerships and cooperation are the key that will determine whether we are successful in preserving citrus in Kern County for generations to come.

Best management practices property owners with citrus can employ:

1. Do not allow the movement of citrus leaf or stem material from the property – check all equipment prior to entering or leaving.
2. Look/scout for psyllids whenever flush is present. If psyllids are found, immediately contact the CDFA Pest Hotline 800-491-1899.
3. Cooperate with agricultural officials for trapping and surveys.
4. Comply with all requested treatments when ACP is detected in the area.
5. Stay informed. Attend industry meetings and sign up to receive news from www.CitrusInsider.org and the local ACP/HLB Grower Liaison (contact information located on the Citrus Insider website).

Late stages of ACP nymphs. Photo courtesy of Rivera Lab

Are Finger Limes Just Another Fad?

Trent Blare (tblare@ufl.edu), Assistant Professor in Food Resource Economics, University of Florida.

There has been growing hype around finger limes from citrus growers, the retail sector, and their customers. Growers are particularly interested in this market as disease pressure such as citrus greening and international competition have made other citrus and fruit markets less appealing. However, many are concerned that finger limes are just a fad and the markets will eventually crash as consumers move on to the next cool food trend. Our research at the University of Florida is examining these markets to determine the potential for growers in Florida and throughout the U.S. to take advantage of the emerging finger lime market.

Finger limes are known as the “citrus caviar,” because of their unique compressed, round juice vesicles that are distinct from other citrus crops’ delicate, tear shaped fruit sacs. This feature combined with its bright colors and tangy flavor make finger limes a great garnish used in high end restaurants and as a perfect accent to a cocktail. As more and more chefs, bartenders, and suppliers in the hospitality industry become familiar with the fruit, they are falling in love with them and demand for finger limes is rapidly growing.

Figure 1. Finger lime plant (left – courtesy of Jeff Wasielewski, UF/IFAS) and fruit (right – courtesy of Cristina Carriz UF/IFAS).

Many growers and suppliers of finger limes are hopeful that the demand for this fruit will expand beyond the hospitality sector to mass markets, as consumers across the U.S. and around the world become more familiar with the fruit. Finger limes are not only resistant to greening that plagues orange and other citrus production but also have traditionally been grown using few agrochemical inputs (Singh et al. 2017). So, there are expectations that organic markets could provide an additional premium for this fruit. Some research has also pointed out the high prevalence of antioxidants in the fruit, providing finger lime growers and suppliers with potential to enter health food markets (Netzel et al. 2017).

This fruit, which is native to Australia, has only in the last several years become commercially available to growers across the US, after first having been cultivated in California in late 1960s (Singh et al. 2017). In fact, nearly all of the current production in the U.S. is in central and southern California and the big island of Hawaii. There are only about 15,000 trees, which are owned by less than a dozen growers (Karp 2009). So, there is room to expand production especially by Florida growers, who supply East Coast markets. Prices are quite elevated for the fruit; for instance, during the spring of 2020 finger limes were priced at \$32 for 80 grams or 8 limes on Amazon or \$18 for 9 to 10 finger limes from one of the only suppliers in South Florida. Questions remain whether these prices will remain elevated as more and more growers enter the market.

Over the next two years, we at the University of Florida will be exploring the potential for finger limes in these markets and how to develop inclusive supply chains to improve the participation of all growers in them. We will hold taste testing panels and interviews with suppliers, chefs, and bartenders at trade fairs to introduce them to the product, gauge their interest in the fruit, and estimate their willingness to pay for finger limes. The analysis of this research will allow us to estimate the potential demand of the fruit and how many growers could participate in this market. Additionally, we will examine the supply chain to determine which factors need to be addressed to improve growers' access to these growing markets. Please be on the lookout for further updates as we examine the potential growers to tap into growing finger lime markets and determine what can be done to sustain the demand for them.

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Topics in Subtropics

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