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Olive Notes
Tulare County

May 2021

Developing a Nitrogen Fertilizer Plan for Olive Orchards

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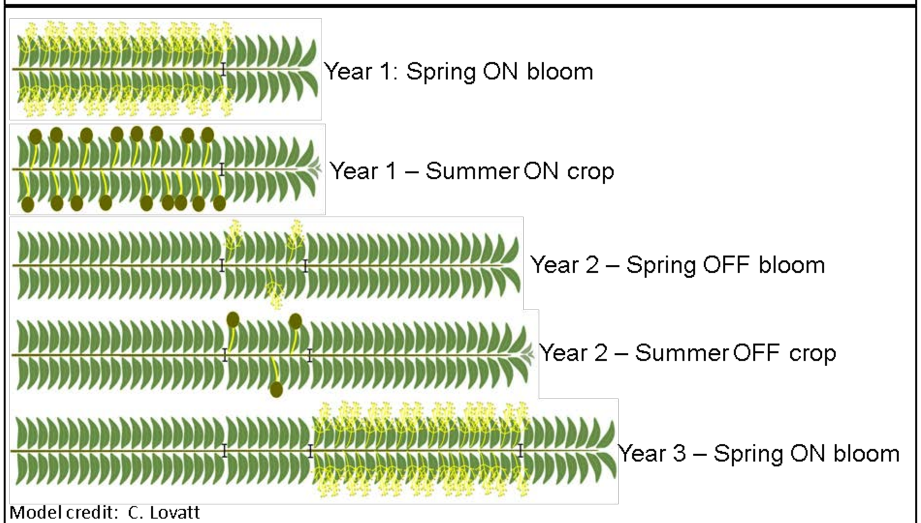
Nitrogen management plans (NMP) for California olive orchards are essential for the Irrigated Lands Regulatory Program and can increase net return. A good NMP has the potential to increase yield, improve oil quality and mitigate biotic and abiotic stresses while reducing nitrogen losses from the orchard.

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.



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.

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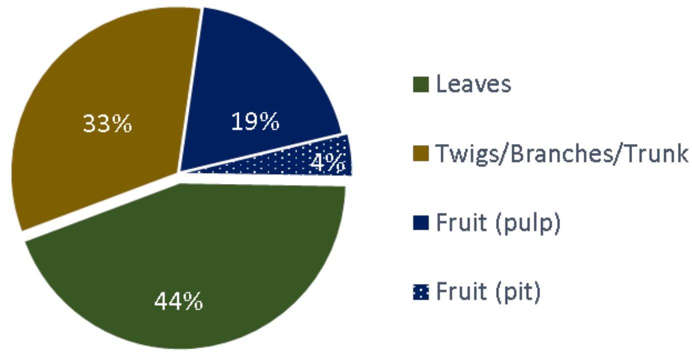
Foliar Sampling for Nitrogen Analysis. By convention, foliar nutrient analysis is conducted in late July-early August in California. Fully-expanded leaves are collected from the middle to basal region of the current year's growth at a height of about 5-8 feet from the ground. To capture a general estimate 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.



Adapted from: Rodrigues et al. 2012

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.

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).

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.

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.
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 pruning's 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.

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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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 olive trees, 96 trees per acre, (Figure 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.

Figure 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 (Figure 2) and evaluated the current pistachio trunk shakers (Figure 3) for harvesting efficiency in existing orchards, 96-139 trees per acre, modified with mechanical + hand pruning, (Figure 4 and 5) and in newly planted hedgerow orchards (Figure 6).

Figure 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.

Figure 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). 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 will easily be

Figure 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.

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.

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 (Figure 3). Trunk shakers harvest the olives closest to the trunk and main scaffolds more efficiently than those at the top of the canopy. 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 (Figure 2). Shown in (Figure 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.

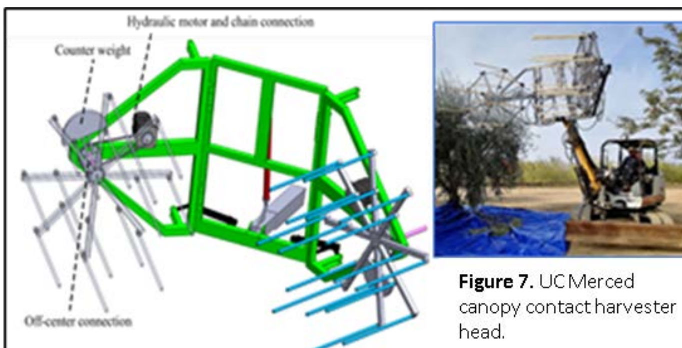

Figure 7. UC Merced canopy contact harvester head.

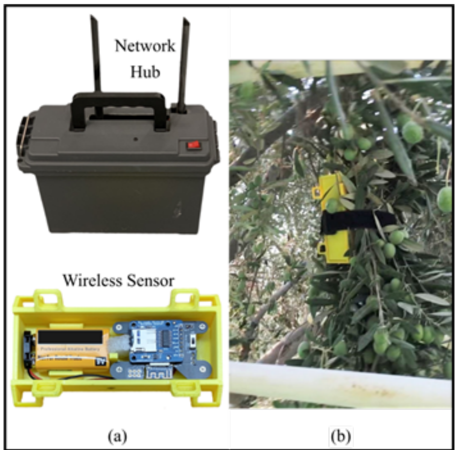

Figure 8. Wireless sensor module and network hub (a) and wireless sensor module installed on olive branches for data collection (b).

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.

Progress with UC Merced Canopy Shaker:

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, (Figure 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.

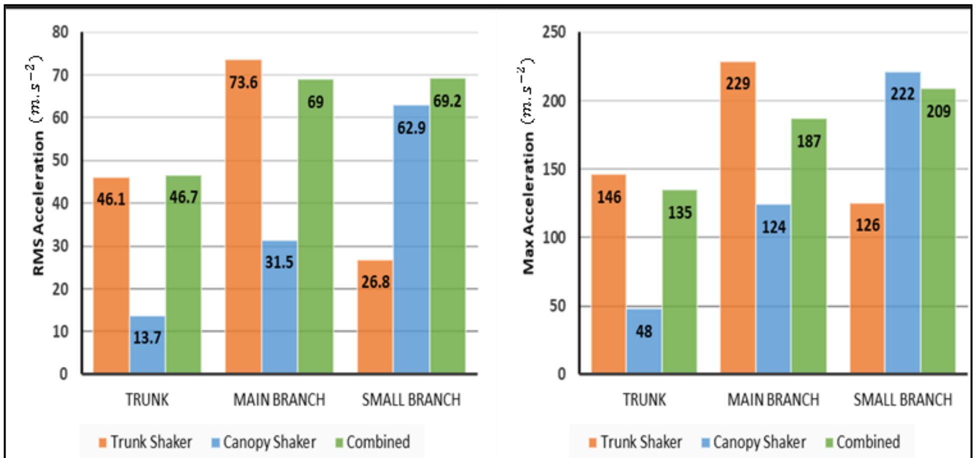

Figure 9. Root mean square or vibration at each part of the tree (left) and maximum acceleration produced by the two harvesters alone and together within each part of the tree (right).

Figure 9 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.

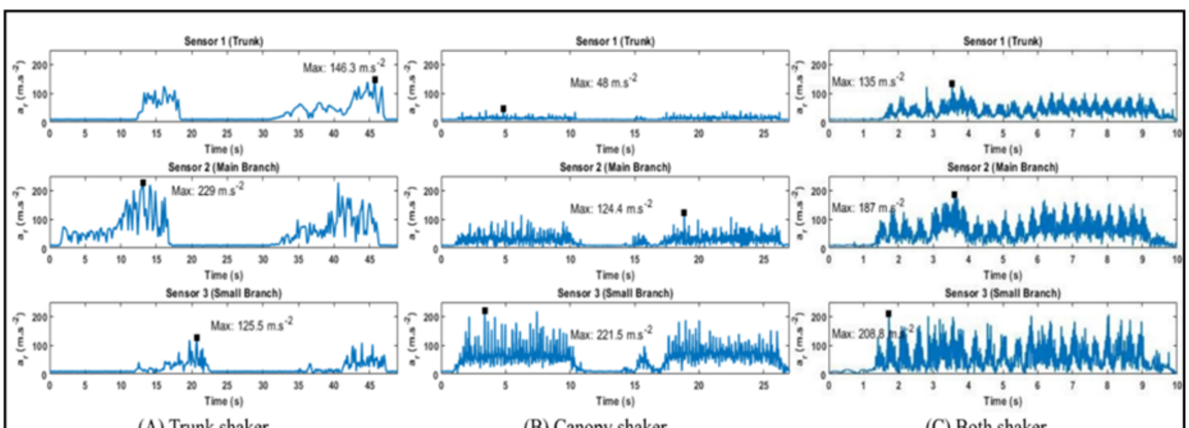

Figure 10. Vibration transmission through the tree using (A) trunk shaker, (B) UC Merced canopy shaker and (C) both shakers operating simultaneously.

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	

Figure 10 B 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 11. Trunk and canopy shaker simultaneously shaking an olive tree.

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.

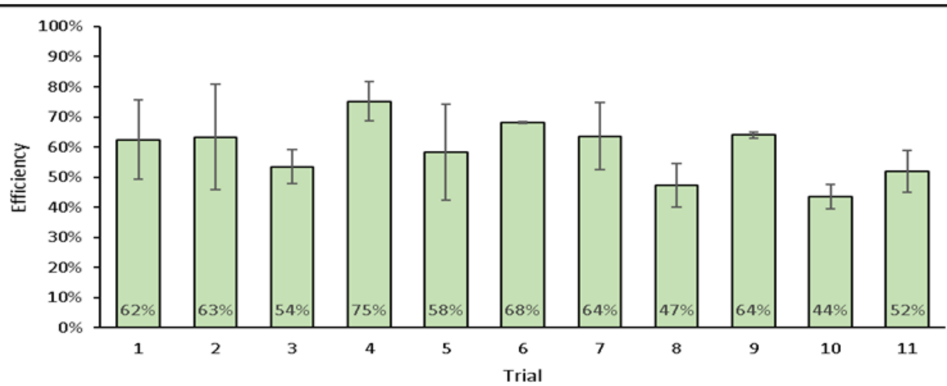

Figure 12. Harvest efficiency for all 11 trial combinations. Trials 1-9 used the canopy contact and trunk shaker simultaneously. Trial 10 used the UC Merced Canopy shaker alone and trial 11 used the OMC trunk shaker alone.

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:

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

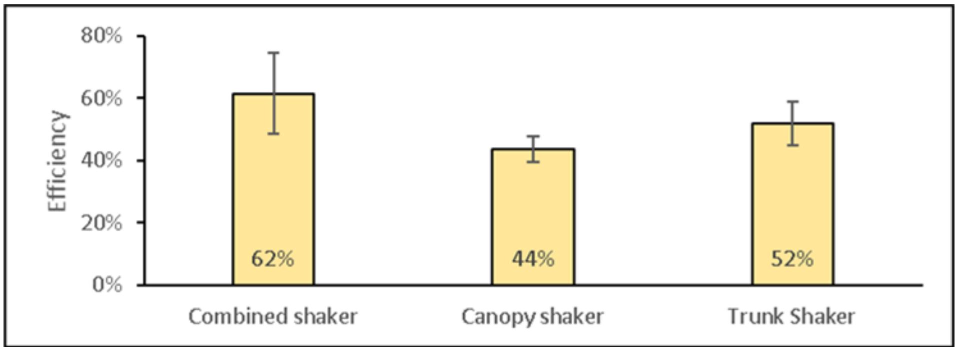

Figure 13. Average harvest efficiency for three methods demonstrating the average higher efficiency when the trunk and canopy shaking are combined.

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.

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.

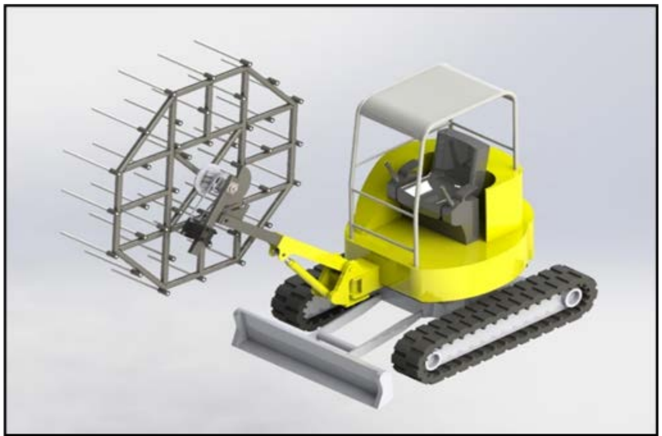

Figure 14. Proposed shaker design with a side-mounted canopy shaker.

Specific Objectives for 2021:

- 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 trees 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.

Citations

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