Evaluation of Pistachio Trunk Shaker Harvester Efficiency

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Introduction:
Preliminary data in 2009 suggested the trunk shaking harvesters currently used in California had lower than expected efficiency. These limited, preliminary trials conducted September 28, 2009 indicated the shaker left an average of 38% (by weight) of the in shell split nuts in the tree; after drying and grading an average of approximately 5 pounds of split inshell nuts per tree. For this reason a more complete evaluation of harvesters was repeated October 25th, 2010 with four commercial and two experimental harvesters at Paramount Farming Company's Dudley Ridge Ranch.

Methods:
The trees were harvested October 22, 2010. The trees, among the oldest on the ranch ranged in height from 20.5 to 22 feet tall and averaged 21.2 feet tall, and from 44.0 to 59 inches in circumference, average 47.4 inches, measured 18 inches above the ground. Each tree was shaken for 8 seconds, the nuts caught in a tarp and the remaining fruit gleaned from the tree. If large enough both harvested and gleaned samples were submitted for grading.

While shaking the trees an image analysis procedure using 300 frames per second was used to determine the rate of fruit removal. This image analysis procedure was implemented to determine the harvest rate of fruit removal over time for the total duration of the shake tests. The recorded video images were analyzed with the "Tracker" software developed by Douglas Brown and the "Image J" software developed by Wayne Rasband.

A white target was placed on the ground as a reference frame for the image analysis. The area of harvested fruits covering the white reference was correlated with number of pixels in the framed image. The higher the number of fruit covering the white frame the higher the number of computed pixels. The use of the this approach made it possible to look at the video images frame by frame to extract the information while the tree was being harvested by the particular shaker head. The high-speed videos were recorded at a speed of 300 frames per second. Figure 1 shows a sample image of the white target used as a reference and the respective image with the corresponding number of computed pixels.

Fig. 1. – Original image, left, converted to a binary image, right. The white pixels present on the white area were converted into black colors. Because of the tarps were shaded during experiments, there were some noise in the images that were filtered.

Figure 2 below shows typical images of actual harvested fruits, right, analyzed and converted to pixels.

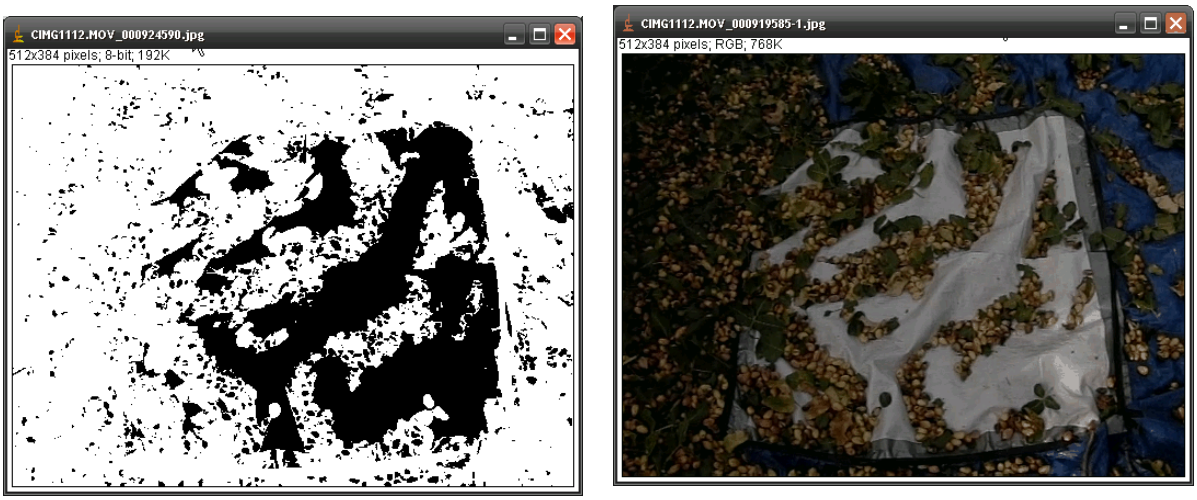

Figure 2. Original image contained harvested fruit, right, converted to a binary image. The 32-bit color image was converted into binary image on the left. The boundary shown in fig.1 was used for as a reference to remove extra pixels present outside of the reference frame.

Figure 3 demonstrates how a typical percent area of harvested fruit divided by the original reference frame area was obtained.

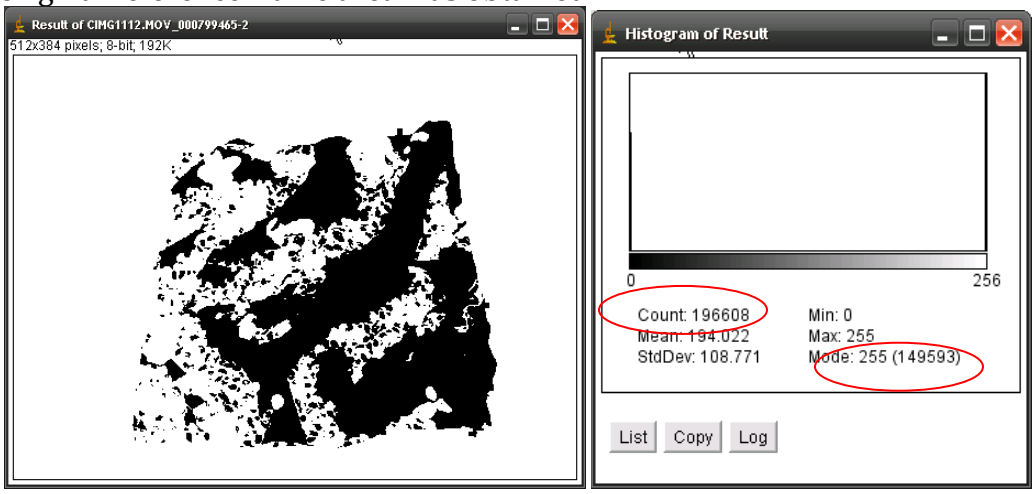

Figure 3. The pixels in the outside of white tarps were removed. (The images of tarps were added to the images of fallen fruits and leaves). The histogram counted the number of pixels according to the shade of darkness of color in Image J software used for calculating the white pixels and black pixels in the above image. Since the black pixels in above image were fallen fruits and leaves, the number of black pixels is the total number of pixels in the image (512, width, *384, height, =196608 pixel)

and the number of white pixels, 255 (149593 pixel). Thus the number of pixels of fallen fruits and leaves is 47015 (196608-149593) pixels. Therefore the pixels of fruits occupy the 58% of white tarps

Results:

Harvester efficiency as a function of trunk circumference:

Individual harvester results are given in Table 1 below. The harvesters ranged from 82 to 96 % efficient, averaging 87% efficiency overall. Included in this evaluation are two new experimental trunk shakers that both averaged 96% efficiency. Without the results from these two harvesters included the harvester efficiency averaged 83%. There were no statistically significant differences in harvester efficiency among the four commercial harvesters. However, when the two experimental harvesters were included in the analysis both were significantly more efficient than the four commercial harvesters.

Efficiency Comparison of Four Commercial And Two Experimental Harvesters

Harvester	Harvest Removal Efficiency (%)	Average Trunk Circumference (inches)
I	86b	47.8
II	79b	46.8
III	82b	49.2
IV	*96 (Experimental)a**	*44*
V	*96 (Experimental)a**	*47.4*
VI	84b	49.6
Average	**87 (of all 60) 83: NSD (without 2 experimental harvesters)**	**47.4**

* Values within ***these two cells*** are significantly different from values with different letters within the same column per T-test @ p≤ 0.0001

Table 1. The table gives the average efficiency of the individual harvesters tested and the average trunk circumference of the trees shaken. Harvesters IV and V, indicated by *italics* were experimental harvesters that produced a 13% higher average efficiency than the other harvesters. Without these two, 96% efficiencies, included the average harvester efficiency was the (83%) given in parentheses in the "Average" row of the table. There were no statistically significant differences in efficiency among the four commercial harvesters if the two experimental harvesters were not included in the statistical analysis. If the two experimental harvesters were included the two experimental harvesters were statistically significantly more efficient than the four commercial harvesters.

A consistent pattern was detected when the 30 values from the six harvesters were analyzed together. As trunk circumferences increased in circumference, particularly above 50 inches, the efficiency of all the shakers tested decreased.

The results are presented as a graph in Figure 4 below. While the trend line in the graph below strongly indicates a decrease in harvester efficiency with increasing trunk circumference the R^2 of 0.30 suggests the relationship is not strong. However, this is most likely due to the low number of replications per harvester. With more replications the correlation of decreasing efficiency with increased tree circumference would be stronger and the R^2 value higher.

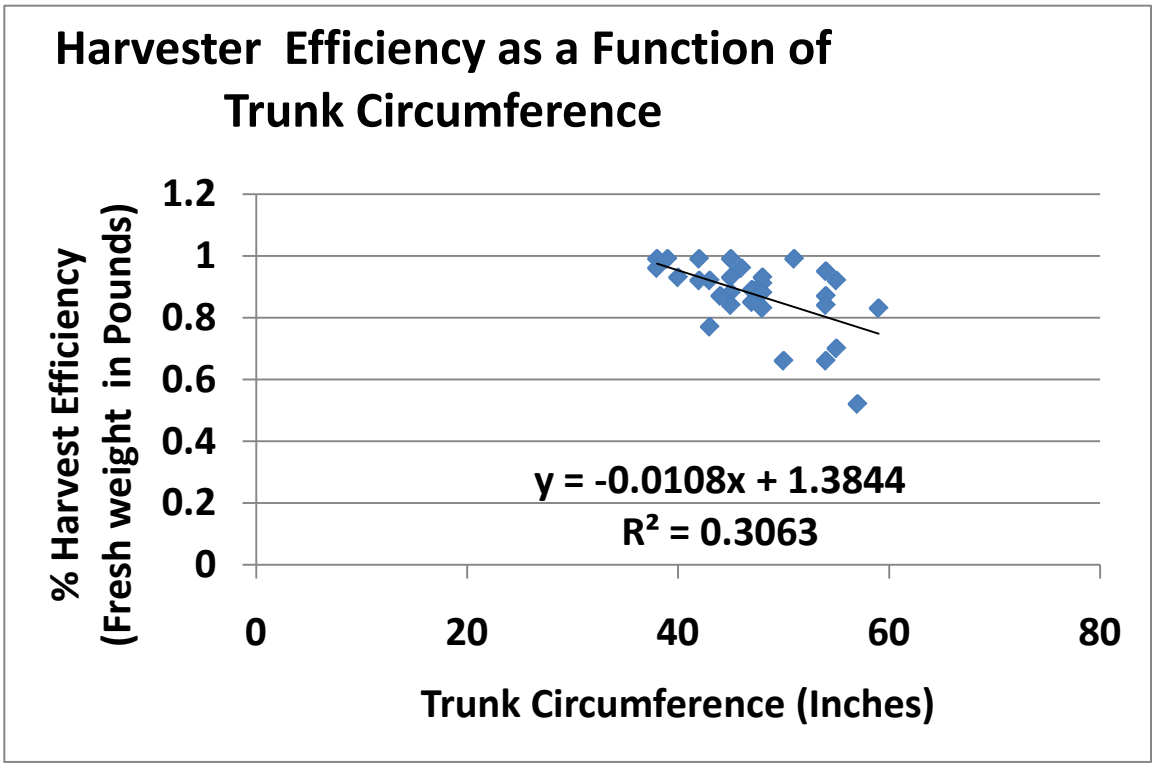

Figure 4. This graph demonstrates that as the trunk circumference (horizontal axis) increases the harvester removal efficiency (vertical axis) decreases.

Comparison of Experimental and Current Commercial Harvester Efficiency:
Figure 5 below shows a comparison of fruit removal between an experimental and current commercial trunk shaking harvester. The modified experimental shaker removes the fruit at a higher rate, left, compared to the traditional shaker, right.

Comparison of Fruit Removal over Time between a an Experimental and a Commercial Harvester

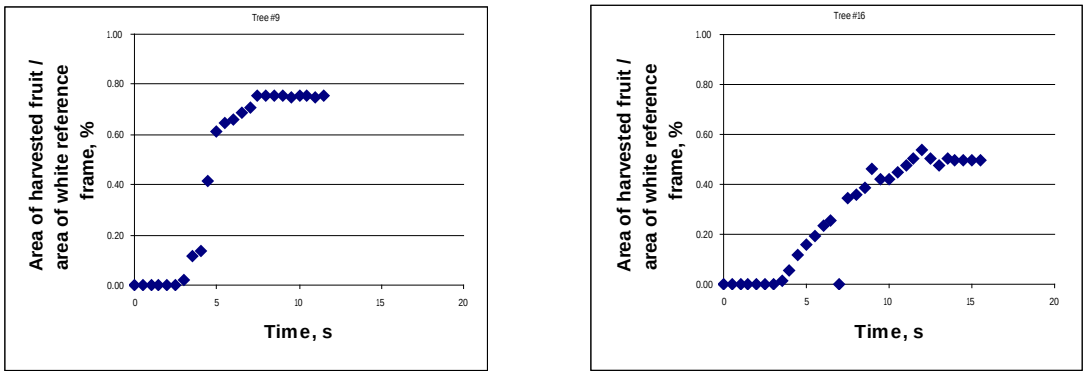

Figure 5. Graph on the left shows the rate of fruit removal by the experimental harvester compared with the commercial harvester in the graph on the right.

The experimental harvester removed most fruit during the first three to four seconds while the regular harvester required a full eight seconds. Therefore, the experimental harvester is able to harvest the fruits at half of the total time required for the current commercial harvester.

Conclusions:

These results suggest that as pistachio tree trunk size increases trunk shaking harvesters will need to be improved to achieve the highest harvesting efficiency possible. Or different harvesting methods, possibly direct canopy contact harvesters, may need to be developed.

Alternatively, a planned pruning program to decrease tree canopy height may maintain trunk shaking harvester efficiency because trunk shakers remove crop closest to the trunk best .

Another, more expensive solution would be planned orchard removal and replanting.

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