Foliage Shaker for Citrus Harvesting — Part II: Harvesting Trials

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HARVESTING trials were conducted in 1972 in which a vertical foliage shaker was used to harvest 'Hamlin' and 'Valencia' oranges. The main objective of the trials was to compare the fruit removal effectiveness of two shaking modes—a near-sinusoidal mode and a quick-return mode in which an 8-in. vertical stroke was applied at a distance of up to 4 ft from the limb ends.

In 'Hamlin' oranges, there was no difference in the mature fruit removal efficiency of the two shaking modes. Shaking for a 10-sec duration per clamp at 160 cpm and 200 cpm removed 70.8 percent and 78.7 percent of the mature fruit, respectively.

Shaking duration per clamp was 10 and 20 sec at 200 cpm in Valencia oranges. The near-sinusoidal mode removed an average of 2 percent more mature fruit than did the quick-return mode and the 20-sec shake removed 4 percent more mature fruit than did the 10-sec shake. Average mature fruit removal was 79.7 percent while the subsequent yield reduction of mature fruit averaged 18 percent.

INTRODUCTION

The concept of shaking the outer foliage of citrus trees was developed for selective harvesting of 'Valencia' oranges. This variety is harvested when both the mature and young (next year's) fruit are on the tree. Therefore, the most desirable mechanical shaking action for harvesting must be selective to maximize mature fruit removal while minimizing young fruit removal and tree damage. The foliage shaker concept, which employs a large amplitude, low-frequency shake, appears to offer one of the most selective shaking actions for harvesting citrus (Chesson 1973, Hedden and Coppock 1971, Sumner 1973).

The design and kinematics of a citrus foliage shaker driver were discussed in Part I of this series (Sumner et al. 1974). The objective of the harvesting trials reported in this paper was to compare the fruit removal effectiveness of two shaking modes (sine and quick-return) on a machine that utilized the foliage shaker drive system.

FIG. 1 Vertical foliage shaker used in Hamlin- and Valencia-orange harvesting experiments.

SHAKER AND HARVESTING METHOD

Fig. 1 shows the machine used in the harvesting trials. The prime mover and most of the shaker mast was manufactured by ITF Corporation*, Longwood, Florida. The drive for the shaker mast was designed and constructed by personnel at the Agricultural Research and Education Center at Lake Alfred.

Harvesting was accomplished by positioning the machine at successive locations around the periphery of the tree. At each successive location the machine was positioned into the tree with its logitudinal axis approximately tangent to the circumference of the tree canopy. In this position 8-ft-long tines engaged a chord length of the canopy circumference. After the tines clamped the outer foliage (up to 4 ft from the limb ends) of the tree, shaking proceeded for a specified duration. The removed fruit was picked up by hand and conveyed to the machine's storage bin. The tines were then unclamped and the machine was moved around the periphery of the tree to successive locations where the shaking procedure was repeated.

'HAMLIN' ORANGES

The first experiment, in which 'Hamlin' oranges were harvested, was designed to gather information on the harvesting rate of the machine and the effectiveness of two shaking modes at 160 and 200 cpm in removing mature fruit. The trees were on a 25 ft x 25 ft setting and were 15 to 18 ft both in height and canopy diameter. Twenty-four trees were harvested in a randomized complete block design with 4 harvesting treatments (see Table 1) and 6 replications. The results are summarized in Table 2.

There was no difference between the percentage of mature fruit removed by the near-sinusoidal mode and the percentage removed by the quick-return mode. Shaking at 200 cpm removed significantly more fruit (8 percent) than did shaking at 160 cpm. The harvesting time per tree averaged 7.1 min, with an average of 4.17 clamps per tree. The harvesting rate was somewhat better at 200 cpm, principally due to the greater percentage of fruit removed. Fruit left on the tree was generally near the tree trunk or near the tree top. Usually, fruit in these locations was shaken little or

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TABLE 1. EXPERIMENTAL TREATMENTS USED IN HARVESTING OF HAMLIN ORANGES

Treatment No.	Shaking mode*	Shaking frequency, cpm
1	Near-sinusoidal (NS)	160
2	Near-sinusoidal (NS)	200
3	Quick return at bottom (QR)	160
4	Quick return at bottom (QR)	200

* Shaking amplitude = 8 in.; duration of shake per clamp = 10 sec

not at all.

'VALENCIA' ORANGES

The development of a satisfactory mechanical harvesting system for 'Valencia' oranges is considerably more difficult than for other orange varieties, mainly because both young and mature fruit of this variety are on the tree at harvest time. This difference, in comparison with other orange varieties, is further complicated by the fact that young fruit characteristics change drastically during the harvest season (Coppock 1972). These characteristics cannot be ignored, because they determine to a great extent whether or not a concept is feasible. Therefore, the harvesting experiment with 'Valencia' oranges was conducted on three dates – April 25, May 15, and June 5, 1972. It involved five harvesting treatments (four shaker and one hand-picked check, see Table 3) replicated six times on each harvest date for a total of 5 x 6 x 3, or 90 trees, in a randomized, complete block design. An 8-in. stroke (amplitude) at 200 cpm was used for all shaker treatments. The 'Valencia' trees were very uniform in size and shape, ranging between 15 and 20 ft high, and had low skirts. They had a high percentage of inside fruit and many fruiting limbs.

In 1973, all trees were hand picked during the week of April 23, and the fruit was evaluated in the packinghouse to get data on fruit weight and internal quality. All data were statistically analized for significance at the 5 percent level. Some characteristics of the mature and young 'Valencias' in the 1972 harvest are shown in Fig. 2.

Mature and young fruit removal results using the shaker are shown in Figs. 3 and 4. The means for each treatment number (1 through 4) are depicted for each date of harvest. Treatment 2 provided superior removal of both mature and young fruit, except for May 15, when Treatment 4 removed more young fruit. In general, Treatment 3 removed the least fruit of both types. On the average, mature fruit removal was 2 percent higher (significant) with the near-sinusoidal mode than with the quick-return mode, and the 20-sec shake removed 4 percent more mature fruit (significant) than did the 10-sec shake.

Mature fruit removal increased somewhat at the later harvesting dates. This increase cannot be explained by a change in the bonding force (Fig. 2). However, it might be explained, in part, by the greater number of shaker clamps per tree at the later harvesting dates. The number of clamps per tree for the three dates averaged 5.5, 6.0, and 6.0 respectively. The increased number of clamps for the latter two harvesting dates was a direct result of the effort by the shaker operator in increase mature fruit removal by reducing the quantity of foliage grasped per clamp or by providing greater overlap between successive clamps. Overall test results showed that approximately 100 lb of mature fruit was removed per clamp by the 10-sec shake and about 110 lb of fruit by the 20-sec shake. The average mature fruit removal during the experiment for the four shaker treatments was 79.7 percent from trees that averaged 766 lb of fruit per tree.

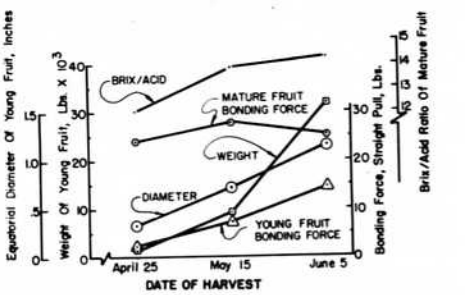

FIG. 2 Some characteristics of mature and young Valencia oranges (1972).

The influence of shaking mode on young fruit removal was significant for all three harvesting dates. The near-sinusoidal mode removed the most fruit on April 25 and June 5, but removed the least on May 15. The reason for this reversal was not apparent. As expected, the 20-sec-duration shake removed more young fruit than did the 10-sec shake, but the difference was not statistically significant. Large differences in the number of young fruit shaken off at each of the three dates cannot be adequately explained by the bonding force (straight pull) and weight data in Fig. 2. Obviously, the bonding force measurements did not indicate the ease of removal by these shaking means.

Harvesting dates and treatments in 1972 did not significantly affect the internal quality parameters of percentage of juice by weight, percent soluble solids (Brix), percent acid, Brix/acid ratio, and lb-solids per box of the mature fruit in 1973.

Mature fruit yields in 1973 were adjusted by a covariance analysis in which the 1972 yields were used as the independent variable. The analysis indicated that the two sets of data were linearly related and the adjustment was beneficial. The 1973 yields were adjusted as follows:

1973 adj. yield = 1973 yield - 0.6615 (1972 yield - 766) and the results are

TABLE 2. RESULTS OF HAMLIN ORANGE HARVESTING EXPERIMENT

Treatment No., description	Fruit yield, lb per tree	Fruit* removal, percent	Harvesting time† per tree, min	Harvesting rate‡ lb per min
1, NS,‡ 160 cpm	522a‖	70.5a‖	7.0a‖	52.2ab‖
2, NS, 200 cpm	576a	78.7 b	7.0a	65.5 b
3, QR,§ 160 cpm	504a	71.1a	8.1 b	44.1a
4, QR, 200 cpm	513a	78.6 b	6.2a	65.9 b

* Fruit bonding force averaged 21.6 lb. Average fruit weight was 0.37 lb.

† Includes only time to position, clamp, shake, and unclamp.

‡ Near-sinusoidal mode.

§ Quick-return mode.

‖ In the respective columns, means which are followed by different letters are statistically different at 5 percent level (Duncan's Test).

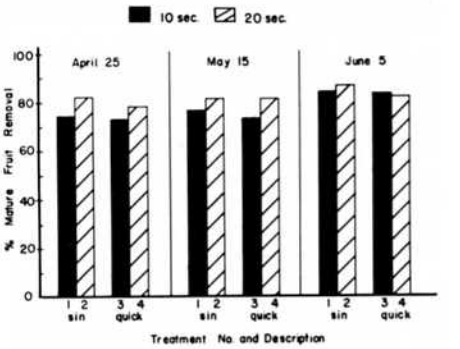

FIG. 3 Percentage of mature fruit removed for the vertical foliage shaker treatments 1-4 (see Table 3) on 3 dates in Valencia-orange harvesting experiments.

TABLE 3. TREATMENTS USED IN VALENCIA-ORANGE HARVESTING EXPERIMENT

Treatment no.	Shaking mode*	Shaking duration per clamp, sec
1	Near-sinusoidal	10
2	Near-sinusoidal	20
3	Quick-return	10
4	Quick-return	20
5	Hand-picked check	—

* Shaking amplitude = 8 in. at approximately 200 cpm.

plotted in Fig. 5. Treatment 5 (hand-picked fruit) has been included as a check. Yields associated with Treatment 3 were consistently as high or higher than those of the other shaker treatments for all dates. The shaking mode did not significantly affect yields. Overall, the 20-sec-duration shake significantly reduced yields as compared with those resulting from the 10-sec-duration shake. This reduction increased with date, and was sufficient to cause a significant date by duration interaction.

The average of all shaker treatments (1 through 4) shows significantly reduced yields (lb per trees) as compared with those from the hand-picked check (Treatment 5). At the first, second, and third harvesting dates, the reductions were 11, 16, and 27 percent, respectively.

A consideration of the data from each harvesting date shows that the relative order of magnitude of the 1973 adjusted reductions in mature fruit yield for each shaker treatment were predicted fairly well by the 1972 young fruit removal records. The only exception occurred on the 2nd harvesting date. Greater 'young' fruit removal in 1972 was associated with the quick-return mode, but the near-sinusoidal mode gave the greatest yield reduction in 1973. A good explanation was not apparent. It was speculated that the near-sinusoidal mode may have caused significant stem damage for many of the young fruit left on the tree, thereby causing a substantial post-harvest drop of young fruit and thus, a greater reduction in 1973 mature fruit yield than had been judged by the harvesting records of the 1972 young fruit removal. Table 4 shows the relationship between the average number of young fruit removed per tree in 1972, for the shaker treatments 1 through 4, and the 1973 reduction in the average number of mature fruit per tree for those treatments as compared with the hand-picked check (Treatment 5).

These data indicate that the 1973 yield reduction in the number of mature fruit were 12, 181, and 144 percent, respectively, of the number of young fruit removed in 1972. This result indicated that all shaker treatments may have damaged a significant number of young fruit-stem systems left on the tree on the last two dates, and many of the damaged fruit may have dropped off before the 1973 harvest.

An important economic variable in processed fruit that determines the feasibility of a harvesting concept is the yield in lb-solids per acre that should result from its application. These values (Fig. 6) were calculated for the treatments in this experiment by multiplying the respective adjusted lb-solids per acre (1973), by the percentage of mature-fruit removals in 1972. Removal for the hand-picked check (Treatment 5) was assumed to be 100 percent. Overall, Treatment 2 was best among the shaker treatments and superior on April 25 and May 15. Treatment 1 was slightly better on June 5. Results were not significantly affected by the shaking mode. On the April 25 harvesting date, the 20-sec shake was superior to the 10-sec shake. The two shaking durations gave comparable results on May 15, with the 10-sec shake being best on June 5. The lb-solids yield resulting from harvesting with Treatments 1 through 4 averaged 69, 66, and 61 percent, respectively, of that from hand picking on the three dates.

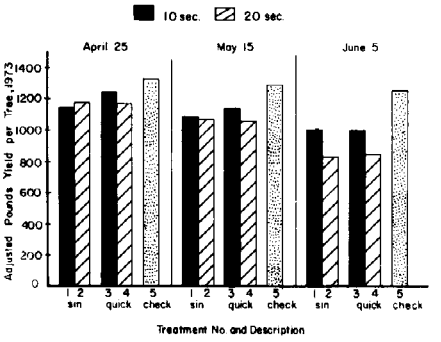

FIG. 5 Adjusted pounds of mature fruit per tree for treatments 1-5 (see Table 3) on 3 dates in Valencia-orange harvesting experiments.

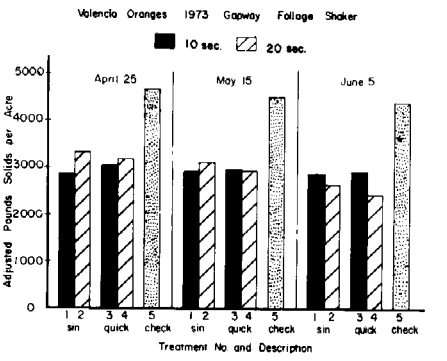

FIG. 6 Adjusted pounds-solids per acre which could be obtained by using harvesting treatments 1-5 (see Table 3) on 3 dates in Valencia-orange harvesting experiments.

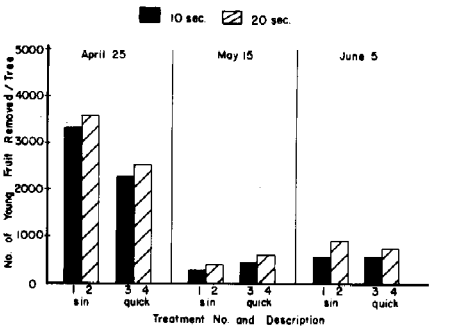

FIG. 4 Number of young fruit removed per tree by vertical foliage shaker treatments 1-4 (see Table 3) on 3 dates in Valencia-orange harvesting experiments.

DISCUSSION AND CONCLUSIONS

When the shaker was used to harvest 'Hamlin' oranges, the two shaking modes were operated for a 10-sec duration at 160 cpm and 200 cpm. There was no difference in the percentage of mature fruit removed by the two modes when averaged over both shaking frequencies. At 160 cpm and 200 cpm the two modes averaged 70.8 and 78.7 percent removal, respectively. The overall average for number of shaker clamps per tree was 4.17, harvesting time was 7.1 min per tree, and harvesting rate was 57 lb per min.

'Valencia' oranges were harvested at a shaking frequency of 200 cpm for

TABLE 4. NUMBER OF YOUNG VALENCIAS REMOVED IN 1972 HARVEST AND REDUCTION OF MATURE FRUIT IN 1973

Attribute	Harvesting date		
	April 25	May 15	June 5
Average number of young fruit removed per tree in 1972 harvest, Treatments 1 through 4	2926	434	705
Average 1973 reduction in number of mature fruit removed per tree for Treatments 1 through 4 as compared with hand-picked check, Treatment 5	352	785	1013

both modes. The durations of shaking time per clamp were 10 sec and 20 sec. Tests were conducted on April 25, May 15, and June 5, when the young fruit diameters averaged 0.33, 0.71, and 1.16 in. for the respective dates. The percentage of mature fruit removed for the two modes was not statistically different, although higher percentages were associated with the near-sinusoidal mode on all three dates. The 20-sec shake resulted in significantly higher mature fruit removal than did the 10-sec shake, except on June 5. Except for April 25, the number of young fruit removed was significantly higher for the 20-sec shake than for the 10-sec shake. Shaking mode affected the number of young fruit removed in that the number was significantly higher for the near-sinusoidal mode than for the quick-return mode on April 25 and June 5, and significantly lower on May 15.

In 'Valencia' oranges, the results in this paper represent basically two shaking modes, in one grove condition, for one season. In some respects the trees in this experiment were ideal for the foliage shaker. They had not been hedged or topped and had a normal rounded canopy, limbs were numerous and not excessively large in the vicinity of the outer canopy, and adequate space existed around the trees for proper positioning of the shaker. Some tree characteristics, however, were disadvantageous for the foliage shaker. As with many other 'Valencia' trees in Florida during the 1972 harvest season, considerable inside fruit existed. The shaking action applied by the foliage shaker in the outer tree canopy was not sufficient to remove much of the inside fruit. Many of the limbs were long and willowy, and fruit were set along much of their length. Shaking action applied at any point on the limbs was not transmitted efficiently along the limb's length. Harvesting the trees with any other type of shaker would have been difficult. Mature fruit removal from these trees was not as high as desired. Other tests (Hedden and Coppock 1971) have been reported in which better removal occurred with a different foliage shaker under different grove conditions.

Yield reduction in the 'Valencia' tests discussed herein occurred for all shaker treatments at all harvest dates. The 1972 shaker treatments reduced the weight of the mature fruit yields in 1973 an average of 11, 16 and 27 percent, respectively, on the three harvesting dates, as compared with the yields from hand-picked checks. These reductions were greater than those reported in other tests (Hedden and Coppock 1971). Based on the percentage of 1972 mature fruit removed and the 1973 yield reductions, the shaker treatments mechanically recovered an average of 69, 66, and 61 percent, respectively, of the potential fruit weight and lb-solids yield for the three harvesting dates. Neither shaking mode offered a significant advantage in this regard. It should be remembered, however, that even though the more severe shaker treatments (2 and 4) generally caused the greater yield reductions, these same treatments were capable of obtaining a higher lb-solids per acre yield at first and second harvest dates, because their higher mature fruit removals more than offset their greater yield reductions. This was not the case on the last harvest date (June 5), when less severe shaking action (1 and 3) was desirable. The best shaker treatments mechanically removed 72, 70, and 66 percent, respectively, of the potential yield (hand-picked check) of lb-solids (see Fig. 6) on harvesting dates 1, 2, and 3. These percentages might be increased by using:

1 Improved shaking modes.

2 Trees and fruiting better suited for the foliage shaker.

3 An effective abcission chemical to provide preharvest loosening of the fruit.

These results clearly demonstrate that for the grove conditions and shaker used in these tests, the quick-return mode offered no significant advantages over the near-sinusoidal mode.

References

1 Chesson, J. H. Selective mechanical harvest studies for Valencia oranges and Marsh grapefruit. ASAE Paper 73-1524, ASAE, St. Joseph, Mich. 49085.

2 Coppock, G. E. 1972. Properties of young and mature 'Valencia' oranges related to selective harvest by mechanical means. TRANSACTIONS of the ASAE 15(2):234-238.

3 Hedden, S. L. and G. E. Coppock. 1971. Comparative harvest trials of foliage and limb shakers. Proc. of Fla. State Hort. Soc. 84:88-92.

4 Sumner, H. R., J. D. Whitney and S. L. Hedden. Foliage shaker for citrus harvesting. Part I — Design and kinematics of shaker drive system. TRANSACTIONS of the ASAE (this issue).

5 Sumner, H. R. 1972. Selective harvesting of 'Valencia' oranges with a vertical canopy shaker. TRANSACTIONS of the ASAE 16(6):1024-1026.