Performance of an Oscillating, Forced-Air Concept for Removing Citrus Fruits

Jodie D. Whitney
Assoc. Member ASAE

THE United States in recent years has produced more tonnage of citrus than all other crops of tree fruit combined (14)*. Production in Florida in the 1966-67 season was 8,816,400 tons, more than three-fourths of the nation's citrus production (7).

Harvest labor has become more expensive in recent years. In 1957 a mechanical harvesting project was established at the Citrus Experiment Station. Initially, research efforts by Coppock et. al. (3, 4, 9) were directed toward increasing productivity of the hand picker. Generally, their investigations revealed that such increases in productivity did not offset the cost of assistance (equipment, etc.). This led to investigations of mechanical methods of removing fruit from the tree (6).

In some tree fruits, high-velocity air streams have been tried for fruit removal. A pulsating airstream from an 8-in. round outlet was used experimentally by Adrian (2) to remove prunes from the tree. Air velocities up to 13,200 fpm removed only 40 to 50 percent of the prunes. Quackenbush et. al. (10) and Abu-Gheida et. al. (1) investigated a pulsating, upwardly-directed air stream for the purposes of deciduous fruit removal and lowering the fruit gently after removal to prevent bruising. Air velocities up to 8,000 fpm were required. The feasibility of power and air volume requirements of this method was questionable since all the fruit on a tree would probably have to be harvested simultaneously.

In 1961, preliminary tests were conducted with an oscillating, forced-air concept of removing oranges and grapefruit (8). Fruit removal ranged from 40 to 95 percent with air velocities between 8,660 and 9,930 fpm. The extent of fruit damage eliminated this method as a mean of harvesting for the fresh fruit market.

Postharvest decay was also increased. This implied that, for processed fruit, the time interval between harvesting and processing would probably have to be held to a minimum. Leaf damage was evident on all trees in the tests. This damage appeared to be less severe in grapefruit than in oranges.

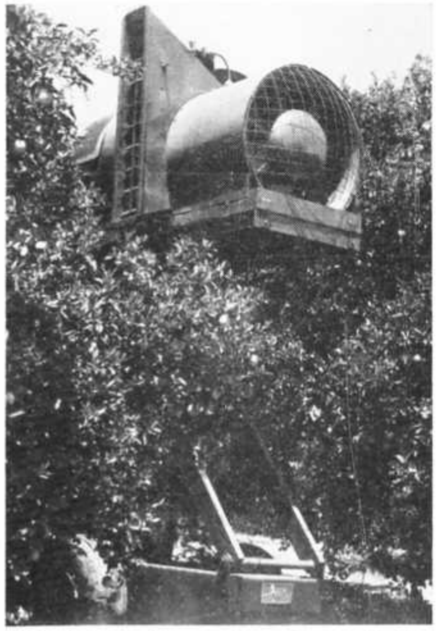

FIG. 1 The Citrus Experiment Station equipment used to develop the oscillating, forced-air stream (in its upper position).

The purpose of this study was to evaluate an oscillating, forced-air concept of removing citrus fruits with regard to the percent of fruit it removed and its effect on subsequent fruit yields.

Materials and Methods

Figs. 1 and 2 show the equipment used to develop the oscillating, forced-air stream for fruit removal. An engine driven 44-in. vane-axial fan discharged air into a radial diffuser. From the diffuser, the air moved perpendicularly to the fan shaft into a diverging, rectangular cross-section which was 12 in. wide and 86 in. high at the discharge opening. Eight in. upstream from the opening, 10 air foils were mounted on shafts 7 in. apart; the trailing portion of the foils were oscillated vertically through an 80 deg arc.

The power unit, fan and discharge outlet were mounted on a trailer with a pantograph lift mechanism. This facilitated raising the equipment to its upper position, a distance of 86 in. In this way, the total height of the projected air pattern was 22 ft at a distance of 105 in. (approximate center of tree) from the outlet. Towing the equipment past opposite sides of a tree in its upper and lower positions was equivalent to one pass. Doing this twice was equivalent to two passes.

To evaluate the oscillating, forced-air concept, 7 treatments were included in an experiment. They are presented in Table 1. One check or conventional handpick treatment was included. The treatments were initially applied in the 1963-64 season in Pineapple oranges, Marsh grapefruit and Valencia oranges. Within each variety, the treatments were replicated on three dates with one plot per treatment. The plot size for Pineapple oranges and Marsh grapefruit in the 1963-64 season was four trees. It was reduced to two trees in subsequent seasons. In Valencia oranges, the plot size was three trees throughout the experiment.

In the 1964-65 season, treatments 6 and 7 were initiated in Hamlin oranges with two replicates or dates of harvest. Within each replication, there was one treatment per plot and two trees per plot.

The first date of harvest in each variety corresponded to the time when the fruit passed minimum acceptable maturity standards as indicated by the Brix/acid ratio (11). The time interval between successive dates of harvest with each variety was approximately 2 to 3 weeks.

A harvest replication was usually completed in less than 2 days. Fruit removed by the forced-air concept was allowed to fall to the ground; it was then picked up by hand and weighed

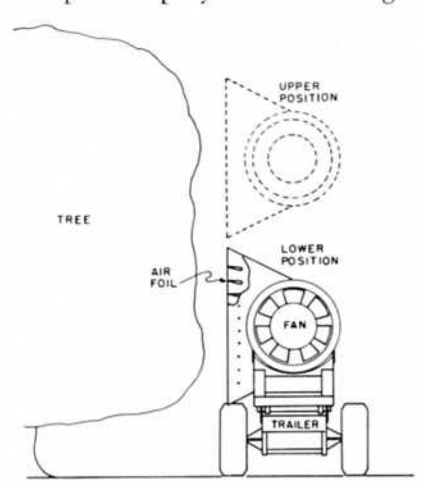

FIG. 2 Rear view of equipment used to develop the oscillating, forced-air stream.

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The author is: JODIE D. WHITNEY, assistant agricultural engineer, University of Florida, Citrus Experiment Station, Lake Alfred.

* Numbers in parentheses refer to the appended references.

† Model SD-12-15 manufactured by Martin-Decker Corporation.

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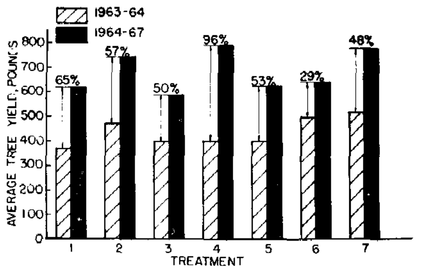

FIG. 3 Effect of treatments on the yields of Pineapple oranges.

with scales† by individual plots. Fruit remaining on the trees was handpicked and weighed in the same manner. The check plot yield was also obtained by weighing.

At the time of harvest, Brix/acid ratio and bonding force to fruit weight ratio (F/W at 45 deg between stem and main axis of fruit) were determined from a 40-fruit sample taken from the trees to be harvested. The method of measurement has been described elsewhere (5). Such information was gathered in an attempt to relate percent removal to some factor which could be readily measured. The F/W ratio is logically related to percent fruit removal and generally decreases with increasing maturity which is indicated by the Brix/acid ratio.

All treatments were applied as indicated through the 1965-66 season. During the 1966-67 season, treatments 1 through 6 were not applied, but yield data were taken on all plots. The experiment was terminated at the end of the 1966-67 season.

Results

Yields

Figures 3, 4 and 5 show the effect of the various treatments on yields of Pineapple oranges, Marsh grapefruit and Valencia oranges. It should be noted that initial (1963-64) yields varied considerably among treatments in all varieties. The initial yield data were analyzed statistically according to a randomized complete block design with dates of harvest as replications.

The analysis showed the average yield of handpicked trees was significantly higher than that of the trees harvested by the forced-air concept in Pineapple and Valencia oranges (Table 2). Even in Marsh grapefruit, the average yield of the handpicked trees was considerably higher. Because of this large variation, effects of each treatment on subsequent yields were evaluated by referencing the respective initial yields as 100 percent. Numbers above the bars in Figs. 3 through 8 refer to the average percentage increase or decrease in subsequent yields when compared with the yield of the 1963-64 season.

TABLE 1. TREATMENTS IN THE EXPERIMENT

Treatment*	No. of passes	Fan rpm	Air speed at outlet, fpm	Air foil oscillation rate, cpm
1	1	2,000	8,200	65
2	1	2,100	9,000	67.5
3	1	2,200	9,800	70
4	2	2,000	8,200	65
5	2	2,100	9,000	67.5
6	2	2,200	9,800	70
7	Check	....	....	....

* Equipment towed at ½ mph.

TABLE 2. AVERAGE TREE YIELD IN POUNDS IN 1963-64 SEASON

Method of harvest	Variety: Pineapple oranges	Marsh grapefruit	Valencia oranges
Handpick	523	1,567	600
Forced-air	424*	1,486	508*

* *Indicates significant difference at 0.05 level.*

The yield data of the last 3 seasons, expressed as a percentage of the initial yields, were analyzed for the 3 varieties according to a split plot in time design (12). Dates of harvest, treatments and seasons were blocks, whole units and subunits in time, respectively. The forced-air treatment sum of squares was further partitioned into meaningful components related to the effects associated with the number of passes and air speed.

In Fig. 3, yields of Pineapple oranges for the forced-air treatments (1 through 6) increased from 29 percent to 96 percent with an average of 59 percent. This compares with an increase of 48 percent in the handpicked trees (Treatment 7). Only the most severe forced-air treatment (No. 6) showed less increase (not statistically less) than the handpicked trees (Treatment 7). The only significant differences (0.05 level) indicated by the analysis of variance were variations in seasonal yields. Interactions between treatments and seasons, treatments and dates, and seasons and dates were not significant.

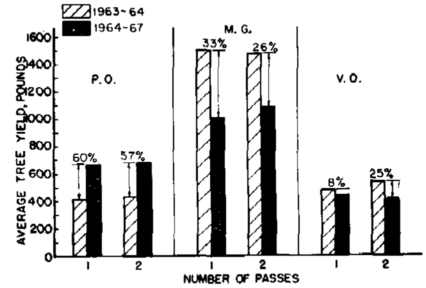

FIG. 6 Effect of number of passes on tree yields. P.O.—Pineapple oranges; M.G.—Marsh grapefruit; V.O.—Valencia oranges.

Slightly smaller increases in yield were associated with later harvest dates for all treatments. The effects of number of passes and air speed were not significant (Figs. 6 and 7). However, both figures indicate that smaller yield increases were associated with the more severe treatments.

Yield data for Marsh grapefruit are portrayed in Fig. 4. No significant differences were indicated between treatments or dates of harvest. Interactions were not significant. However, seasonal yields were significantly different (0.05 level). Decreases in forced-air yields ranged from 20 percent to 35 percent with an average of 30 percent. Check yields decreased by 25 percent. The number of passes and air speed had no significant effects on yields. (Figs. 6 and 7). It should be noted that the greater yield decreases in Marsh grapefruit were associated with the smaller number of passes and higher air speeds. Although these results were somewhat contradictory, the statistical analysis did not indicate a significant interaction between the two factors.

In Valencia oranges (Fig. 5) yields did not increase with any of the treatments. For the forced-air treatments, reductions in yields averaged 17 percent with a high of 33 percent in Treatment 6. This compares with a 5 percent decrease for the check trees. According to Dunnett's procedure (13), only the yields of Treatment 6 were significantly less at the 0.05 level than

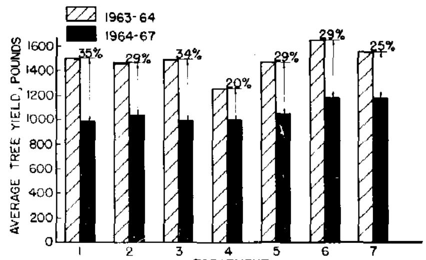

FIG. 4 Effect of treatments on the yields of Marsh grapefruit.

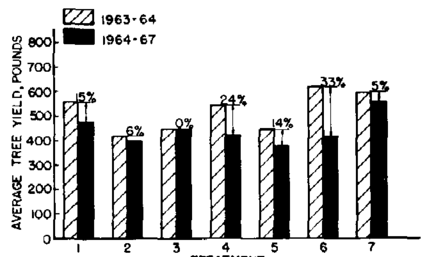

FIG. 5 Effect of treatments on the yields of Valencia oranges.

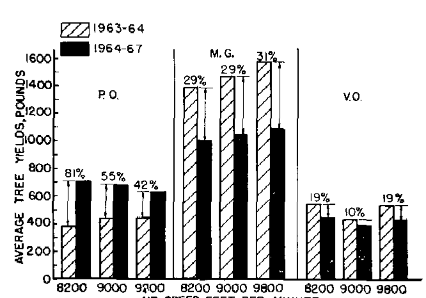

FIG. 7 Effect of air speed on tree yields. P.O.—Pineapple oranges; M.G.—Marsh grapefruit; V.O.—Valencia oranges.

TABLE 3. AVERAGE PERCENT FRUIT REMOVAL OF OSCILLATING, FORCED-AIR TREATMENTS IN THE 1963-64, 1964-65 AND 1965-66 SEASONS

Treatment No.	Pineapple oranges	Marsh grapefruit	Valencia oranges
1	53.1	67.6	39.3
2	60.1	71.8	48.6
3	64.2	76.6	54.9
4	68.1	78.4	63.0
5	74.7	84.7	69.3
6	74.8	80.7	70.2

TABLE 4. REGRESSION ANALYSIS INFORMATION RELATING PERCENT REMOVAL TO BRIX/ACID RATIO AND F/W

Variety	Percent removal (Y) is	X is	r^2	sy • x, percent
Marsh grapefruit	201.3 − 15(X)	Brix/acid	0.28	8.1
Marsh grapefruit	55.4 + 1.9(X)	F/W	0.16	8.8
Valencia oranges	45.4 + 0.9(X)	Brix/acid ratio	0.06	6.6
Valencia oranges	95.9 − 1.3(X)	F/W	0.74	3.5

those of the check trees. Variations in seasonal yields were not as great as those in Pineapple oranges and Marsh grapefruit, but were significantly different at the 0.05 level. No significant interactions were indicated. Two passes reduced yields significantly (0.01 level) over one pass (Fig. 6), while air speed showed no significant effects (Fig. 7).

Figure 8 shows the average effect of harvest method, i.e., all forced-air treatments versus handpicking. No significant differences were indicated between harvest methods. This figure represents a summary of the yield data for the experiment and otherwise demonstrates the ability of the citrus tree to withstand a specific type of physical abuse without adversely reducing yield.

Although expected, this experiment did not conclusively show that yield reductions were increased at later harvest dates in Valencia oranges. This might be explained by (a) low percent removals obtained and (b) the later harvest dates did not occur in the latest portion of the harvest season.

The limited data on Hamlin oranges (not shown) indicated that Treatment 6 increased subsequent yields by 5 percent while check yields increased by 12 percent. In addition, yield increases for Treatment 6 were less for the last harvest date than for the first.

Percent Removal

Percent removal data from Pineapple oranges, Marsh grapefruit, and Valencia oranges are presented in Table 3. These data defined a 3 x 6 factorial run as a randomized block design with harvest dates as blocks. The treatment sum of squares was partitioned into the effects of number of passes, air speed and the interaction of these two factors.

The number of passes significantly (0.05 level) affected percent removal in all varieties (Fig. 9). Two passes increased removal from 10 percent to 20 percent over that obtained with one pass.

Figure 10 shows that percent removal generally increased with air speed. For Pineapple and Valencia oranges, percent removal was significantly (0.05 level) increased with air speed in a linear relationship. The higher air speeds did not significantly increase percent removal in Marsh grapefruit. Overall percent removal was increased from 2 percent to 5 percent per 800 fpm increase in air speed.

Percent removal was significantly (0.05 level) increased with the last harvest date in Pineapple oranges. This could usually be explained by a marked reduction in F/W values for the fruit. Seasonal effects were also significant (0.05 level) in Marsh grapefruit and Valencia oranges. In addition, for these two varieties, a significant (0.05 level) season x treatment interaction indicated that the treatments did not perform the same from season to season.

The data on percent removal, Brix/acid ratio and F/W were analyzed according to the least squares method to see if a meaningful linear relationship existed. Nine data points (three harvest dates within each of three seasons) existed for each variable. Each datum point for percent removal was the average of all forced-air treatments. The resulting regression lines, equations that define the lines, and data points are depicted in Fig. 11 for Pineapple oranges. Table 4 shows similar information on Marsh grapefruit and Valencia oranges.

Percent removal, Y, the dependent variable, is expressed in terms of the independent variable, X; either Brix/acid or F/W. Also shown are coefficients of determination, r^2, and the standard deviation, Sy • x, of the percent removal data from the regression line.

None of the relationships were very satisfactory, as indicated by the low r^2 values. However, some general observations can be made. Percent removal did increase with increasing Brix/acid ratio and decreasing F/W in Pineapple oranges. In Marsh grapefruit no trends were indicated. This was due, in part, to the small ranges of values in the data. In Valencia oranges percent removal increased with decreasing F/W while no relationship existed with Brix/acid ratio.

Generally, changes in percent removal were predicted better by changes in F/W values. This result was not unexpected since a logical relationship exists between the two variables.

Data on percent removal for Treatment 6 in Hamlin oranges averaged 72 percent.

Discussion of Results

Results from this experiment indicate that the citrus varieties most susceptible to tree damage and decreased yields by the forced-air treatments are, in descending order, Valencia, Pineapple, Hamlin, and Marsh. The varieties most difficult to remove in descending order follow same pattern except that Pineapples and Hamlins are exchanged. In general, the more severe forced-air treatments caused greater yield decreases. Using the forced-air concept of removal it is obvious that the variety least likely to be mechanized is Valencias. Besides being difficult to remove Valencias are more susceptible to tree damage because the immature, next season's crop of fruit is present when the mature crop is harvested.

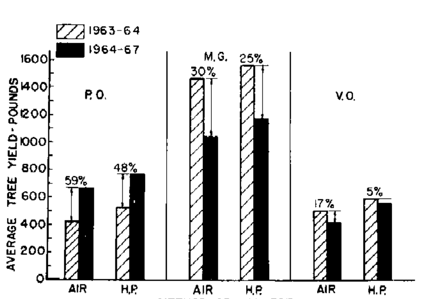

FIG. 8 Effect of harvest method on tree yields. P.O.—Pineapple oranges; M.G.—Marsh grapefruit; V.O.—Valencia oranges.

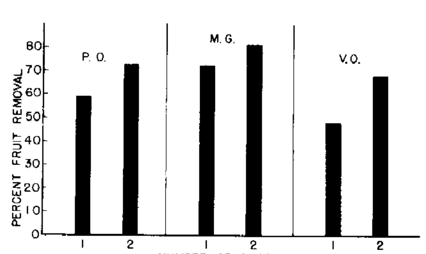

FIG. 9 Effect of number of passes on percent fruit removal. P.O.—Pineapple oranges; M.G.—Marsh grapefruit; V.O.—Valencia oranges.

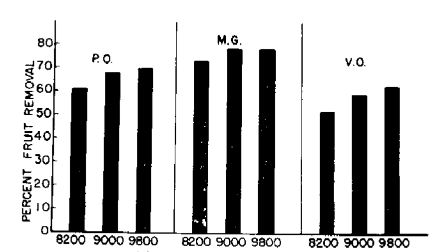

FIG. 10 Effect of air speed on percent fruit removal. P.O.—Pineapple oranges; M. G.—Marsh grapefruit; V.O.—Valencia oranges.

The linear correlations of percent fruit removal, F/W, and Brix/acid ratio were not as good as might be expected. Changes in tree structure probably accounted for some of the inconsistent results. In addition, the type of F/W measurements made may not accurately reflect the ability of forced-air concept to remove fruit.

Tree damage by the forced-air treatments was usually discernible immediately following harvesting and for several days thereafter. This damage was most severe on the outer periphery of the tree canopy nearest the forced-air discharge. Some leaves were shredded and a small percentage of them were removed. Comparing all varieties, less shredding was evident in the grapefruit leaves and was probably due to their greater thickness. Ends of some small limbs were also shredded and sometimes resulted in deadwood.

In most cases, damage inflicted by the forced-air treatments in a given season was not apparent in the following season. Visible differences in the forced-air and check trees at the end of the experiment were very small. Peels on a portion of the immature crop of Valencia oranges were usually scarred by contacting other parts of the tree as a result of the forced-air treatments. As might be expected, the highest percent of fruit removed was obtained on the outer periphery of the tree canopy nearest the air outlet. The lowest percent fruit removed was obtained farthest from the forced-air discharge. This was in a vertical plane including the tree trunk line and parallel to the direction of travel.

The forced-air concept of fruit removal which was described in this paper has some disadvantages. It must be remembered, however, that this represents the concept in its initial stages of development. Many of the problems that presently exist with the concept could probably be overcome with the proper abscission chemicals. One of the greatest incentives for further research on the concept is its potential for high harvesting capacity.

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