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CITRUS FRUIT REMOVAL WITH AN AIR HARVESTER CONCEPT

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ABTRACT

Between 1963 and 1967, the Citrus Experiment Station air harvester was tested as a device for removing citrus fruits. The average cumulative effect of all air-harvester treatments was to slightly reduce subsequent tree yields in most varieties. When compared with check trees, these reductions averaged 5% and 12% in 'Marsh' grapefruit and 'Valencia' oranges, respectively. Except for 'Marsh' grapefruit, the most severe treatment resulted in the greatest yield reductions.

Percent removals obtained with the air harvester were below acceptable levels even for the most severe treatments. The highest removals averaged 74.8%, 84.7%, and 70.2% for 'Pineapple' oranges, 'Marsh' grapefruit, and 'Valencia' oranges, respectively.

INTRODUCTION

In recent years in the United States, citrus has produced more tonnage than all other crops of tree fruit combined (12). Production in Florida in the 1966-67 season was 195,920,000 boxes, which amounted to more than three-fourths of the citrus production in the United States (6).

Labor to harvest citrus has become more expensive and more difficult to manage in recent years. Tangible evidence of the seriousness of this problem was the establishment of a mechanical harvesting project at the Citrus Experiment Station in 1957. Initially, research efforts by Coppock and Jutras (3, 4, 8) were directed toward increasing the productivity of the hand picker by assisting him in various ways. Their investigations revealed that generally, increases in productivity of the hand picker did not offset the cost of assistance (equipment, etc.). This led to investigating mechanical methods of removing fruit from the tree (5).

In some tree fruits, airstreams had been tried as a means of fruit removal. A pulsating airstream from an 8-inch round outlet was used by Adrian (2) to remove prunes from the tree. Air velocities up to 13,200 fpm removed only 40% to 50% of the prunes. Quackenbush, *et al* (9) and Abu-Gheida, *et al* (1) investigated a pulsating, upwardly-directed airstream for the purpose of (a) fruit removal and (b) lowering 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 the whole tree would probably have to be harvested simultaneously.

In 1961, preliminary tests were conducted with an air harvester concept of removing oranges and grapefruit (7). Percentage fruit removal ranged from 40% to 95% with air velocities between 8,660 and 9,930 fpm. The extent of damage to the fruit was sufficient to eliminate this method as a means of harvesting for the fresh fruit market. Postharvest decay was also increased compared to handpicked fruit. 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.

The purpose of this study was to evaluate an

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air harvester concept of removing citrus fruits as to the (a) percent of fruit it removed and (b) its effect on subsequent tree yields.

Materials and Methods

Figure 1 shows the air harvester used for fruit removal. An engine-driven 44-inch, vane-axial fan discharged air perpendicular to the fan shaft into a diverging, rectangular outlet 12 inches wide and 86 inches high. The discharged air was oscillated up and down through an 80° arc by 10 air foils in the outlet. The power unit, fan, and discharge outlet were mounted on a trailer with a pantograph mechnism. This allowed a total height of 22 feet to be covered with the airstream at about 9 feet from the outlet (approximate center of tree) by towing the equipment by a tree in the lower and upper positions. When this was done on opposite sides of a tree, it was considered equivalent to one pass. Doing this twice was equivalent to 2 passes.

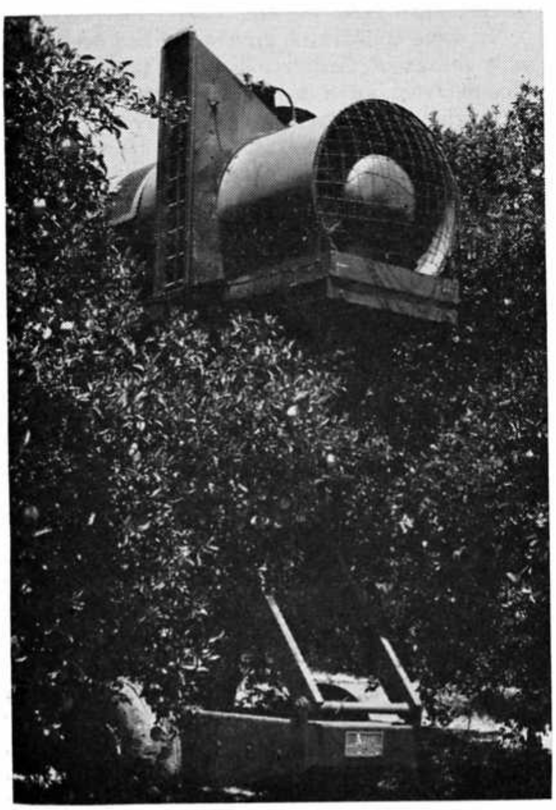

Fig. 1.—The Citrus Experiment Station air harvester in its upper position.

To evaluate the air harvester concept, 7 treatments were included in the 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 3 different dates of harvest with one plot per treatment. The plot size for 'Pineapple' oranges and 'Marsh' grapefruit in the 1963-64 season was 4 trees but was reduced to 2 trees in subsequent seasons. In 'Valencia' oranges, the plot size was 3 trees throughout the experiment.

In the 1964-65 season, Treatments 6 and 7 were initiated in 'Hamlin' oranges with 2 replicates or dates of harvest. Within each replication, there was one treatment per plot and 2 trees per plot.

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

A replication was usually completed in less than 2 days. The air-harvested fruit was allowed to fall to the ground; it was picked up by hand and weighed 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.

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.

Table 1. Treatments* in the experiment.

Treatment no.	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 1/2 mph.

The experiment was terminated at the end of the 1966-67 season.

Results and Discussion

Percent removals for the various air-harvester treatments are presented in Table 3. Figures 2, 3, and 4 show the effect of the various treatments on yields of 'Pineapple' oranges, 'Marsh' grapefruit, and 'Valencia' oranges. First, it should be noted that considerable variation existed in initial (1963-64) yields 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 average air-harvested trees in 'Pineapples' and 'Valencias' (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%. Numbers above the bars in Figures 2, 3, and 4 refer to the average percentage increase or decrease in subsequent yields when compared with the yield of the 1963-64 season.

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 (10). Dates of harvest, treatments, and seasons were blocks, whole units, and subunits in time, respectively.

In Figure 2, yields of 'Pineapple' oranges for the air-harvester treatments (1 through 6) increased from 29% to 96% with an average of 59%. This compares with an increase of 48% in the handpicked trees (Treatment 7). Only

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
Air harvester	424*	1,486	508*

*Indicates significant difference at .05 level.

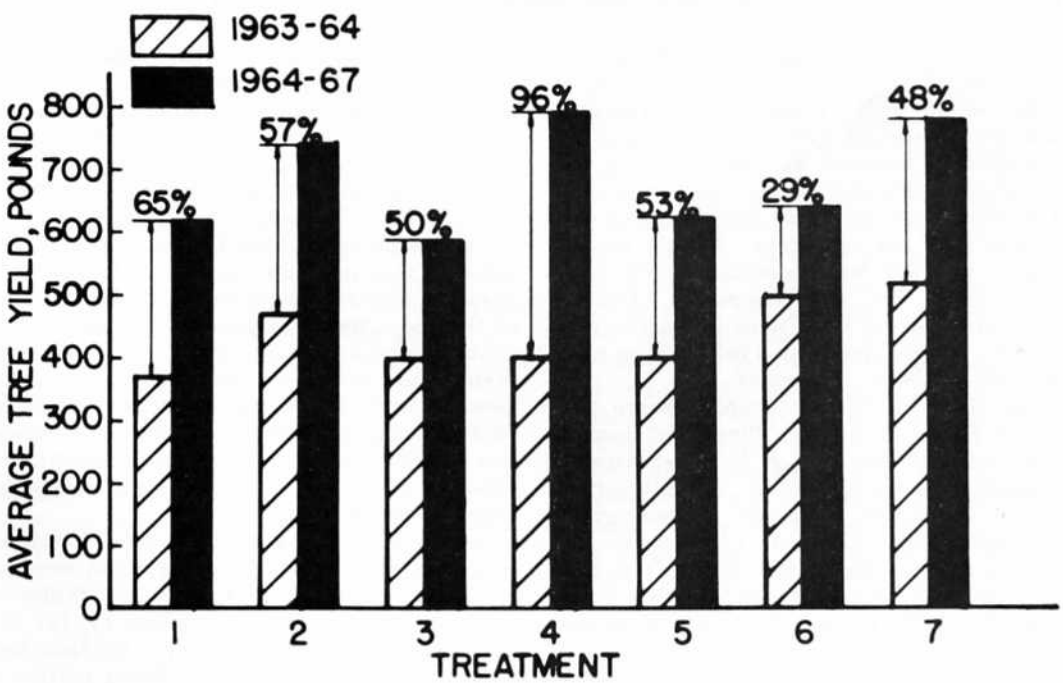

Fig. 2.—Effect of treatments on the yields of 'Pineapple' oranges.

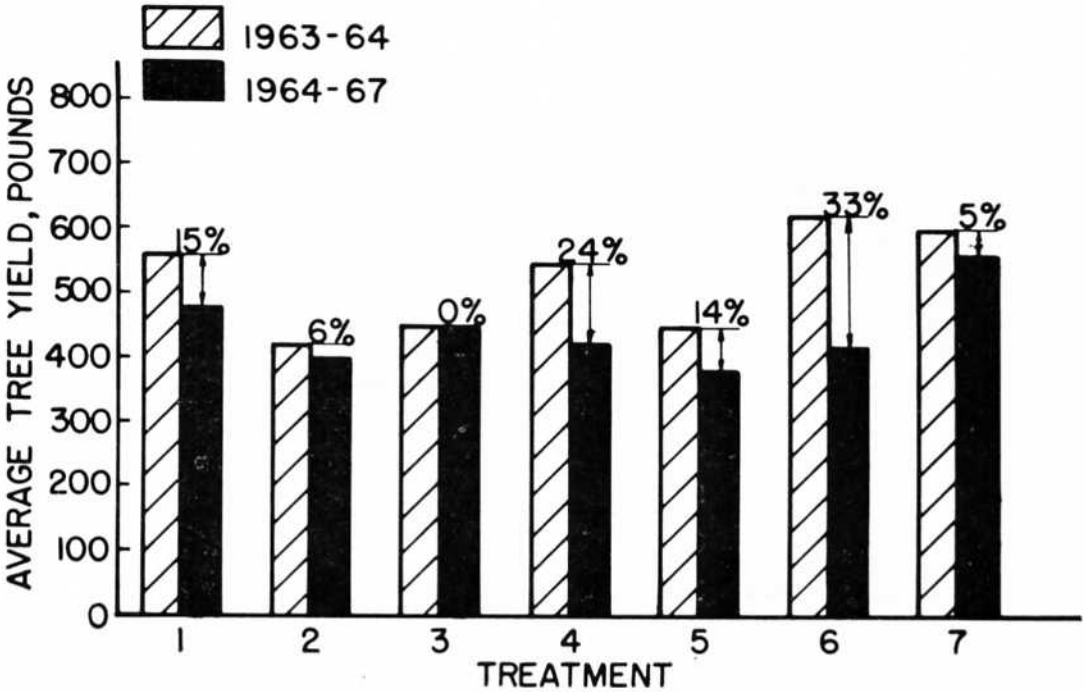

Fig. 3.—Effect of treatments on the yields of 'Marsh' grapefruit.

the most severe air-harvester treatment (no. 6) showed less increase (not statistically less) than the handpicked trees (Treatment 7). The only significant differences (.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. Slightly smaller increases in yield were associated with later harvest dates for all treatments. Overall, smaller increases in yield were associated with the larger percent removals (Table 3) or more severe air-harvester treatments.

Yield data for 'Marsh' grapefruit are portrayed in Figure 3. As with 'Pineapple' oranges, no significant differences were indicated between treatments or dates of harvest. All interactions were not significant. However, seasonal yields were significantly different (.05 level). Decreases in air-harvester yields ranged from 20% to 35% with an average of 30%. Check yields decreased by 20%. Percent fruit removal ranged from 67.6% to 84.7% (Table 3). The more severe air-harvester treatments, even though they did remove a higher percentage of fruit, did not result in greater yield decreases as was noted in 'Pineapple' oranges.

In 'Valencia' oranges (Figure 4), yields did not increase with any of the treatments. For the air-harvester treatments, reductions in yields averaged 17% with a high of 33% in Treatment 6. This compares with a 5% decrease for the check trees. According to Dunnett's procedure (11), only the yields of Treatment 6 were significantly less at the .05 level than those of the check trees. In general, the most severe air-harvester treatments were associated with grater yield reductions and higher percent removals (Table 3). Variations in seasonal yields were not as great as those in 'Pineapple' oranges and 'Marsh' grapefruit, but were significantly different at the .05 level. No significant interactions were indicated.

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.

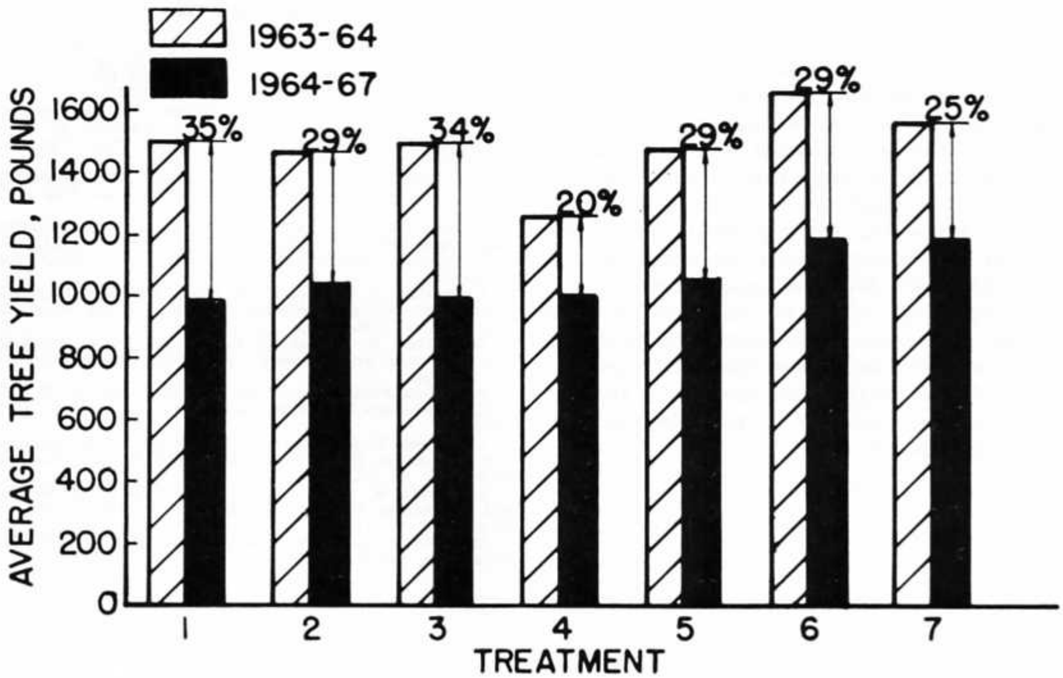

Fig. 4.—Effect of treatments on the yields of 'Valencia' oranges.

The limited data on 'Hamlin' oranges (not shown) indicated that Treatment 6 removed an average of 72% of the fruit and increased subsequent yields by 5%. Check yields increased by 12%. For the air harvester, yield increases were less for the last harvest date than for the first.

Results from this experiment indicate that the citrus varieties most susceptible to damage and decreased yields by the air-harvester treatments are, in descending order, 'Valencia,' 'Pineapple,' 'Hamlin,' and 'Marsh.' The greater susceptibility of the 'Valencia' can be explained in part by (a) its fruit is more difficult to remove and (b) the immature crop of fruit is present when the mature crop is removed.

Table 3. Average percent fruit removal of air-harvester 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

Other observations should also be noted. Tree damage by the air harvester 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 air harvester. 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 air harvester in a given season was not apparent in the following season. Visible differences in the air harvester 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 air-harvester 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 air harvester. This was in a vertical plane including the tree trunk line and parallel to the direction of harvester travel.

The air harvester concept of fruit removal which was described in this paper has some disadvantages. It must be remembered, however, that this represents the concept of its initial stages of development. Since its inception, the concept has been developed much further by a private company. Many of the problems that presently exist with the concept could probably be overcome with the proper abscission chemical.

One of the greatest incentives for further research on the concept is its potential for high harvesting capacity.

LITERATURE CITED

1. Abu-Gheida, O. M., B. A. Stout, and S. K. Ries. 1962. Pneumatic tree-fruit harvesting utilizing a pulsating air stream. Agr. Eng. 43(8): 458-461, 466-467.
2. Adrian, P. A 1960. Annu. Rept. U.S.D.A.
3. Coppock, G. E., and P. J. Jutras. 1960. An investigation of the mobile pickers platform approach to partial mechanization of citrus fruit picking. Proc. Fla. State Hort. Soc. 73: 258-263.
4. Coppock, G. E., and P. J. Jutras. 1960. Mechanizing citrus fruit picking. Trans. Amer. Soc. Agr. Eng. 3(2): 130-132.
5. Coppock, G. E. 1961. Picking citrus fruit by mechanical means. Proc. Fla. State Hort. Soc. 74: 247-251.
6. Florida Agricultural Statistics. 1967. Citrus Summary: 3.
7. Jutras, P. J., and G. E. Coppock. 1963. Harvesting citrus fruit with an oscillating air blast. Trans. Amer. Soc. Agr. Eng. 6: 192-194.
8. Jutras, P. J., and G. E. Coppock. 1968. Mechanization of citrus fruit picking. Proc. Fla. State Hort. Soc. 71: 201-204.
9. Quackenbush, H. E., B. A. Stout, and S. K. Ries. 1962. Pneumatic tree-fruit harvesting. Agr. Eng. 43(7): 388-393.
10. Steel, R. G. D., and J. H. Torrie. 1960. Principles and Procedures of Statistics. McGraw-Hill Book Co., Inc., New York. p. 242-245.
11. Steel, R. G. D., and J. H. Torrie. 1960. Principles and Procedures of Statistics. McGraw-Hill Book Co., Inc., New York. p. 111-112.
12. United States Department of Agriculture. 1967. Agr. Statist. p. 248-249.