

Development of a Citrus Removal Device Using Oscillating Forced Air

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THE annual value and yield of the Florida citrus crop averaged 264 million dollars and 145 million boxes between 1960 and 1970 (reference 2). During the same period, annual production costs remained relatively constant while the per box cost of picking increased by 75 percent (Brooke 1970 and Spurlock 1971). In an effort to slow or halt this upward trend of picking costs, mechanical harvesting concepts have been under development over the last few years (Hedden et al. 1969). The concept discussed in this paper is intended for the harvest of citrus fruit destined for processing.

INITIAL DEVELOPMENT

The development of an oscillating,

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FIG. 1 Equipment used at the Agricultural Research and Education Center at Lake Alfred to develop an oscillating, forced-air stream.

forced air concept for citrus fruit removal began in 1961 at the Agricultural Research and Education Center at Lake Alfred (Jutras and Coppock, 1963). Basically, the test machine (Fig. 1) discharged a 1-ft wide, vertical column of air into the tree. In the discharge, horizontal vanes were pivoted about their upstream edge and oscillated through an included angle of approximately 60 deg. This tended to create an oscillating, air blast in any exposed part of the tree. Air velocities between 8,600 and 10,000 fpm at the discharge, and 50 to 80 oscillations per minute, resulted in fruit removals as high as 95 percent in grapefruit. It was estimated that approximately 1 hp-hr of energy was required to remove a 90-lb box of fruit. Between 1963 and 1967, this same machine was tested to determine its ability to remove fruit and its effect on subsequent fruit yields (Whitney 1968 and 1970). Data from a 4-year experiment indicated maximum removals of 70 to 75 percent in oranges and 85 percent in grapefruit. Generally, subsequent yields were reduced about 5 percent in early and midseason fruit and 12 percent on late season fruit. The estimated energy input per 100 lbs of fruit removed was 1 hp-hr in grapefruit.

Also in 1963, FMC Corporation started developing the first of three machines which utilized the oscillating, forced air concept. In the subsequent discussion, these machines will be referred to as FMC-1, FMC-2, and FMC-3.

FMC-1

FMC-1 was tested in 1963 and 1964 and is shown in Fig. 2. Two, engine-

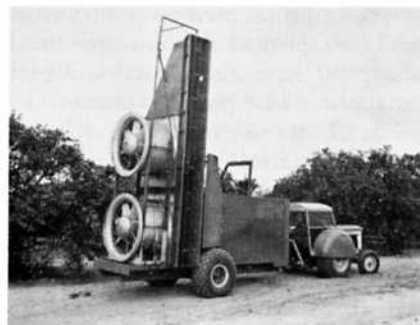


FIG. 2 FMC-1 with vertical plates,

driven, 44-in. vane axial fans forced approximately 120,000 cfm through a rectangular discharge 17 ft high. In most tests, the discharge width was 10 or 12 in. Percent removal tests were conducted to investigate different mechanisms for directing and oscillating air at the discharge to obtain optimum fruit removal. These mechanisms were vertical plates, horizontal plates, and wobble plates.

Tests with FMC-1 were made with either a total of two or four passes, respectively (one or two from each row middle), per tree at 1/2 mph ground speed. This was equivalent to an average total air blast exposure time per tree of 50 or 100 sec, respectively, with tree spacings of 20 ft in the row.

Wobble plates were tested initially. They were mounted on a rotating shaft which was positioned vertically and centered in the air discharge. The plates were elliptical in shape with their minor axis perpendicular to the shaft and the major axis forming an acute angle with the shaft. As the shaft rotated at a constant rpm, the discharged air was

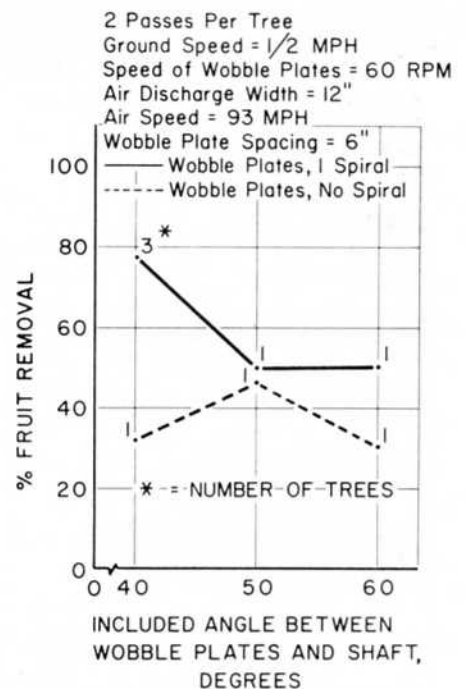


FIG. 3 Effect of included angle between wobble plates and shaft and wobble plate spiral of FMC-1 on percent removal in Valencia oranges (4/17-19/63).

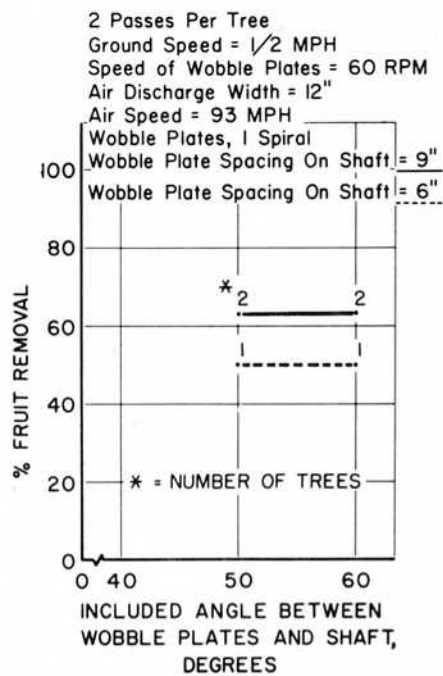


FIG. 4 Effect of included angle between wobble plates and shaft and wobble plate spacing of FMC-1 on percent removal in Valencia oranges (4/17-19/63).

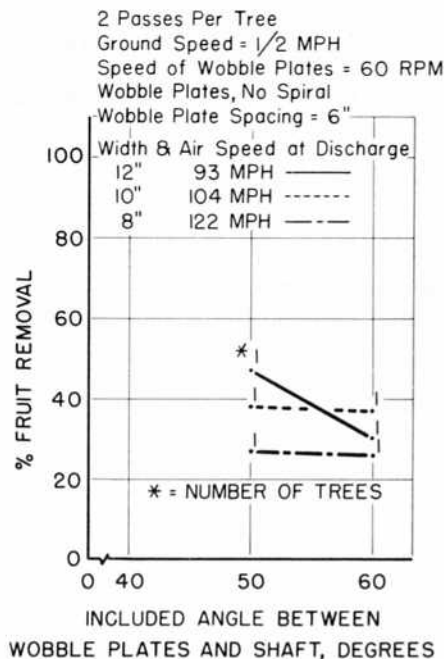


FIG. 5 Effect of included angle between wobble plates and shaft, air discharge width, and air speed at discharge of FMC-1 on percent removal in Valencia oranges (4/17-19/63).

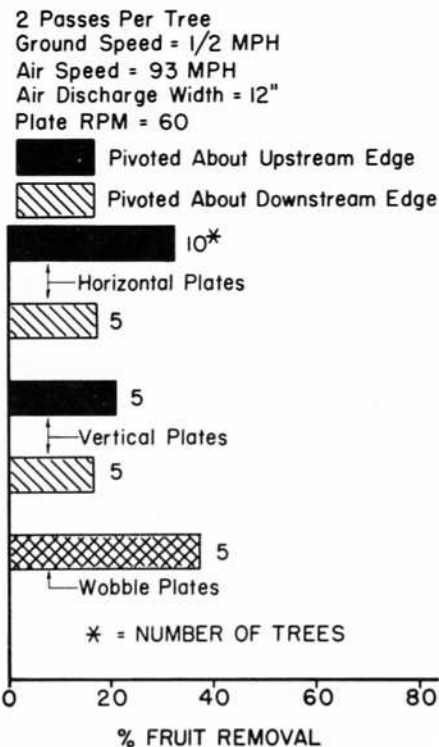


FIG. 6 Effect of type of plates on FMC-1 on percent fruit removal in Pineapple oranges (12/9-19/63).

alternately directed upward and downward. As with the oscillating horizontal plates described above, this tended to create an oscillating air blast in any exposed part of the tree.

Figs. 3, 4, and 5 show some of the initial fruit removal results in Valencia oranges. It should be pointed out here that the fruit removal data collected on the FMC-1 were not conclusive, but exploratory in nature to show trends. Fig. 3 shows the effect of angle between

wobble plates and shaft and the spiral arrangement of the plates. With no-spiral, all plate minor axes were in the same vertical plane. With one-spiral, the minor axes of the plates were spaced equiangular about one revolution of the shaft. In effect, this represented one-spiral of a helix. One-spiral wobble plates performed slightly better than those with no-spiral. The 40 deg angle between wobble plates and shaft gave better removal than 50 deg or 60 deg. Fig. 4 shows that a 9-in spacing between plates resulted in better removal than did 6 in. With the no-spiral plates, better fruit removal performance was indicated (Fig. 5) with a wide discharge and lower air velocity as compared to a narrow discharge and high air velocity.

Late in 1963, performance of vertical, horizontal, and wobble plates were compared on the FMC-1 in Pineapple oranges. Wobble plate performance was slightly superior (Fig. 6). Also, pivoting vertical or horizontal plates upstream removed a higher percentage than when they were pivoted downstream. In all subsequent tests, the vertical and horizontal plates were pivoted upstream.

Fig. 7 shows a slightly different arrangement tried in Marsh grapefruit. The horizontal plates were operated both in-phase and out-of-phase. In-phase, the angular orientation of all plates about their pivot shafts was identical at any given time. Out-of-phase, the angular orientation of each adjacent plate was different at any given time. More specifically, the plates were

oriented equiangular about their pivot shafts so that the topmost and bottommost plates were always one cycle out-of-phase with respect to each other in their total oscillation (up to down to up). In-phase operation with the vertical plates was analogous to that of the horizontal plates. Performance of out-

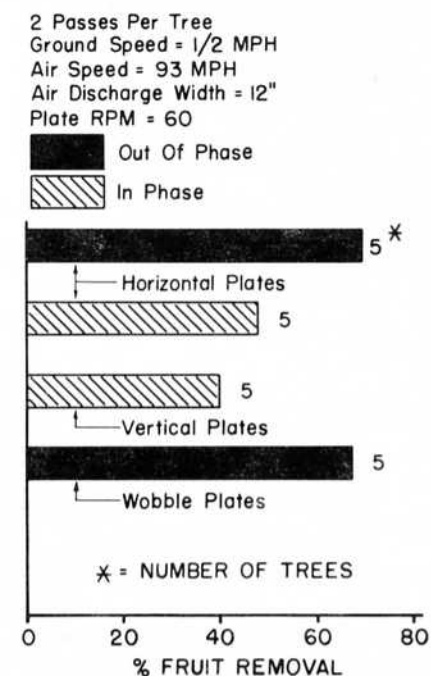


FIG. 7 Effect of type and phase of oscillators on FMC-1 on percent fruit removal in Marsh grapefruit (1/6-17/64).

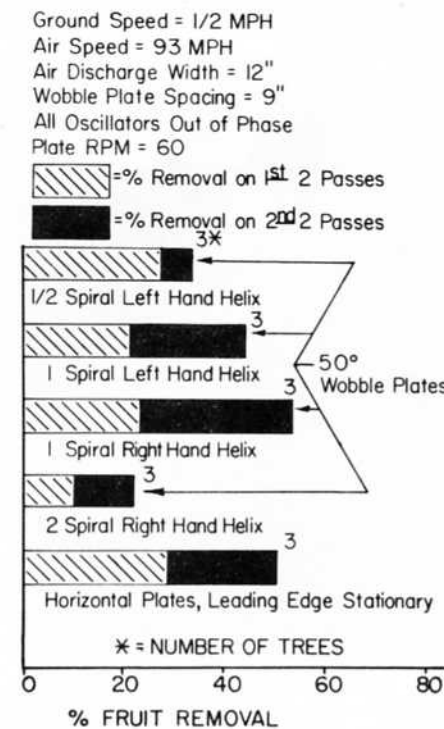


FIG. 8 Effect of number of spirals, type of helix, and type of plates on FMC-1 on percent fruit removal in Valencia oranges (4/2-8/64).

Ground Speed = 1/2 MPH
 Air Speed = 93 MPH
 Air Discharge Width = 12"
 40° Wobble Plates
 Plate RPM = 60

= % Removal on 1st 2 Passes
 = % Removal on 2nd 2 Passes

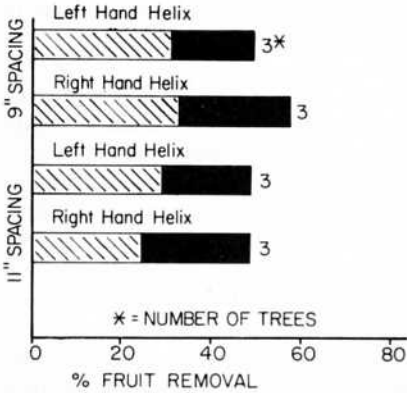


FIG. 9 Effect of direction of helix and wobble plate spacing, and number of passes of FMC-1 on percent fruit removal in Valencia oranges (4/9-13/64).

of-phase horizontal plates was comparable to the wobble plates and superior to in-phase horizontal and vertical plates. Fig. 8 compares the performance of different wobble plate arrangements and horizontal plates in Valencia oranges in 1964. The one-spiral wobble plates removed a higher percentage of fruit than did other wobble plate arrangements and was comparable to that of the horizontal plates. In Fig. 9,

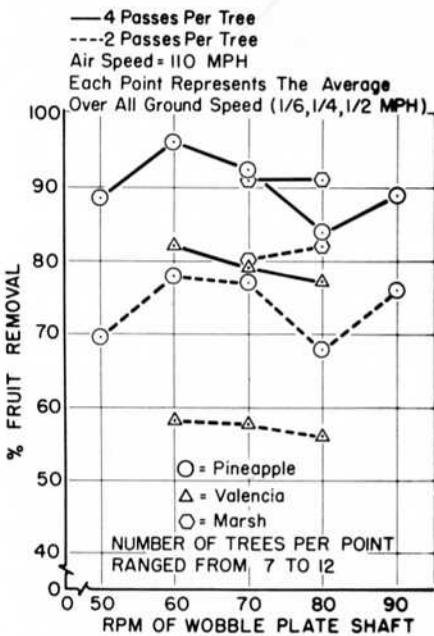


FIG. 12 Effect of revolutions per minute and number of passes of FMC-2 on percent fruit removal in Pineapple and Valencia oranges and Marsh grapefruit.

Ground Speed = 1/2 MPH
 Air Speed = 93 MPH
 Air Discharge Width = 12"
 Wobble Plate Spacing = 9"
 Plate RPM = 60
 1 Spiral In Wobble Plates

= % Removal on 1st 2 Passes
 = % Removal on 2nd 2 Passes

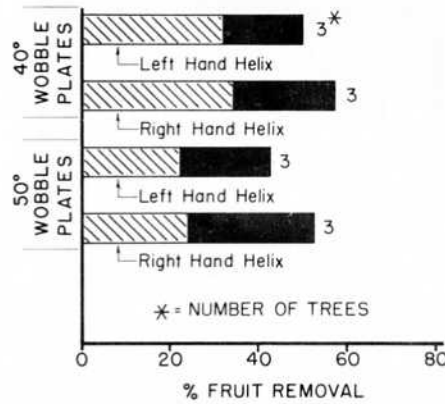


FIG. 10 Effect of number of passes, direction of helix, and included angle between wobble plates and shaft of FMC-1 on percent fruit removal in Valencia oranges (4/2-10/64).

similar removal results are depicted for wobble plates with 9- and 11 in. spacing. Slightly higher removal was indicated in Figure 10 for 40 deg wobble plates.

Summarizing the results with FMC-1, the one-spiral wobble plates performed better than those with 2-, 1/2-, and no-spiral. Fruit removal with one-spiral wobble plates was comparable to horizontal plates, but superior to vertical plates. Both horizontal and vertical plates were pivoted about their downstream and upstream edges. Higher fruit removal was always associated with the latter arrangement. Fruit removal was better with a greater distance between wobble plates.

FMC-2

FMC-2 was constructed because a greater air discharge height was desirable for tall trees. It was tested in the 1964-65 season and is shown in Fig. 11. Air was forced through a rectangular discharge (10 in. wide by 20 ft high) by three engine-driven, vane axial fans. Wobble plates were mounted 9 in. apart at an included angle of 50 deg with their vertical supported shaft. Fig. 12 shows some results relating wobble plate shaft speed and percent removal. The most extensive tests were conducted in Pineapple oranges. 60 to 70 rpm provided a slightly better removal than did the higher and lower speeds for both two and four passes per tree. In Marsh grapefruit, rotating the wobble plate shaft at 70 or 80 rpm gave comparable



FIG. 11 FMC-2 showing "wobble plates" in air outlet.

results. Performance in Valencia oranges was best at 60 rpm with both two and four passes per tree.

Percent removal of the FMC-2 was greatly affected by its ground speed. Fig. 13 shows some results in Hamlin and Pineapple oranges. Removal in Hamlin at 1/6 and 1/4 mph was comparable at 91 percent. At 1/2 mph removal dropped off considerably to 62 percent. In Pineapple oranges, removal was slightly higher at comparable operating conditions of FMC-2. Four passes increased removal by 10 percent to 20 percent over that for two passes. In Fig. 14, grapefruit removal was approximately the same at 1/4 mph and 1/2 mph after 4 passes per tree. Results of removal in Valencias were similar to those in Hamlin.

Air speed at the discharge of FMC-2 affected its removal potential somewhat. Fig. 15 shows that optimum removal in Pineapple oranges was at air speeds of approximately 100 mph. Similar results were obtained in Valencias at a wobble plate shaft speed of 70 rpm.

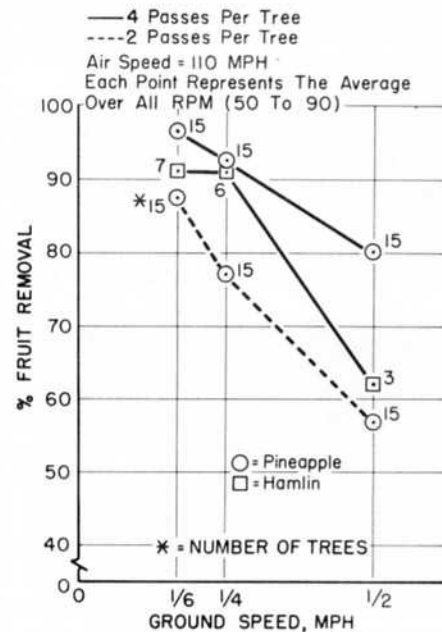


FIG. 13 Effect of ground speed and number of passes of FMC-2 on percent fruit removal in Pineapple and Hamlin oranges.

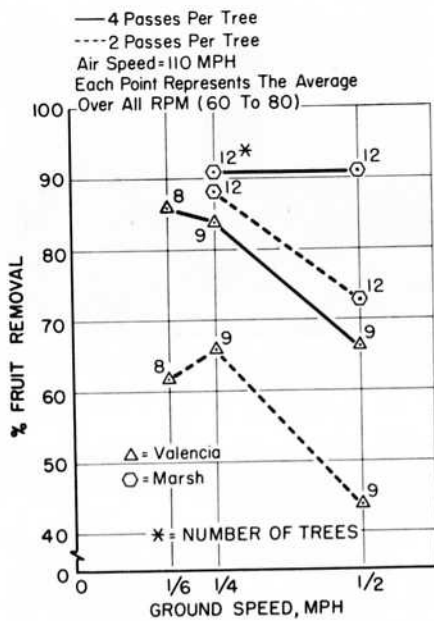


FIG. 14 Effect of ground speed and number of passes of FMC-2 on percent fruit removal in Valencia oranges and Marsh grapefruit.

In summary, fruit removal with the FMC-2 was best when air was discharged at 100 mph and the wobble-plate shaft was rotated at 60 to 70 rpm. Fruit removal in oranges ranged from 86 percent in Valencias to 97 percent in Pineapples when the trees were exposed to the air discharge for approximately 300 secs (four passes at 1/6 mph). Fruit removal performance of the FMC-2, as well as the FMC-1, was poorest in the area of the tree most distant from the machine. Specifically, this area was in a vertical plane including the tree trunk line of the drive row and parallel to the direction of travel. In an attempt to improve the performance of the forced-air concept in this plane, greater air capacity was designed into FMC-3.

FMC-3

During the 1965-66 season, FMC-3 was tested (Fig. 16). It had essentially twice the air moving capacity of the FMC-2. The main components of the FMC-3 were two rectangular discharges and six, 34-in vane axial flow fans

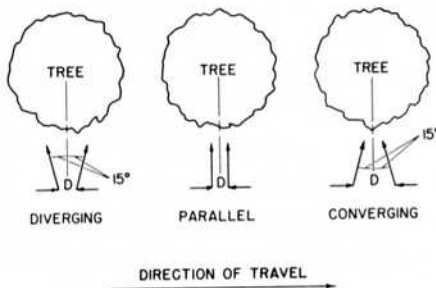


FIG. 17 Direction of air discharge and spacing, D , for the three discharge orientations.

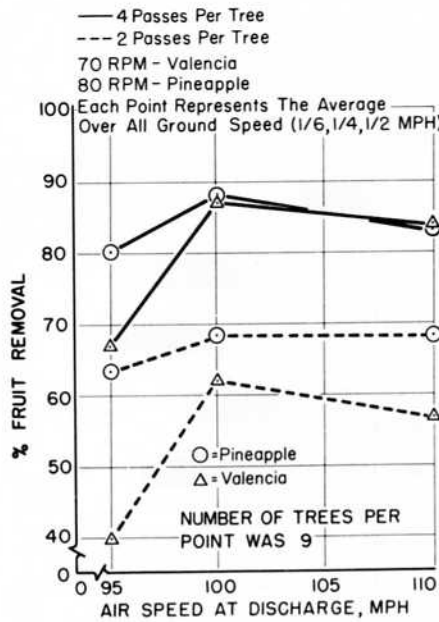


FIG. 15 Effect of air speed and number of passes of FMC-2 on percent fruit removal in Pineapple and Valencia oranges.

driven by three gasoline-powered industrial engines. Three fans supplied air to each discharge, approximately 10 in. wide and 20 ft high. In each discharge, wobble plates were mounted on a rotating vertical shaft, 9 in. apart and 50 deg with the shaft. The plates on each of the two shafts were mounted as one-spiral of a helix. Rotation of the shafts was synchronized at 70 rpm.

The first series of tests conducted with FMC-3 were designed to determine the relative orientation of the two discharges that would give maximum fruit

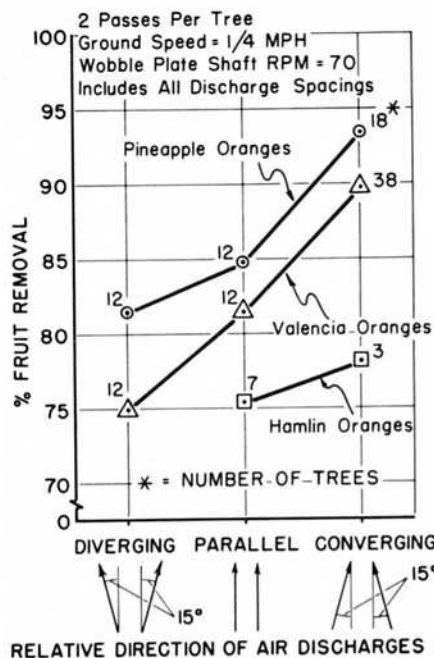


FIG. 18 Effect of relative direction of air discharges of FMC-3 on percent fruit removal.

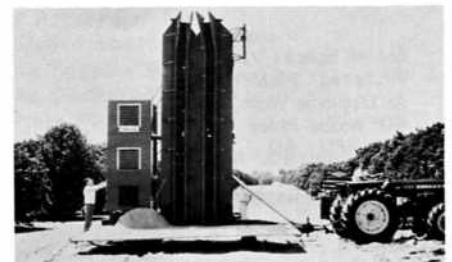


FIG. 16 Side view of FMC-3 with temporary catch frame attached and air discharges in converging orientation.

removal and minimum apparent tree damage. Different orientations were achieved by two major adjustments—distance between discharges and relative direction of air discharges. Fig. 17 illustrates the adjustments. The distance between discharges, D , took on values of 39 and 56 in. The relative directions of discharges were converging, parallel, and diverging. Fig. 18 illustrates the effect of discharge orientation on fruit removal. For each of the air discharge orientations on the abscissa, and within each variety, the data were averaged over all distances, D between discharges. Fruit removal increased as the discharge orientation changed from diverging to parallel to converging. These data indicated that the percent fruit removal increased as the air moving capabilities were concentrated into one general area.

The second series of tests supplied information on the effect of ground speed on percent removal. Fig. 19 depicts the results in Valencia oranges and Marsh grapefruit. As expected, percent fruit removal was greatly affected

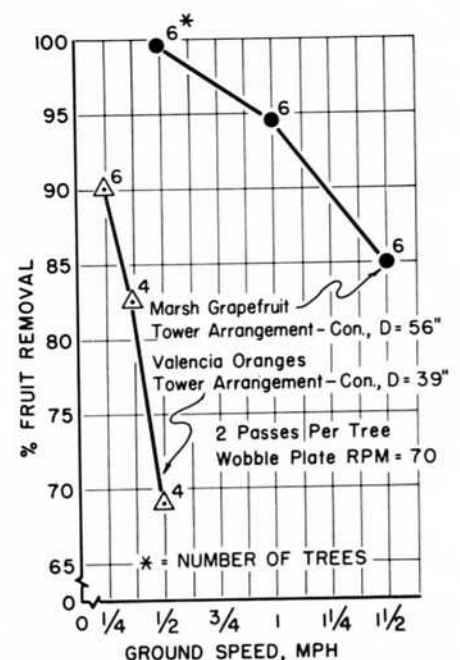


FIG. 19 Effect of ground speed of FMC-3 on percent fruit removal.

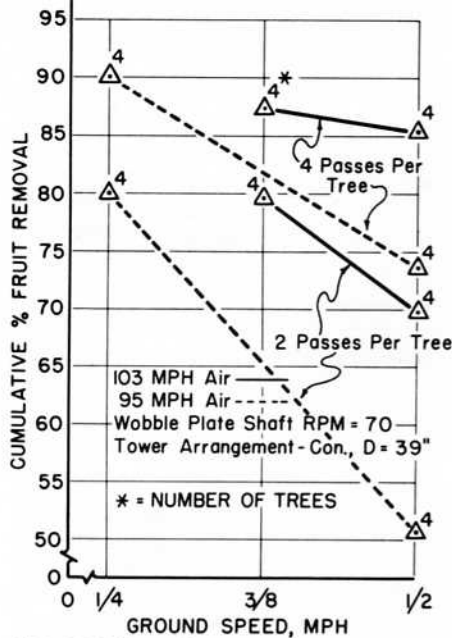


FIG. 20 Effect of ground speed, number of passes, and air discharge speed of FMC-3 on cumulative percent fruit removal in Valencia oranges.

by ground speed or exposure time. Also, this figure indicates that grapefruit are generally easier to remove than oranges. In Valencia oranges at 1/4 mph and 90 percent removal, the estimated air-energy input per tree was 15 hp-hr. With a total per tree fruit yield of 460 lb, 3.6 hp-hrs were required per 100 lb of fruit removed. At 1/2 mph and 70 percent removal, 100 lb of fruit were removed with 2.3 hp-hr. In Marsh grapefruit at 1/2 mph and 99 percent removal, 0.92 hp-hr removed 100 lb where the total per tree fruit yield averaged 830 lb. At 1-1/2 mph and 85 percent removal, an energy input of 0.36 hp-hr removed 100 lb of fruit.

The third series of tests were conducted in Valencia oranges in an effort to maintain reasonable mature fruit removal while minimizing immature fruit removal. This variety presents a unique problem for mechanical harvesters in that two crops of fruit occur on the tree simultaneously. These crops are (a) the mature fruit intended for harvest and (b) immature fruit of the next season's crop. Depending on the time of harvest after bloom, the immature fruit weight ranges up to 0.1 lb while the mature fruit weight is fairly constant at 0.4 lb. As the mature fruit harvesting season progresses, the immature fruit weight approaches 0.1 lb so that towards the latter portion of the season, mature fruit removal by most shaking methods (including air) also removes significant quantities of immature fruit (Hedden and Coppock, 1968).



FIG. 21 Front view of FMC-3 harvest system.

Tests were conducted on a set of trees at increased ground speeds, lower air velocities, and two passes per tree. Because mature fruit removal was lower than desired, two additional passes per tree were made on the same set of trees 26 days later. Mature fruit removal results are shown in Fig. 20. Comparable fruit removal was obtained after four passes per tree with 90 mph air and 1/4 mph ground speed and with 103 mph air at both 3/8 and 1/2 mph ground speed.

TWO-YEAR STUDY

Materials and Methods

A 2-year study involving three experiments was initiated in 1969 to further evaluate the FMC-3. Abscission chemicals were used in an attempt to reduce the fruit bonding force and improve the performance of the FMC-3. The objectives of this program were to determine (with and without abscission chemicals) (a) the effect of the forced-air removal concept on subsequent fruit yields, (b) the percentage fruit removal of the concept, and (c) any changes that would improve its performance.

The harvesting experiments in 1969 were conducted with a system as shown in Fig. 21. It consisted of the FMC-3 with a mounted catch frame and a towed matching catch frame for the tree side opposite the FMC-3. The catch frame mounted on the FMC-3 was a telescoping inclined plane which allowed adjustment of the catch frame extension between the FMC-3 and the tree trunk. The catch frame also pivoted about its mounting points on the FMC-3 so that the height of the catch frame at the tree trunk could be adjusted. A continuously moving closure around the tree trunk was accomplished with panels on a powered, endless chain. Blank spaces (with no panels) approximately 2-ft wide were indexed around the tree trunk by an operator as the machine moved down the row of trees. This operator also controlled the telescoping and height of the catch frame. The opposite side catch frame had a series of

TABLE 1 TREATMENTS APPLIED IN THE EXPERIMENTS

Treatment No.	Description*
1	FMC-3, 1/4 mph ground speed, no chemical applied
2	FMC-3, 1/4 mph ground speed, chemical applied
3	FMC-3, 3/8 mph ground speed, no chemical applied
4	FMC-3, 3/8 mph ground speed, chemical applied
5	Handpick check, no chemical applied
6	Handpick check, chemical applied

*Air discharged from FMC-3 at approximately 100 mph from two, 10-in. wide discharges, 39 in. apart and converging at a 30 deg acute angle. Two passes were made per tree. One-spiral wobble plate 9 in. apart on shaft operating at 70 rpm. Rotation of wobble-plate shafts was synchronized.

conveyors and elevators to transfer the removed fruit into a high-lift truck.

Each experiment was set up in a similar manner as follows: A total of 24 trees was included in a split-plot-in-space-and-time (season) design with four replications (Steel and Torrie, 1900). Each replication was split into two main units. One main unit in each replication was sprayed with an abscission chemical. Each tree received a spray mixture which varied in volume from 2 to 15 gal. In 1969, Hamlin and Parson Brown oranges were sprayed with hexamic acid (2 lb per tree) while Valencia oranges were sprayed with 4 percent cycloheximide (23 mls per tree). In 1970, cyclheximide was used on all varieties. The other main unit was not sprayed. Within each main unit, three harvesting treatments (methods of removal) were used, one per tree. The treatments included in the two main units in each replication are shown in Table 1.

During the conduct of each experiment, pull tests were made to determine the bonding force of both fruit and leaves as shown in Figures 22 and 23. The weight of each pulled fruit was determined and recorded since percent-

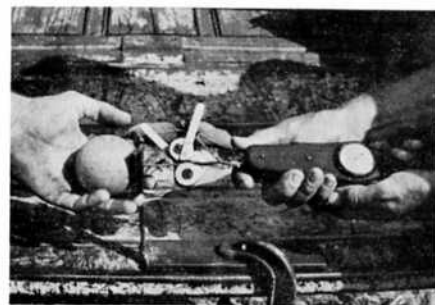


FIG. 22 Technique used to determine fruit bonding force with scale and Model ML-20 (Hunter Spring Co.).

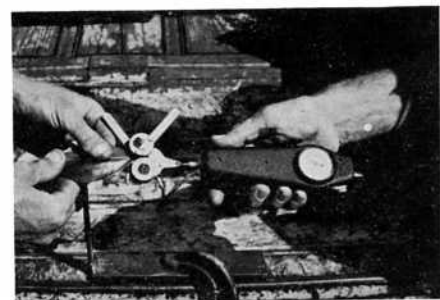


FIG. 23 Technique used to determine leaf bonding force with scale Model ML-10 (Hunter Spring Co.).

age fruit removal by shaking is inversely related to the ratio of the bonding force and weight of the fruit (F/W). Leaf bonding force was recorded because leaf droppage had been observed after the application of some abscission chemicals in previous experiments. Increased leaf removal by FMC-3 was inevitable if the bonding force of the leaves was reduced significantly by the chemicals. This could conceivably reduce the fruit removal effectiveness of the FMC-3 and also be detrimental to tree health and vigor.

Yield and removal data were recorded in the first 2 years while only yield data were recorded the third year. In all cases, data in successive years for a given treatment represent the same trees.

Results

The results for the three experiments are depicted with bar graphs in Figs. 24-27. Those figures concerning yields compare the average in 1969 with the overall averages in 1970 and 1971, inclusive. In addition, the percentage increase or decrease in yield is shown at the top of the bars. Statistical analyses were conducted on the last two years' yield data.

Hamlin

In Hamlins (Fig. 24), treatment effects were not significant (0.05 level)

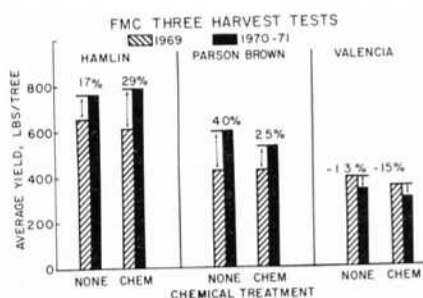


FIG. 25 Effect of abscission chemicals on fruit yield of Hamlin, Parson Brown, and Valencia oranges.

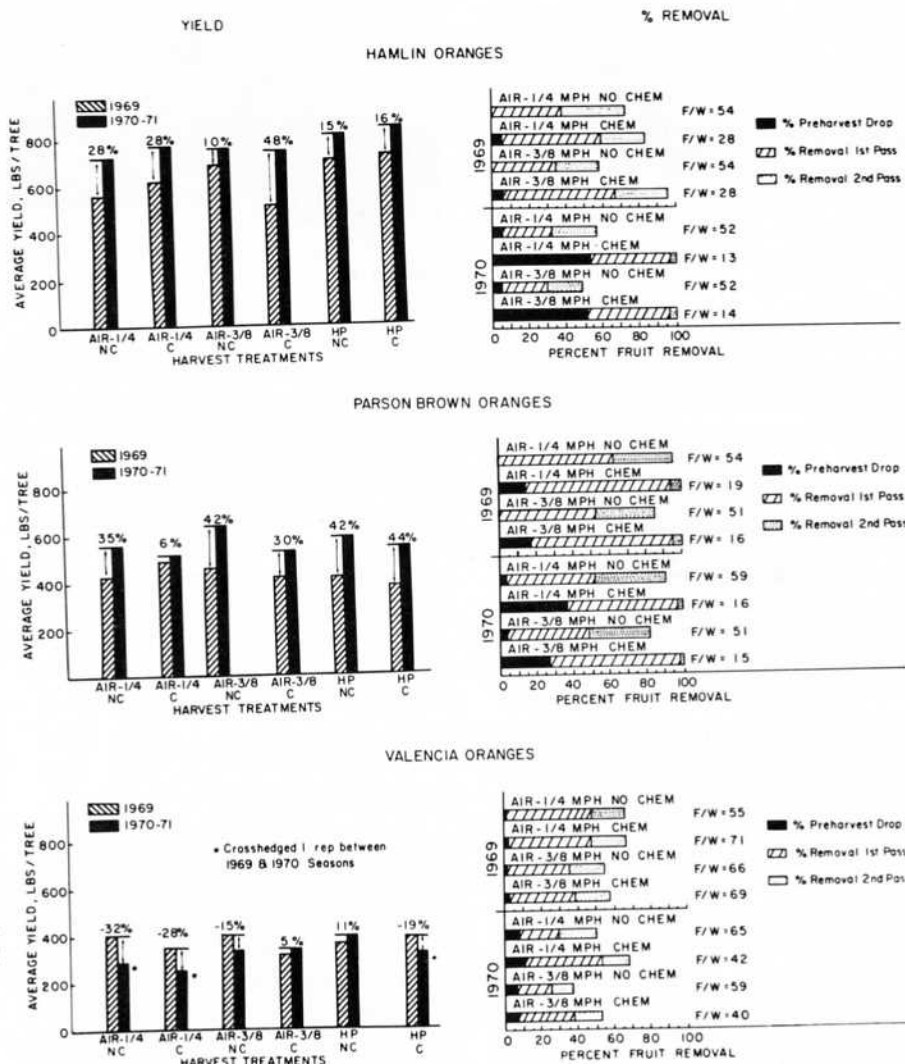


FIG. 24 Yield and percent fruit removal from trees in the FMC-3 2-year study. NC=no abscission chemical; C=abscission chemical.

with Treatment 5 as the check. Specifically, chemical (main plot) effects and method (FMC-3 at 1/4 and 3/8 mph and handpick in subplots) effects were not significantly different (Fig. 25 and 26).

Percent removal and related data are shown for 1969 and 1970 in Fig. 24. Tre height in Hamlins ranged from 18 to 20 ft. Percent fruit drop prior to harvest was greater with the chemically treated

trees (Treatments 2, 4, 6), especially in 1970. As expected, percentage fruit removal of the FMC-3 was greatly increased as a result of the reduced F/W. In fact, the F/W was reduced sufficiently in 1970 that 100 percent removal could probably have been obtained at 1/2 to 3/4 mph and two passes per tree. Another significant result was that the

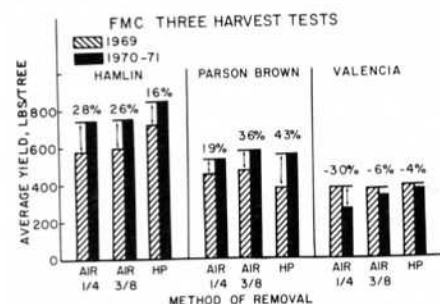


FIG. 26 Effect of method of removal on fruit yields of Hamlin, Parson Brown, and Valencia oranges.

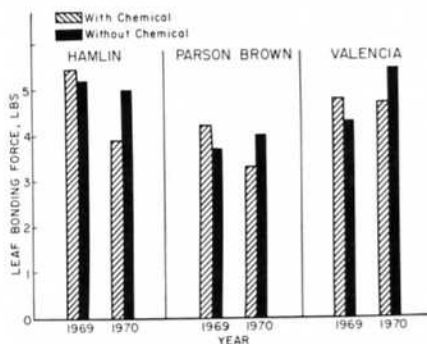


FIG. 27 Effect of abscission chemicals on leaf bonding force in Hamlin, Parson Brown, and Valencia oranges.

leaf bonding force was not significantly affected by the chemicals (Fig. 27).

Parson Brown

Average per tree yields for 1970 were significantly (0.05 level) higher (643 lb) than those of 1971 (484 lb). Neither chemicals or methods of harvest significantly (0.05 level) affected yields for 1970 or 1971. Chemicals did not significantly (0.05 level) reduce the leaf bonding force (Fig. 27). Fig. 24 shows that the chemicals reduced the F/W ratio of the fruit by 2/3 and markedly increased preharvest fruit drop and percent fruit removal of the FMC-3, especially at 3/8 mph. As with Hamlin oranges, percent removal of the FMC-3 with the chemically sprayed trees would probably have been 100 percent at 1/2 to 3/4 mph and two passes per tree. It should be noted here that the percent fruit removal in nonchemically treated trees was higher than that in Hamlins for comparable F/W ratios. The explanations offered for this difference were that the Parson Brown trees (a) were smaller (15 to 18 ft high) and (b) had smaller main support limbs which could be shaken with more amplitude. Also, Hamlin oranges tended to be borne in clusters rather than be uniformly distributed within the bearing volume of the tree. The clusters tended to load localized volumes of the tree and were difficult to set in shaking motion by the forced-air.

Valencia

The immature fruit diameters averaged 1.36 and 1.67 in., respectively, at the time of the 1969 and 1970 harvests. The 1970 yield average (346 lb) was significantly (0.01 level) higher than that of 1969 (291 lb). Chemical effects were not statistically significant. However, Wilson (1969) has observed that some abscission chemicals, when applied early in the season, can substantially reduce Valencia yields. The effects of abscission chemicals on the Valencia orange during its harvest season have not been established. Yields associated with Treatment 5 (handpick check) were significantly greater than those of Treatments 3, 4, and 6 (0.05 level) and Treatments 1 and 2 (0.01 level). In addition, yields associated with the handpick method (Treatments 5 and 6) were not significantly greater than FMC-3 method at 3/8 mph (Treatments 3 and 4). The FMC-3 method at 1/4 mph (Treatments 1 and 2) significantly (0.05 level) reduced yields when compared to the other 2 methods. It should be stated that average yields for

1970-71 were lowest for Treatments 1, 2, and 6; these were also the treatments in which 1 tree or 1 replication (out of 4) was accidentally cross-hedged between the 1969 and 1970 harvests. The yield data from these three trees were included in the above analysis of variance. In general, when compared with the check, Valencia yields were reduced about 15 and 40 percent with FMC-3 at 3/8 mph and 1/4 mph, respectively. According to the data from this experiment, the time of harvest associated with these yield reductions corresponds to an immature fruit diameter in the neighborhood of 1.5 in.

Percentage mature fruit removal was not good in 1969 or 1970, even with the chemical (Fig. 24). In 1969, the chemicals were applied twice with no mature fruit loosening. The F/W ratio of the mature fruit in 1970 was reduced by about 1/3, but was not adequate to substantially increase mature fruit removal. Other reasons for poor mature fruit removal by the FMC-3 was excessive tree height, distribution of fruit on the tree, and large support limbs. The trees averaged 23 feet in height (3 ft higher than the air discharge), and most of the fruit was in the top 10 ft of the tree. The strength of the large support limbs reduced their shaking amplitude. The F/W of the immature fruit and the leaf bonding force were not affected by the chemical in either year.

SUMMARY

The development of an oscillating, forced air concept for citrus fruit removal began in 1961 at the Agricultural Research and Education Center at Lake Alfred. Air velocities up to 110 mph resulted in percent fruit removals of 70 to 85 percent. FMC Corporation began development on the concept in 1963. Their first machine (FMC-1) was tested with vertical, horizontal, and wobble plates to manipulate a column (1 ft wide by 17 ft high) of 100 mph air. Horizontal and wobble plates gave superior fruit removal performance. The second machine (FMC-2) was 20 ft high and used wobble plates to manipulate the air. Fruit removal with the FMC-2 was best when air was discharged at 100 mph and the wobble plate shaft was rotated at 60 to 70 rpm. Fruit removal ranged from 80 to 95 percent when the trees were exposed to the air discharge for approximately 300 sec. The third machine (FMC-3) had twice the air volume delivery capability of the FMC-2. It was found that concentrating

the air delivery capability of the FMC-3 into one general area of the tree resulted in greater fruit removal as compared to dividing the total discharge into two separate areas.

In a further 2-year study with the FMC-3 Hamlin, Parson Brown, and Valencia oranges were harvested and abscission chemicals were used. Yields of the Hamlin and Parson Brown oranges were not significantly reduced by machine or chemical treatments. In Valencia oranges, yields were reduced 15 to 40 percent by the machine treatments, but none by the chemical treatment. These effects were associated with the time in the harvest season when the immature fruit diameter was approximately 1.5 in. Tree damage as a result of the machine treatments in all three varieties consisted of some leaf removal and shredding and some small limb breakage. This damage has been discussed in more detail elsewhere (Whitney, 1970).

Percentage fruit removal of the FMC-3 varied over a wide range. In Hamlin oranges in 1970, for example, total percent removal without chemical loosening (F/W = 52) was 56.5 percent at 1/4 mph at a removal rate of 8100 lb of fruit per hr. With chemical loosening (F/W = 14) at 3/8 mph, total percent removal (two passes) and percent removal after one pass were 100 percent and 95.8 percent, respectively. The removal capacity at two passes per tree was 22,000 lb per hr; while one pass, it was 42,000 lb per hr. These capacities include the preharvest drop. The air energy expended was approximately 1 hp-hr per 100 lb of fruit removed (includes preharvest drop) or 2 hp-hr per 100 lb of fruit actually removed by the FMC-3.

Performance of the oscillating forced air concept has been dependent on a number of factors. A low percentage fruit removal and harvesting capacity usually resulted when (a) the fruit F/W was not reduced by an abscission chemical or other means, (b) when tree height was greater than that of the air discharge, (c) when tree structure was not favorable, and (d) when the fruit set was heavy. With regard to the latter two factors, fruit removal was low when the trees had lightly foliated, large limbs and/or the fruit was borne on clusters. Apparently, in these situations, the periodic forces produced by the blasts of air were not sufficient for vigorous limb shaking action.

This concept has considerable potential as a method of removing citrus at a
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fast rate if an abscission chemical is developed which will consistently reduce the mature fruit F/W to 20 or 30 and will not produce detrimental side effects. At this low F/W ratio, considerable preharvest drop may occur. If this be the case, catch frames may not be feasible and the fruit may have to be picked up from the ground.

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