Selective Harvesting of Valencia Oranges with a Vertical Canopy Shaker

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FLORIDA'S average annual production of Valencia oranges for the past 5 years (1966-1971) was 60 million boxes per year, which accounted for 46 percent of the Florida orange crop (Florida Dept. of Agr. 1971). The Valencia variety requires 14 month to mature. Therefore, the young (immature) fruit for the following year's crop is on the tree at harvest time. Trunk, limb, and air shakers effectively remove grapefruit and other varieties of oranges (Hedden and Coppock 1965, 1968; and Whitney and Patterson 1972). However, removing Valencia oranges with these methods often reduces subsequent yields, because a substantial portion of the young fruit is removed when the mature fruit is harvested.

The objective of this study was to investigate the vertical canopy shaker method of harvesting and to determine the influence of frequency and stroke on selectivity and removal of Valencia oranges with two shaker drive systems.

LITERATURE REVIEW

Foliage or canopy shakers clamp secondary limbs out near fruit bearing hangers, as compared with other shakers that clamp large primary limbs and trunks. Therefore, it should be possible to exert more control over fruit motion (displacement, velocity, and acceleration) with canopy shakers. Frost and Hedden (1972) showed that a coil-shaped unit that shook secondary limbs removed less young fruit than a limb shaker. Hedden and Coppock (1971) found that a foliage shaker gave better selectivity than the limb shaker for all harvest dates. Lenker and Hedden (1968b) studied optimum shaking action of limb shakers for citrus and found that: (a) Fruit removal was directly proportional to limb displacement and shaking frequency, (b) substantially more Pineapple oranges were removed by a smooth shaking action than by an impact action, (c) higher shaking frequencies removed less fruit with attached stems, and (d) the percentage of fruit removed with stems was affected very little by the type of shaking action and by limb displacement.

Inertial limb shakers for citrus have a 6-in. stroke between the unbalanced weight and the limb clamp and have shaking frequencies up to 350 cpm. Limb displacement varies inversely with limb diameter, and displacement gradually increases in amplitude along the limb to smaller wood (Lenker and Hedden 1968a). For comparable mature fruit removal levels, canopy shakers are expected to require larger shaker displacements than those obtained with limb shakers.

The weight of young fruit and the force required to remove it are important factors in the selective harvesting of Valencia oranges. Coppock (1972) investigated the properties of young and mature Valencia oranges that influence selective harvesting. He found that as young fruit reaches 7/8 in. in diameter, several changes occur which have considerable influence on selective harvesting with limb shakers. Young fruit weight begins to increase rapidly, the force necessary to remove it continues to increase steadily, and natural fruit droppage approaches zero. Coppock's study showed that when mature fruit is harvested after the young fruit is 7/8 in. in diameter, the subsequent yield is reduced, and no statistical difference in subsequent yield occurs as a result of using a subdued shaking action with the limb shaker as compared with a maximum shaking action. As the young fruit grows larger, it is generally increasingly more difficult to maximize mature fruit removal without further decreasing the subsequent yield.

EQUIPMENT AND METHODS

A canopy shaker test unit was designed and constructed to clamp secondary limbs and shake them vertically (Fig. 1). Two separate drive systems (a 1½-in-dia recycling hydraulic cylinder and a hydraulic-driven crank) with stroke adjustments from 4 to 12 in. and frequencies up to 350 cpm were designed to shake the 156-lb shaker unit. The crank drive was powered directly by a hydraulic motor capable of producing 2,000 lb-in. of torque. Later, a flywheel which had a mass moment of inertia of 3.0 lb-in.-sec^2 and which rotated at three times the shaking frequency was connected to the crank drive to reduce variations in shaking frequency and give a smooth shake. The crank drive had a smoother action than the cylinder drive, which had higher peak accelerations at the top and bottom of the stroke.

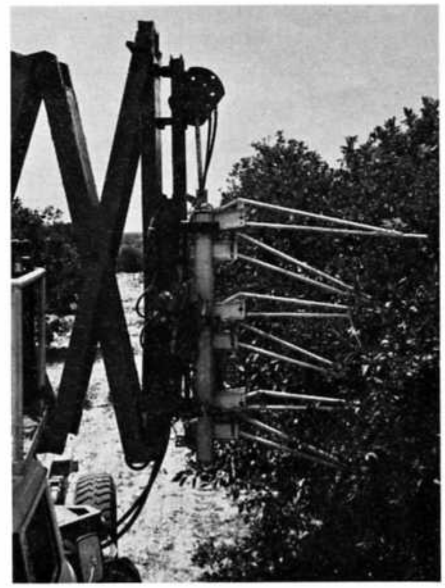

FIG. 1 Foliage shaker unit (clamp tines open) with crank drive system before adding flywheel.

The shaker clamp consisted of three movable tines and three fixed tines, each 5 ft long, spaced 18 in. apart. To clamp the foliage, the movable tines were opened, inserted into the tree, and closed. The shaker was positioned into the tree with a pantograph lift unit which could extend, raise, and rotate to suitable positions for shaking. Shaking direction was always vertical.

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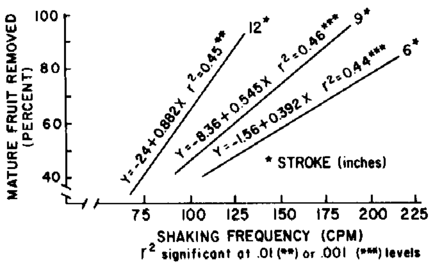

FIG. 2 Effect of shaking frequency on mature fruit removed by the recycling cylinder drive system, May 1970.

1970 TESTS

A test with the recycling cylinder drive and one with the crank drive (without flywheel) were conducted on Valencia orange trees in 1970. Unhedged trees about 18 ft tall with rather dense foliage which were considered good shaker trees were selected. Limb sections containing 20 to 60 mature fruit were clamped with the foliage shaker and shaken for 15 to 20 sec. Most of the mature fruit was removed. For each limb, a determination was made of the percentage of young and mature fruit removed, mature fruit removed with attached stems, and mature fruit left on the limb from the end to 18 in. inside the clamp. The shaking stroke was assumed to be the displacement made by the drive unit.

The test with the cylinder drive was conducted May 20-21 when the young fruit averaged 1 in. in diameter. It appeared from the small percentage of young fruit removed (10 percent or less of the fruit on the tree) that young fruit need not be considered in this test. Therefore, time and attention were directed toward obtaining maximum mature fruit removal with the 6-, 9-, and 12-in. strokes. Twenty limb sections were shaken at each of the three strokes at frequencies that were expected to give good mature fruit removal. Shaking time was approximately 12 sec for each limb.

Because of drive problems encountered with the cylinder drive during these tests, its use was abandoned and the crank drive system was used instead. This drive provided a higher frequency range and also resulted in fewer machine failures.

The crank drive test was conducted June 17-18. The young fruit had increased in diameter to an average of 1.6 in.; most of the natural young fruit droppage had occurred, and young fruit removal became a critical factor. Twelve limb sections were shaken at each of the 6-, 9-, and 12-in. strokes at frequencies which gave good removal with the cylinder drive. Shaking time was approximately 18 sec per limb.

1971 TESTS

The flywheel was added to the crank-drive-shaker for the 1971 tests. Shaker strokes of 6-, 9-, and 12-in. were investigated, as in 1970, but with a wider frequency range. Four replications were made at a low, medium, and high frequency for each stroke setting. Tests were conducted on May 18 and June 8 when the young fruit was 3/4 in. and 1¼ in. in diameter, respectively. Shaking time was 10 sec per limb, and data were collected as in the 1970 tests.

RESULTS OF 1970 TESTS

The percentage of mature fruit removed for the cylinder-drive-shaker as a function of frequency is given in Fig. 2. Fruit removals of 80 to 85 percent were accomplished with 6-, 9-, and 12-in. strokes. The influence of shaking frequency increased as stroke was varied from 6 to 12 in. In the low-frequency range, the crank-drive-shaker (See Fig. 3) removed a higher percentage of mature fruit than the cylinder-drive-shaker. The increased removal with the crank-drive-shaker resulted from its increased shaking time and its different type of motion as compared with those of the cylinder-drive-shaker.

An analysis by multiple linear regression of the percentage of fruit removed gave the following equation of significant independent variables for the crank-drive-shaker test:

Percentage removed = 39.65 + 2.0814 Stroke + 0.16659 Frequency

The slope coefficients for stroke and frequency were significantly different from zero (0.01 level). The average percentage of mature fruit removed with stems was 28, 48, and 33 percent, respectively, for the 6-, 9-, and 12-in. strokes. The percentage of stems as influenced by shaking frequency in the range tested was not statistically evaluated.

The selectivity ratio (No. of mature fruit removed divided by the No. of young fruit removed) gave the following equation of significant independent variables when the data were analyzed by multiple linear regression.

$$\frac{\text{Mature removed}}{\text{Young removed}} = 27.158 - 0.04412 \text{ Frequency}$$

The slope coefficients for stroke and frequency were significantly different from zero (0.001 and 0.01 level, respectively). The multiple correlation coefficient (R) of 0.66 was significantly different from zero (0.001 level). Average selectivity ratios were 8.66a*, 5.30ab, and 2.93b, respectively, for the 6-, 9-, and 12-in. strokes.

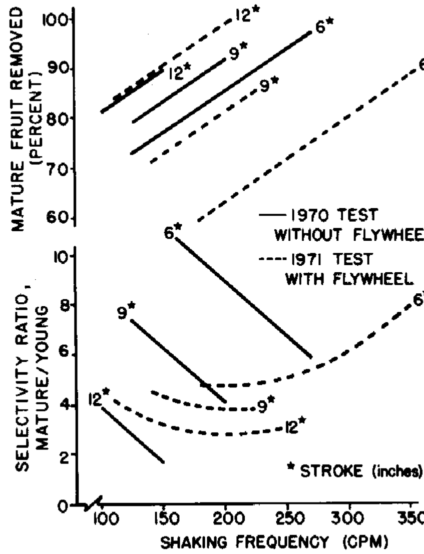

FIG. 3 Mature fruit removed and selectivity ratios for the crank drive shaker system.

RESULTS OF 1971 TESTS

The force necessary to remove mature fruit was considered unchanged between dates of harvest, and removal data for both dates of harvest were combined. An analysis by multiple linear regression of the percentage of mature fruit removed, when using the flywheel, gave the following equation of significant independent variables:

Percentage removed = -6.396 + 5.9559 Stroke + 0.16976 Frequency

The slope coefficients for stroke and frequency were significantly different from zero (0.01 level) and R was 0.68, significantly different from zero (0.01 level). Fig. 3 shows the percentage of removal over the frequency ranges tested for the 6-, 9-, and 12-in. strokes, with and without the flywheel. When the flywheel was added to the shaker, mature fruit removal was reduced with the 6- and 9-in. storke, as indicated by Fig. 3. However, shaking time was 10 sec, as compared with 18 sec without the flywheel.

No significant correlation coefficients were obtained when either stroke or frequency were compared with selectivity ratio for this first test in 1971 when young fruit averaged 3/4 in. in di-

*No significant difference between mean values followed by the same letter. Tukey ω-procedure at 0.01 level.

ameter. Average selectivity ratios of 12.0, 15.0, and 11.0, not significantly different, were determined for the 6-, 9-, and 12-in. strokes, respectively, for the May 18 test.

Selectivity ratios for the June 8 test (young fruit diameter, 1 1/4-in.) averaged 6.0, 3.8, and 3.7, respectively, for the 6-, 9-, and 12-in. strokes. The 6-in. stroke gave significantly better selectivity (0.01 level) than did the 9- and 12-in. strokes; however, the percentage of mature fruit removed was lower for the 6-in. stroke.

An analysis by multiple linear regression of the selectivity ratios for the June 8 test gave the following equation:

$$\frac{\text{Mature removed}}{\text{Young removed}} = 13.34 - \frac{0.3206}{\text{Stroke}} - 0.06465\ \text{Freq.} + 0.001572\ (\text{Freq.})^2$$

The R of 0.67 was significantly different from zero at the (0.001 level). The slope coefficients for stroke, frequency (Freq.), and Freq.^{2} were significantly different from zero (0.01, 0.001, and 0.001 levels, respectively).

The fruit with stems obtained for the 6-, 9-, and 12-in. strokes averaged 28.5, 32.0 and 30.6 percent, respectively. These values were in the same range as in the 1970 test.

DISCUSSION

Valencia orange trees "set" many times the number of young fruit required for a normal crop. The excess young fruit drops throughout the harvest season, changing the number of young fruit which can be mechanically removed without reducing the subsequent fruit yield. The number of mature fruit on the tree changes very little during the harvest season but there can be a considerable variation in the number of mature fruit on the tree from one year to the next. Therefore, selectivity ratios that give no subsequent yield reduction vary during the harvest season and from year to year. A high selectivity ratio is desirable, indicating that a removal device is more effective in removing mature fruit than the young fruit, but it does not indicate whether there will be a subsequent yield reduction. Selectivity ratios can be useful, however in comparing the performance of a machine, as affected by various inputs, at a particular harvest time in a particular grove. In these tests the selectivity ratio was used to compare the effect of shaker stroke and frequency.

The selectivity ratio had an inverse relationship with both the shaking frequency and stroke in the 1970 tests without the flywheel. However, the percentage of mature fruit removd was directly proportional to the shaking frequency and stroke. This indicates that a high removal of mature fruit also resulted in a high removal of young fruit.

The addition of a flywheel to the shaker in the 1971 tests resulted in a curvilinear relationship between selectivity ratio and shaking frequency. The selectivity ratio for the 1971 tests was influenced less by the stroke and frequency than in the 1970 tests.

The data from the tests in both years indicated that the 6-in. stroke gave better selectivity than the 9- and 12-in. strokes. However, tests over a wider frequency range are needed to determine the optimum shaking frequency and stroke for this type of shaker.

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