Trunk Shakers for Citrus Harvesting—Part II: Tree Growth, Fruit Yield and Removal

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ABSTRACT

'HAMLIN' and 'Valencia' oranges were harvested for 5 seasons to evaluate the effectiveness of 4 trunk shaking patterns (2 linear, and 2 multidirectional, with and without abscission chemicals). Fruit yields, removal efficiencies, and trunk circumferences were measured. Hamlin yields were not affected by the shakers; Valencia yields were significantly reduced by one of the multidirectional shaker patterns. Abscission chemicals did not reduce the yields of either Hamlin or Valencia. Abscission chemicals increased shaker removal efficiencies from 64% to 90% in Hamlin and from 74% to 91% in Valencia. Trunk growth was not affected by shaking. The most vigorous linear shaking pattern provided superior harvesting efficiency.

INTRODUCTION

Trunk shakers are widely used commercially to remove various deciduous fruits and nuts in harvest operations (Brown, 1983). Their use in citrus has been limited because of poor fruit removal, bark damage to the Valencia cultivar, and inadequate tree trunk height in a high percentage of Florida groves for a good shaker clamp attachment (Whitney et al., 1983). Research in Florida has demonstrated orange removal efficiencies of 90% or higher with trunk shakers using an abscission chemical (Whitney, 1975; Whitney et al., 1983). In Valencia oranges, having a young and a mature crop on the tree at time of harvest, subsequent yields were reduced up to 20% by the shakers and abscission chemicals (Whitney, 1975; Whitney et al., 1983). Considerable information has been reported on the interaction of limb shakers and abscission chemicals on citrus fruit yields and removal efficiencies. Limb shakers are not as dependent upon abscission chemicals for increasing fruit removal efficiency, however, longer shaking periods are required where no loosening is effected and more young Valencia fruit are removed causing a drop in yield the following year (Wilson et al., 1986). The potential for shaking a tree from a single attachment point, the advent of abscission chemicals for fruit loosening, and the increase in number of trees with a size and shape adaptable for trunk shaking make this fruit removal method more feasible.

The objective of this study was to measure the effects of trunk shaking (with and without abscission chemicals) of citrus tree growth, fruit yields, fruit removal, and harvesting efficiency over five harvest seasons (years). The initial results of this study were reported by Hedden, et al. (1984).

METHODS AND EQUIPMENT

Two experiments were designed to collect performance data on trunk shaking Hamlin and Valencia oranges near LaBelle in south Florida. Trees in each experiment were 15- and 8-years-old, respectively, uniform in size and density, with adequate trunk height for trunk shaker attachment. The trees were representative of many younger plantings on flatwoods soils in south Florida. Each experiment was a randomized, split-plot design which included 60 trees and 6 replications. One of the two 5-tree main plots in each replication was randomly assigned to be sprayed with abscission chemicals (C) before harvest while the other main plot was not sprayed (NC). Within each main plot, 4 shaker and 1 handpicked check treatment were randomly assigned to each tree. These assignments were maintained for the 5 year duration of the experiments.

The trunk shaker and check treatments were as follows:

1. Linear shaker with 60.4 kg of unbalanced rotational mass at 140 mm eccentricity, 458.2 kg total mass excluding the unbalanced mass, operated at 6 r/s.
2. Linear shaker with 90.9 kg of unbalanced rotational mass at 140 mm eccentricity, 272 kg total mass excluding the unbalanced mass, operated at 5 r/s.
3. Multidirectional shaker (FMC* Model 729 shaker head) with two 30.9 kg unbalanced masses rotating in opposite directions at 11 and 13 r/s with 114 mm eccentricity.
4. Same shaker as 3 except both essentric masses rotated in the same direction.
5. Handpicked (check).

The shaker treatment trees were shaken for 7 s. A discussion and analysis of the theoretical and measured shaker motions was presented in Part I of this series.†

Four to 5 days prior to harvest, main plots receiving

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*Trade names are included for the benefit of the reader and do not imply endorsement by the Univerity of Florida, United States Department of Agriculture, or Florida Department of Citrus.

†Whitney, J. D., D. B. Churchill, S. L. Hedden, and G. H. Smerage. 1987. Trunk shakers for citrus harvesting—Part I: Measured trunk shaker and tree trunk motion. APPLIED ENGINEERING in AGRICULTURE (this issue).

TABLE 1. GROWTH OF HAMLIN AND VALENCIA TREES IN TRUNK SHAKER EXPERIMENT

Treatment		Trunk circumference at 200 mm above ground* Hamlin			Trunk circumference at 200 mm above ground* Valencia		
Shaker	Chemical	1982 mm	1986 mm	Circumference increase, %	1982 mm	1986 mm	Circumference increase, %
1—lin. 60.4 kg unbal. mass	NC	650 a	706 a	8.6 a	516 a	584 a	13.3 a
1—lin. 60.4 kg unbal. mass	C	612 a	660 a	7.9 a	462 b	521 b	12.6 a
2—lin. 90.9 kg unbal. mass	NC	645 a	704 a	9.1 a	493 ab	559 ab	13.4 a
2—lin. 90.9 kg unbal. mass	C	638 a	704 a	10.4 a	478 ab	554 ab	16.0 a
3—multi. opp. rotation	NC	666 a	719 a	8.0 a	506 ab	574 a	13.6 a
3 multi. opp. rotation	C	625 a	686 a	9.8 a	511 a	582 a	13.9 a
4—multi. same rotation	NC	648 a	709 a	9.4 a	495 ab	572 a	15.4 a
4—multi. same rotation	C	617 a	666 a	7.8 a	488 ab	561 ab	15.1 a
5—handpick	NC	—	699 a		—	541 ab	
5—handpick	C	—	709 a		—	551 ab	

*Mean separation in columns by Duncan's multiple range test, 5% level

abscission chemicals were treated with an amount dependent upon fruit and tree condition and cultivar. The normal abscission chemical mixture for Hamlin oranges was 75 ppm of RELEASE‡ 5-chloro-3-methyl-4-nitripyrazole), 1.5 ppm of ACTI-AID (cycloheximide), and 0.1% ORTHO X-77 surfactant. The mixture was applied at 5 L/tree. For Valencia oranges, the abscission chemical mixture was 250 ppm of RELEASE and 0.1% ORTHO X-77 surfactant, and applied at 15 L/tree.

Data were collected on fruit removal for 5 years (1981 through 1985) and on fruit yield for 6 years (1981 through 1986). A harvesting efficiency index (HEI) was calculated for each treatment as follows:

$$HEI = (1/6) \sum_{i=1}^{i=6} \frac{(TY_i)(TR_i)}{CY_i} \qquad [1]$$

where

TY_i = 1982 to 1986 average treatment yield in the (i)th replication, kg/tree

CY_i = 1982 to 1986 average check yield of Treatment 5 (NC) in the (i)th replication, kg/tree

TR_i = 1981 to 1985 average treatment fruit remova in the (i)th replication, %

Each tree was observed for incidence of bark damag after it was shaken. Trunk circumferences at 200 mn above ground level were measured as a tree growtl indicator. These measurements were made for 5 year (1982 through 1986) in Treatments 1 through 4 (C anc NC) but for only one year (1986) in Treatment 5 (C anc NC). All data were analyzed statistically and significan differences refer to the F values or Duncan's multipl range test at the 5% level.

RESULTS

Tree Growth

Hamlin: Table 1 shows the trunk circumferenc measurements for 1982 and 1986 and the percentag increase or growth. There were no significant difference among trunk circumferences in the initial shake treatments. All shaker treatment trees grew approximately 60 mm in trunk circumference betweer 1982 and 1986.

Valencia: Table 1 shows the trunk circumferences fo 1982 and 1986 and the percentage increase or growth. Ir 1982, the trunks of shaker Treatment 1 (C) wer significantly smaller than those of shaker Treatments 1 (NC) and 3 (C). By 1986, trunks of all shaker treatment had grown 50 mm or more. Again, the trunks of shake

‡The EUP for RELEASE expired February 1986 and the registration was not renewed for ACTI-AID, therefore, these materials are no longer available for use on citrus.

TABLE 2. HAMLIN ORANGE YIELDS IN TRUNK SHAKER EXPERIMENT

Treatment		Yield, kg/tree*						
Shaker	Chemical	1981	1982	1983	1984	1985	1986	1982 to 1986 avg.
1—lin. 60.4 kg unbal. mass	NC	155.9 a	217.9 ab	85.7 ab	135.1 a	253.8 a	284.0 a	195.4 a
1—lin. 60.4 kg unbal. mass	C	154.6 a	220.7 ab	113.0 a	151.4 a	229.3 abc	228.9 a	188.5 a
2—lin. 90.9 kg unbal. mass	NC	148.5 a	217. ab	73.4 b	142.8 a	195.8 bc	279.1 a	181.6 a
2—lin. 90.9 kg unbal. mass	C	146.1 a	216.7 ab	81.6 ab	157.5 a	246.0 ab	259.5 a	192.2 a
3—multi. opp. rotation	NC	149.3 a	233.4 ab	60.8 b	155.9 a	195.8 bc	246.4 a	178.8 a
3—multi. opp. rotation	C	147.7 a	228.5 ab	72.2 b	165.7 a	194.2 bc	215.8 a	175.5 a
4—multi. same rotation	NC	147.7 a	257.9 a	53.5 b	173.0 a	180.7 c	260.7 a	185.3 a
4—multi. same rotation	C	159.9 a	233.8 ab	74.7 b	159.9 a	217.9 abc	250.9 a	187.4 a
5—handpick	NC	140.4 a	208.5 b	71.0 b	173.0 a	227.7 abc	267.2 a	181.3 a
5—handpick	C	155.9 a	243.2 ab	84.9 ab	150.1 a	203.6 abc	281.9 a	192.7 a

*Mean separation in columns by Duncan's multiple range test, 5% level

TABLE 3. VALENCIA ORANGE YIELDS IN TRUNK SHAKER EXPERIMENT

Treatment		Yield, kg/tree*						
Shaker	Chemical	1981	1982	1983	1984	1985	1986	1982 to 1986 avg.
1—lin. 60.4 kg unbal. mass	NC	150.1 a	215.0 a	127.3 a	126.9 a	192.2 a	259.5 a	184.0 a
1—lin. 60.4 kg unbal. mass	C	120.0 a	159.1 b	104.9 a	92.2 bcd	165.2 a	227.7 ab	149.7 cd
2—lin. 90.9 kg unbal. mass	NC	150.1 a	186.1 ab	113.8 a	90.2 bcd	183.2 a	219.9 ab	158.7 bcd
2—lin. 90.9 kg unbal. mass	C	154.6 a	190.1 ab	90.2 a	115.9 ab	189.3 a	261.1 a	169.3 abcd
3—multi. opp. rotation	NC	148.1 a	177.9 ab	109.8 a	96.7 bcd	146.1 a	225.6 ab	148.5 cd
3—multi. opp. rotation	C	159.1 a	190.1 ab	124.4 a	85.3 cd	163.6 a	255.4 ab	163.6 abcd
4—multi. same rotation	NC	128.9 a	173.8 ab	100.8 a	94.3 bcd	168.1 a	238.7 ab	155.0 bcd
4—multi. same rotation	C	136.3 a	155.9 b	97.1 a	68.5 d	158.3 a	248.5 ab	145.7 d
5—handpick	NC	140.8 a	182.0 ab	143.6 a	110.6 abc	204.4 a	211.3 b	170.5 abc
5—handpick	C	151.8 a	191.4 ab	120.4 a	111.0 abc	206.0 a	262.3 a	178.3 ab

*Mean separation in columns by Duncan's multiple range test, 5% level

Treatment 1 (C) were the smallest, and were significantly less than four of the other shaker treatments but not less than the trunks of the handpick Treatment 5 (NC) trees. The percentage increases in circumferences among shaker trees were not significantly different.

Fruit Yields

Hamlin: The fruit yields of all treatments are shown in Table 2. All trees were uniform with no significant differences in fruit yield the first year (1981) of the experiment. The January 1982 freeze caused considerable defoliation prior to the 1982 harvest. Acti-Aid was not used in the abscission chemical mix because young flush and bloom buds were present at harvest time. The 1982 fruit yields were high and shaker Treatment 4 (NC) was significantly higher than handpick Treatment 5 (NC). The 1983 fruit yields were low as a result of the 1982 freeze damage. Shaker Treatment 1 (C) had the highest fruit yields and was significantly higher than five of the other shaker treatments and handpick Treatment 5 (NC). During the final 3 years of the experiment (1984 to 1986), the trees recovered from the freeze damage and the average fruit yields increased each successive year. Significant differences in treatment yields were noted only in 1985, but the shaker Treatments (1 to 4) were not significantly different from the handpick Treatment 5 (NC).

The overall effects of shakers and/or chemicals on fruit yields are shown in the last column of Table 2. These yields are the averages for 1982 to 1986, subsequent to the initiation of shaking and abscission chemical application. There were no significant differences among all treatments.

Valencia: Table 3 shows the yield data for Valencia oranges. All harvest tests occurred between late March and late April prior to the time when the young fruit would exceed 13 mm in diameter. Initial yields in 1981 were not as uniform as those of the Hamlin experiment, but no significant differences were indicated. As with the Hamlin oranges, Valencia plots were harvested in 1982 after the freeze which resulted in considerable defoliation. The only significant difference was between shaker Treatment 1 (NC) and the two shaker Treatments 1 (C) and 4 (C). No significant differences occurred in 1983 and 1985. In 1984, shaker Treatment 4 (C) was significantly less than two other shaker treatments and the handpick treatments. In 1986, handpick Treatment 5 (NC) was significantly less than two shaker treatments and the handpick Treatment 5 (C). Overall, 1982 through 1986, only shaker Treatment 4 (C) was significantly lessthan handpick Treatment 5 (NC). The abscission chemicals did not affect yields.

Fruit Removal and Harvesting Efficiency

Hamlin: The left-hand portion of Table 4 shows the fruit removal data for the shaker treatments. Significant differences resulted each year between shaker Treatments 1 through 4. Abscission chemicals

TABLE 4. HAMLIN ORANGE REMOVAL AND HARVESTING EFFICIENCY INDEXES IN TRUNK SHAKER EXPERIMENT

Treatment		Percentage fruit removal*						
Shaker	Chemical	1981	1982	1983	1984	1985	1981 to 1985 avg	Harvesting efficiency index*
1—lin. 60.4 kg unbal. mass	NC	58.4 c	64.2 c	43.1 d	54.4 c	58.0 c	55.6 d	63.7 c
1—lin. 60.4 kg unbal. mass	C	99.8 a	91.9 a	78.7 ab	78.7 a	98.1 a	89.4 a	100.4 a
2—lin. 90.9 kg unbal. mass	NC	75.8 b	78.7 b	67.3 bc	64.5 bc	65.4 b	70.3 b	74.0 bc
2—lin. 90.9 kg unbal. mass	C	99.7 a	93.3 a	84.4 a	78.4 a	99.4 a	91.1 a	107.0 a
3—multi. opp. rotation	NC	67.9 b	73.9 b	43.7 d	57.5 c	63.2 bc	61.2 c	60.4 c
3—multi. opp. rotation	C	98.3 a	91.2 a	81.3 ab	79.6 a	99.2 a	89.9 a	94.1 ab
4—multi. same rotation	NC	73.2 b	74.5 b	62.5 c	73.7 ab	70.1 b	70.8 b	75.7 bc
4—multi. same rotation	C	99.8 a	93.1 a	81.4 ab	81.1 a	98.3 a	90.7 a	99.7 a
5—handpick†	NC	—	—	—	—	—	—	100.0 a
5—handpick†	C	—	—	—	—	—	—	114.4 a

*Mean separation in columns by Duncan's multiple range test, 5% level
†Percentage fruit removal assumed to be 100%.

TABLE 5. VALENCIA ORANGE REMOVAL AND HARVESTING EFFICIENCY INDEXES IN TRUNK SHAKER EXPERIMENT

Treatment		Percentage fruit removal*						
Shaker	Chemical	1981	1982	1983	1984	1985	1981 to 1985 avg	Harvesting efficiency index*
1–lin. 60.4 kg unbal. mass	NC	74.0 d	70.5 d	79.4 c	51.3 d	48.2 d	64.7 d	70.6 de
1–lin. 60.4 kg unbal. mass	C	91.9 ab	87.3 a	95.0 a	80.2 ab	97.7 a	90.4 a	79.3 cde
2–lin. 90.9 kg unbal. mass	NC	85.0 bc	83.6 ab	92.1 ab	68.0 bc	74.2 b	80.6 ab	76.3 cde
2–lin. 90.9 kg unbal. mass	C	94.0 a	90.1 a	95.1 a	84.2 a	97.0 a	92.1 a	91.2 abc
3–multi. opp. rotation	NC	80.1 cd	73.5 cd	85.4 bc	64.1 cd	61.4 c	72.9 c	65.0 e
3–multi. opp. rotation	C	93.9 a	83.8 ab	96.8 a	83.5 a	95.1 a	90.6 a	87.2 bcd
4–multi. same rotation	NC	81.9 cd	79.0 bc	79.1 c	70.5 abc	72.7 bc	76.7 bc	69.8 e
4–multi. same rotation	C	92.5 ab	90.8 a	95.9 a	81.8 ab	96.3	91.5 a	78.4 cde
5–handpick†	NC	–	–	–	–	–	–	100.0 ab
5–handpick†	C	–	–	–	–	–	–	105.7 a

*Mean separation in columns by Duncan's multiple range test, 5% level

†Percentage fruit removal assumed to be 100%.

significantly increased the removal efficiency of the shaker treatments each year. Overall, abscission chemicals increased fruit removal significantly from 64.5 to 90.3%. With abscission chemicals, there was no significant difference in the fruit removal among shakers. However, without abscission chemicals, the removal efficiencies of shaker Treatments 2 and 4 were significantly higher than that of shaker Treatment 3, which in turn was significantly higher than that of shaker Treatment 1.

The harvesting efficiency index (HEI) as defined in equation [1], is a measure of the percentage of the crop which could be harvested by each treatment when compared to conventional hand harvesting without abscission chemicals (Treatment 5 NC). The HEI values are shown in the last column of Table 4. The HEI of Treatment 5 (NC) would be 100. Treatment 5 (C) had a HEI of 114.4, which indicated the yields of the chemically treated handpick trees averaged 14.4% more than the Treatment 5 (NC) trees. However, this difference was not statistically significant. There was also no statistical difference among Treatment 5 (NC) and shaker Treatments 1 through 4 with abscission chemicals (C) and Treatment 2 (C) had the highest value of 107.0. Shaker Treatments 1 through 4 without abscission chemicals (NC) were significantly less than Treatment 5 (NC), but differences among shaker treatments were not significant. Abscission chemicals increased the average HEI of shaker Treatments 1 through 4 from 68.4 to 100.3.

Valencia: The left-hand portion of Table 5 shows the percentage fruit removal of the shaker treatments. As with Hamlin, significant differences resulted each year between shaker Treatments 1 through 4. Abscission chemicals significantly increased fruit removal of the shaker treatments each year. The 5-year averages (1981 to 1985) are shown in column 6. Abscission chemicals increased removal efficiencies from 73.7% to 91.2%. With abscission chemicals (C), there were no significant differences in fruit removal among shaker treatments. Without abscission chemicals (NC), the removal efficiency of shaker Treatment 2 was significantly greater than Treatment 3 and shaker Treatment 3 was significantly greater then Treatment 1. Treatment 2 developed the greatest shaking amplitude among the shakers and generally provided superior fruit removal. The amplitudes of Treatments 1 and 3 were similar, but Treatment 3 provided superior fruit removal because it operated at approximately twice the frequency as Treatment 1, thus twice the shake cycles in 7 s.

The harvesting efficiency index (HEI) of handpick Treatment 5 (C) was the highest at 105.7. The HEI's of all shaker Treatments except 2 (C) and 3 (C) were statistically less than Treatment 5 (NC). The low HEI of Treatment 1 (C) may have been due in part to the lower fruit yielding potential of its trees (1981 yields in Table 3). The low HEI of Treatment 4 (C) resulted because it reduced fruit yields as stated earlier. As with Hamlin, Treatment 2 (C) had the highest HEI at 91.2 among shaker treatments. There were no significant differences in the HEI's among shaker Treatments 1 through 4 when considered either without abscission chemicals (NC) or with abscission chemicals (C). Abscission chemicals significantly increased the HEI of Treatment 3 only. On the average, abscission chemicals increased the HEI of the shaker treatments from 70.4 to 84.0.

DISCUSSION

Tree growth was not affected by the shaker treatments or abscission chemicals in Hamlin or Valencia. Bark damage was not an apparent problem with any of the shaking patterns, even in Valencia. Most trees had relatively smooth trunks with sufficient height for the shaker clamp pads.

Hamlin yields were not affected by shakers or abscission chemicals. In Valencia, abscission chemicals did not affect yields, but one shaker treatment (multidirectional shaker, same direction mass rotation) with abscission chemicals had a reduced yield. This significant reduction may have resulted for two reasons. First, Treatment 4 provided the most agressive shaking action between the two multidirectional shaker treatments as evidenced by its higher removal efficiencies (Tables 4 and 5). Second, shaking with abscission chemicals removed mature Valencias faster and more completely than without abscission chemicals, thus subjecting the young Valencias or next year's crop to more shaking energy and damage during the latter portion of the 7 s shake period. The higher frequency shake of the multidirectional shaker appeared to remove more of the young Valencias (next year's crop) than did the low frequency shaking of the linear shaker. Valencias were shaken before May, prior to the time when the young fruit had reached a diameter of 13 mm. Shaking when the young fruit is larger may reduce yield more than was measured in this study.

The average fruit removal of the shakers were increased by abscission chemicals an average of 26 and 17 percentage points in Hamlin and Valencia, respectively. The harvesting efficiency index (HEI) of the shakers, a measure of the percentage of the crop which could be harvested when compared to conventional hand harvesting, was increased by abscission chemicals an average of 31 points in Hamlin and 13 points in Valencia. The linear shaking treatment with the 90.9 kg unbalanced mass (Treatment 2) resulted in the best HEI among shakers, with or without abscission chemicals. Its HEI with abscission chemicals was 107 in Hamlin and 91 in Valencia. The HEI of all shaker treatments with abscission chemicals in Valencia oranges could probably be increased if the shaking time was less than 7 s as used in this study, since it was obsered that most of the mature fruit fell in the first few s of shaking.

CONCLUSIONS

Based on the data from 5-year study, the following conclusions seem to be justified:

1. Trunk circumference growth was not affected by the shakers or abscission chemicals.
2. Hamlin orange yields were not affected by shakers or abscission chemicals, whereas Valencia orange yields were significantly reduced by one multidirectional shaker pattern with abscission chemicals.
3. Average fruit removals of the shakers were increased by abscission chemicals an average of 26 and 17 percentage points in Hamlin and Valencia, respectively.
4. The linear, low frequency, shake pattern with largest displacement provided superior fruit removal performance overall.

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