The Effect of Trunk Shaker Patterns on Florida Orange Removal

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Abstract. *Trunk shakers use multidirectional shaking patterns to remove oranges from trees. Bark slippage has been a problem on some of the more susceptible orange trees using these patterns. A linear shaking pattern offered potential for reducing bark damage (slippage) but its effect on fruit removal performance was unknown. Three field experiments were conducted in mature 'Hamlin' orange trees to measure the fruit removal performance of multidirectional and linear shaking patterns. An abscission chemical was applied in two of the experiments to reduce the fruit detachment force of the oranges. The linear shaking pattern removed 1 to 6 percentage points more oranges than did the multidirectional shaking pattern with a 6– to 7–cm displacement at 7–Hz frequency and a shaking time of 5 to 10 s/tree.*

Keywords. *Citrus harvesting, Abscission chemicals, Vibration.*

Trunk shakers were initially investigated for mechanical harvesting of Florida citrus in the 1970s (Whitney, 1995), but they and other fruit removal devices were not commercially accepted during this period. In 1991, there was renewed interest in studying citrus harvesting problems and in 1993, Fruit Harvesters International (Alva, Fla.) began development of a trunk shake–catch harvest system. In 1994, the Florida Department of Citrus initiated a research and development program on mechanical harvesting systems. The program has funded the investigation of various approaches to fruit removal and harvesting of processed oranges (Brown, 1997; Peterson, 1998; Whitney, 1999). Trunk shakers have been the most prevalent means of removing fruit. One problem with trunk shakers has been bark damage (slippage) by the clamping pads, particularly on early and mid–season orange trees that are not dormant and on late–season 'Valencia' orange trees.

All trunk shakers under development utilize multidirectional shaking patterns and two parallel trunk clamp pads (Whitney, 1999). Multidirectional patterns are believed to be the most effective for removing fruit from the tree because they shake in many different directions, and are developed by two sets of rotating unbalanced masses mounted on vertical shafts rotating at different speeds. The point at which the position of the two masses coincide to develop the maximum horizontal shaking force changes each time the masses coincide, generating the multidirectional shaking motion. Thus, the shaking force (and resulting motion) is at various angles with respect to the parallel clamp pads. When the shaking motion or force is perpendicular to the pads, there is no shearing force on the bark. As the motion goes from perpendicular to parallel to the pads, the forces are in a direction, which transmit shear forces to the trunk bark. To minimize the shear forces transmitted to the bark, all trunk shaker manufacturers use a slip sling (which makes contact with the bark) lapped over the main clamp sling (which holds the pad in place). The slings are made from smooth neoprene covered conveyor belting. The contact area between the slip sling and the main clamp sling is lubricated to minimize the friction between the slings, thus reducing the shearing forces transmitted to the bark. When trunk bark is very susceptible to slipping, as can be the case with early and mid–season orange trees which are not dormant and 'Valencia' trees, these techniques which have been adopted to minimize friction and shearing, are not always sufficient to prevent bark slippage. A linear shaking pattern perpendicular to the clamp pads should reduce or eliminate shearing forces on the bark, but may compromise effectiveness of fruit removal.

The objective of this study was to compare orange removal percentages and motions of a multidirectional and a linear shaking pattern to determine if the linear shaking pattern warranted development as a means of reducing bark slippage.

Materials and Methods

Three field experiments were conducted with an Orchard Rite Model 9400 monoboom trunk shaker (Yakima, Wash.) in mature orange trees. The shaker had unbalanced masses mounted on two separate vertical shafts that were chain driven in opposite directions from a single hydraulic motor. For the multidirectional shaking pattern, one unbalanced mass drive sprocket had 42 teeth, while the other had 48 teeth. This setup developed a pattern, which repeated itself every seven rotations of the 48–tooth sprocket. For the linear shaking pattern, both unbalanced mass drive sprockets had 48 teeth, and the unbalanced masses were timed to coincide

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on a line perpendicular to the parallel clamp pads. For both patterns within each experiment, the unbalanced masses, rotational speeds, and shaking time per tree were kept the same. During shaking, acceleration levels on the shaker head (clamp pad center) and on representative trunks within each experiment were recorded in the xy–horizontal plane by a DaqBook 120 (Iotech, Cleveland, Ohio). The PCB Model 353B33 accelerometer signals (PCB Piezotronics, Inc., Depew, N.Y.) were integrated using Dadisp software (DSP, Cambridge, Mass.), which quantified the displacement and frequency of the shaking pattern. Trunk circumferences and shaker clamp heights, known to affect trunk shaker fruit removal (Whitney et al., 1988), were measured on all trees.

Experiment 1

Early season 'Hamlin' orange trees (4 to 5 m tall on a 7.6– × 3.7–m spacing) were used in this experiment. To loosen the fruit, three abscission chemical treatments were applied in 3700 L/ha on 6 January 2000 with a John Bean Titan (Durand Wayland, LaGrange, Ga.) sprayer. The spray mixture contained Release (CMN–Pyrazole, Abbott Laboratories, Chicago, Ill.) at 100 ppm and Kinetic at 0.1% v/v. The treatments (T3B1, T2B2, T1B3) corresponded to 3/4, 1/2, 1/4, respectively, of the total sprayer discharge being directed to the upper half (T) of the tree canopy and the rest to the bottom half (B). The spray treatments and an unsprayed control were assigned in randomized complete block design in four replications (3 trees/plot). To determine fruit looseness prior to harvest, fruit detachment forces (FDF) were measured on five fruit each at 1.5 m (bottom) and 3 m (top) heights in the middle tree of each plot four days post spray. Average fruit weight was determined using these 10 fruit. Pre–harvest fruit drop was determined by counting the drop on the center trees in each plot and multiplying by the average fruit weight. Five days post spray, each of the end trees in each plot was shaken for 10 s, being randomly assigned either the multidirectional or linear shaking pattern. Total unbalanced mass was 250 kg. Fruit removed by the shaker was weighed, as was the fruit left on the tree, to determine the fruit removal percentage of the shaker.

Experiment 2

This experiment was similar to Experiment 1 and was conducted in the same 'Hamlin' orange grove. The spray treatments, applied 11 February 2000, were identical to Experiment 1 except the spray volume was 2400 L/ha. The unbalanced mass in the shaker head was reduced to 205 kg. Measurements were the same as those made in Experiment 1.

Experiment 3

On 23 February 2000, this experiment was conducted in 24 mature 'Hamlin' trees 4 to 5 m tall. The trees were on two row raised beds spaced 7.6 m between row and alternately spaced 3 and 4.5 m in row. No abscission chemicals were applied. The treatments (multidirectional and linear shaking pattern) were replicated six times and were randomly assigned to two tree plots (paired trees at 3 m in row spacing) or four trees per replication. The unbalanced mass in the shaker head 205 kg and each tree was shaken for 5 s. Measurements were the same as those made in Experiments 1 and 2, except FDF were not measured.

All data were statistically analyzed using the GLM procedure in SAS (SAS, 1990). Duncan's Multiple Range Test was used to separate means at the 5% level of significance. Pearson correlation coefficients were calculated for shaker fruit removal, fruit yield, trunk circumference, and shaker clamp height.

Results and Discussion

Experiment 1

Experiment 1 results are summarized in table 1. The average FDF in the tree bottom was significantly reduced only by T1B3, whereas in the tree top, all Release treatments reduced significantly FDF. Fruit drop was minimal and was increased significantly only by T3B1. The trees were uniform in that there were no significant differences between fruit yields and trunk circumferences among the trees shaken by the multidirectional or the linear shaking, or among all trees used with both shaking patterns. Shaker clamp heights were not significantly different between treatments, shaking patterns, or any combinations of the two. Fruit removal (drop + shaker removal) percentage of both shaking patterns was not significantly affected by the spray treatments, and the shaking patterns were not significantly different from each other (overall averages for multidirectional and linear patterns were 92.8 and 93.4%, respectively). Fruit removal was positively correlated with clamp height ($r = 0.001$, $p = 0.99$), trunk circumference ($r = 0.05$, $p = 0.85$), and negatively correlated with yield ($r = -0.18$, $p = 0.50$). Shaker head displacements perpendicular to the clamp pads averaged 7 cm at 7–Hz frequency.

Table 1. Harvest results in Experiment 1.

				Multidirectional Shake				Linear Shake			
Abscission Chemical Treatment[a]	FDF Bottom (N)[b, c]	FDF Top (N)[b]	Fruit Drop (%)	Fruit Yield (kg)	Trunk Circum. (cm)	Clamp Height (cm)	Fruit Removal (%)	Fruit Yield (kg)	Trunk Circum. (cm)	Clamp Height (cm)	Fruit Removal (%)
Control	73 a	88 a	0.6 a	228 a	72 a	22 a	93.0 a	233 a	76 a	20 a	92.1 a
T1B3	54 b	66 b	1.1 ab	228 a	78 a	21 a	92.0 a	228 a	71 a	22 a	93.8 a
T2B2	64 ab	61 b	1.3 ab	233 a	73 a	24 a	91.3 a	233 a	70 a	20 a	93.0 a
T3B1	66 ab	62 b	1.4 b	237 a	72 a	24 a	94.8 a	216 a	71 a	21 a	94.6 a

[a] T1B3 – •1/4 of chemical applied to top half of canopy, 3/4 applied to bottom half of canopy; T2B2 – chemical applied uniformly along height of canopy; T3B1 – 3/4 of chemical applied to top half of canopy, 1/4 applied to bottom half of canopy.
[b] Within each column, means followed by the same letter are not statistically different at the 5% level.
[c] Top and bottom samples were located at 1.5 and 3 m heights, respectively.

Table 2. Harvest results in Experiment 2.

Abscission Chemical Treatment[a]	FDF Bottom (N)[b, c]	FDF Top (N)[b]	Fruit Drop (%)	Multidirectional Shake: Fruit Yield (kg)	Multidirectional Shake: Trunk Circum. (cm)	Multidirectional Shake: Clamp Height (cm)	Multidirectional Shake: Fruit Removal (%)	Linear Shake: Fruit Yield (kg)	Linear Shake: Trunk Circum. (cm)	Linear Shake: Clamp Height (cm)	Linear Shake: Fruit Removal (%)
Control	58 a	65 a	0.7 a	228 a	76 a	20 a	84.9 a	237 a	78 a	23 a	93.6 a
TIB3	47 a	56 a	1.6 ab	220 a	77 a	24 ab	96.7 b	208 b	70 b	25 a	96.3 b
T2B2	42 a	48 ab	1.9 bc	204 a	70 a	26 b	95.8 b	220 ab	75 ab	22 a	95.9 b
T3B1	52 a	34 b	2.9 c	233 a	74 a	18 a	93.3 b	220 ab	69 b	23 a	95.9 b

[a] T1B3 – •1/4 of chemical applied to top half of canopy, 3/4 applied to bottom half of canopy; T2B2 – chemical applied uniformly along height of canopy; T3B1 – 3/4 of chemical applied to top half of canopy, 1/4 applied to bottom half of canopy.
[b] Within each column, means followed by the same letter are not statistically different at the 5% level.
[c] Top and bottom samples were located at 1.5 and 3 m heights, respectively.

Experiment 2

The results are summarized in table 2. Average FDF for the control trees dropped to 62 N compared to 80 N in Experiment 1, and this was probably due to an increase in fruit maturity. Only T3B1 significantly reduced the FDF in the tree tops. Fruit drop was significantly increased by T2B2 and T3B1. For the trees shaken by the multidirectional pattern, fruit yields and trunk circumferences were not significantly different. Shaker clamp heights were significantly higher for T2B2. All Release treatments significantly increased fruit removal, with an overall average increase of about 10 percentage points. For the trees shaken by the linear pattern, fruit yields of T1B3 were significantly less than the control. The trunks of the control trees were significantly larger than those of T1B3 and T3B1. Shaker clamp heights were not different. All Release treatments significantly increased fruit removal, with an overall average increase of about 2.5 percentage points. In comparing the two shaking patterns, average shaker head displacements perpendicular to the clamp pads of 6 cm at 7 Hz were measured. Overall, fruit removal was significantly higher with the linear pattern (95.4 vs. 92.7%). Fruit removal was slightly higher for T1B3 than for the other Release treatments, and suggests that more chemical on the bottom fruit of the tree (even though the FDF did not confirm looser bottom fruit for that treatment) may have had more influence on increasing shaker fruit removal. In these trees, fruit on long hangers on the bottom of the tree may have been more difficult for the trunk shaker to remove than fruit in the tree tops, thus better loosening on the bottom fruit may have increased fruit removal percentage. As in Experiment 1, fruit removal was positively correlated with clamp height ($r = 0.43$, $p = 0.09$) and negatively correlated with yield ($r = -0.34$, $p = 0.20$) and trunk circumference ($r = -0.43$, $p = 0.09$).

Experiment 3

The results are summarized in table 3. Although FDF was not measured on the experimental trees, fruit FDF measurements in similar trees nearby in the same grove (in another experiment) indicated a 94 N average. None of the variables measured in this experiment were significantly different. Fruit removal was 3 percentage points higher for the linear pattern, but not statistically different at the 5% level. Shaker head displacement and frequency were 6 cm and 7 Hz, respectively. Comparing the control treatments in Experiments 2 and 3, fruit removals were generally greater in Experiment 3, even though the shake time per tree was reduced from 10 to 5 s. The higher fruit removals in Experiment 3 probably resulted because trunk circumferences were smaller and clamp heights were higher than those in Experiment 2 (see correlations in Experiment 2).

Shaking Patterns

Figures 1 and 2 show typical displacements measured for the linear and multidirectional shaking patterns in Experiment 2. Note that in both figures tree trunk displacements perpendicular to the clamp pads were similar to those of the shaker head, while the tree trunk displacements parallel to the clamp pads were less than those of the shaker head. The trunk displacements perpendicular to the clamp pads should be similar to shaker displacements unless the accelerometers are at markedly different heights above ground. Parallel to the clamp pads, the difference in trunk and shaker displacements was attributed to slippage between the trunk and clamp pads. The contact area between the lap sling and the clamp sling was lubricated, and allowed the lap sling to slip on the clamp sling, thus reducing the shaking force (or displacement) of the shaker transmitted to the trunk. It was hypothesized that the multidirectional shaking pattern removed less fruit than the linear shaking pattern because a portion of its shaking cycle was less effective in transferring shaking force and displacement to the tree trunk.

There was little apparent bark damage (slippage) with either of the shake patterns during the tests in 'Hamlin' oranges. However, later tests with the linear shake pattern on 'Valencia' orange trees (more susceptible to bark slippage than 'Hamlin' orange trees) indicated minimal bark slippage compared to previous seasons when the same trees had been shaken with the multidirectional pattern.

Table 3. Harvest results in Experiment 3.

Shaker Treatment	Fruit Yield (kg)[a]	Trunk Circum. (cm)	Shaker Clamp Height (cm)	Fruit Removal (%)
Multidirectional	224 a	62 a	31 a	91.6 a
Linear	216 a	61 a	29 a	94.9 a

[a] Within each column, means followed by the same letter are not statistically different at the 5% level.

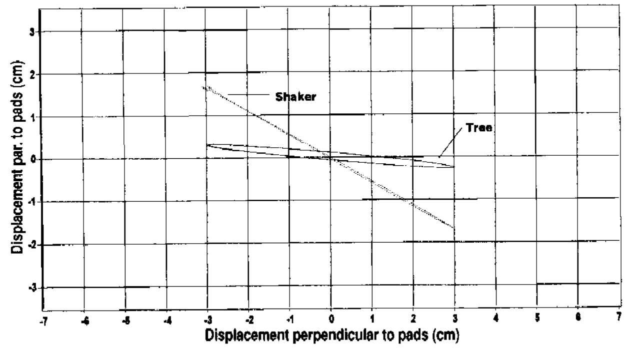

Figure 1. Displacement of shaker and tree trunk for one linear shaking cycle on representative tree in Experiment 2.

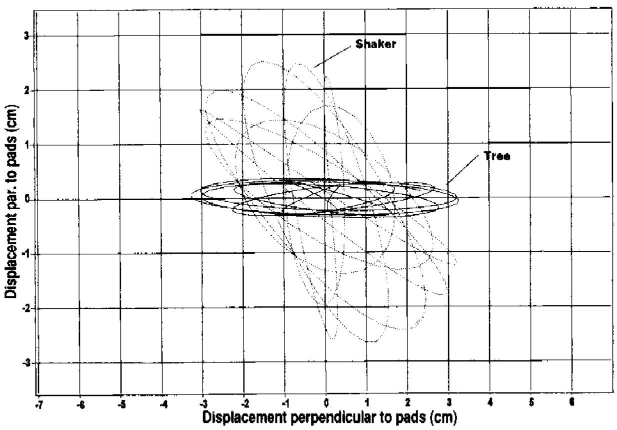

Figure 2. Displacement of shaker and tree trunk for 7 multidirectional shaking cycles on representative tree in Experiment 2.

Conclusions

1. Orange removal percentage of the linear shaking pattern was generally superior to the multidirectional shaking pattern by 1 to 6 percentage points with a 6– to 7–cm shaker head displacement, 7–Hz frequency, and a shaking time of 5 to 10 s/tree. Pursuing the linear pattern of shaking appears warranted.
2. Orange removal percentage was positively correlated with shaker clamp height and negatively correlated with fruit yield.

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