

# Performance of Mechanical Citrus Harvesters in Florida

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**Abstract.** A new initiative to develop mechanical harvesters for processed citrus began in 1993 when Fruit Harvesters International (FHI) began development of a trunk shake-catch system. In 1994, the Florida Department of Citrus (FDOC) began funding a research and development program on various types of harvesters. Fruit removal devices that have been tested include trunk shakers, various types of canopy shakers, and a canopy penetrator. One fruit pickup machine has also been tested. Harvest efficiency data, the effect of grove and tree characteristics on performance, and economic considerations are presented for various harvesting systems.

The Florida citrus industry has been concerned about the availability and cost of harvesting labor since the 1950s. Research and development efforts on labor aids and mechanical harvesting through the mid-1980s have been previously reported (Whitney, 1995). During that period, the mechanical harvesters that were developed could only compete with conventional manual harvesting methods in a very limited set of conditions. The devastating freezes that occurred in the 1980s reduced production to about one-half of the record 1979-1980 crop of 11.6 MT, and resulted in a marked increase in new citrus plantings in South Florida. High fruit prices, coupled with low production and adequate harvesting labor, minimized interest in mechanical harvesting until 1991 when the new plantings rapidly increased production and fruit prices dropped significantly. New harvesting research was initiated in 1992 by Citrus Research and Education Center (CREC) scientists in Lake Alfred. At that time, the effect of harvesting practices on fruit quality was investigated by Miller et al. (1995). They found that dropping citrus on the ground resulted in three times the decay as compared with citrus harvested directly into a picking bag.

In 1993, Fruit Harvesters International (Alva, Fla.) initiated development of a mechanical citrus harvesting system (trunk shake-catch). Using a commercial trunk shaker (Compton Enterprises, Inc., Chico, Calif.), they found orange removal with the shaker was inadequate. Hedden et al. (1988) and Whitney et al. (2000a) reported low orange removal efficiencies ( $\approx 70\%$ ) with a comparable multidirectional FMC trunk shaker (FMC Corp., Madera, Calif.). For the 1994-95 season, Fruit Harvesters International designed a new shaker that developed greater displacements at lower frequencies and orange removal was increased.

The Florida citrus industry initiated a research and development program in 1994 that was administered by the Florida Department of Citrus (FDOC). The program goal was to develop harvesting methods to ensure the harvesting of future crops at a competitive cost. Harvesting machines, built under contract with the FDOC for development, were designed for oranges destined for processing.

The objective of this paper is to summarize the performance results of mechanical citrus harvesting systems under development since 1995.

## Trunk Shakers

*Fruit Harvesters International.* In 1994, the Fruit Harvesters International harvester consisted of two self-propelled units (a shaker with deflector and a receiver) mounted on rubber tracks. Harvested oranges were stored in collapsible, canvas-like containers that were dropped off when full and picked up for emptying by a conventional fruit handling ("goat") truck. Because of difficulties with handling the containers, they were discarded in favor of a bulk bin trailer towed behind the receiver unit. When full, the trailer bin was emptied into a fruit handling truck.

*Compton Enterprises.* Under a development contract with the FDOC, Compton Enterprises, Inc., developed a shake-catch harvester.

It was similar to the Fruit Harvesters International harvester in that it also had a shaker with deflector unit and a receiver unit. Both Compton harvester units were self-propelled and were mounted on rubber tires. Compared to shakers used in the harvest of California tree crops, the citrus shaker had considerably more unbalanced mass and eccentricity to develop greater displacements at lower frequencies. Initially, oranges were stored in tubs used in conventional manual harvesting, but subsequently changed to a bin trailer similar to that of Fruit Harvesters International. Tests with the harvester during the 1995-1996 season resulted in orange removals from 84% to 94% in early and mid-season oranges, and 74% in 'Valencia' oranges (Whitney, 1999). Each tree was shaken for 5 to 14 s at a shaker displacement of  $\approx 5$  cm and frequency 7 to 10 Hz. Three percent to twelve percent of the orange missed the catch-frame. Down-the-row harvesting rates ranged from 1 t/h in yields of 30 t/ha to 9 t/h in yields of 65 t/ha.

*Coe orchard equipment.* Another shake-catch harvester was developed by Coe Orchard Equipment, Inc., Gridley, Calif. It also had two units mounted on rubber tires with a bin trailer for orange storage towed behind the receiver unit. Like the Compton shaker, the unbalanced mass and eccentricity of the Coe shaker had been increased considerably to produce greater shaker displacements at lower frequencies. Commercial tests during the 1999-2000 season (Roka, 2000) indicated the harvester recovered greater than 90% of the early and mid-season oranges in South Florida at harvest rates of  $\approx 100$  trees/h.

*Stackhouse Bros.* During the 1999-2000 season, Stackhouse Bros Harvesting, Hickman, Calif., used a few monoboom-mounted Orchard Rite trunk shakers (Orchard Rite Ltd., Inc., Yakima, Wash.) to shake oranges onto the ground from old trees 7 to 10 m tall in the "Ridge" production area of Florida. The oranges were picked up by manual harvesters. The shakers were used because manual harvesters refused to harvest the trees and/or the cost of manual harvesting was very high.

*Trunk shaker problems.* To varying degrees, all trunk shakers have had problems with bark damage in shaking 'Valencia' orange trees. Compared to early and mid-season orange trees that are usually dormant in the cooler fall and winter months, the bark on 'Valencia' (harvested during the warmer spring and early summer months) is more prone to slippage and subsequent damage. Shear forces and uni-axial pressures on the bark must be minimized to alleviate damage. Relatively short trunk heights on many existing trees and current trunk shaker clamp pad size and design can result in contact between the top and bottom of the pad and trunk. The top of the pad comes in contact with the scaffold limbs while the bottom of the pad comes in contact with the top of the roots. In 'Valencia', either of these contacts can cause bark slippage or high unit pressures that result in bark damage.

Trunk shaker manufacturers have traditionally used multidirectional shake patterns with parallel clamp pads for shaking trees. Multidirectional shaking patterns have been used because they move the tree structure in many directions and are thought to provide optimal shaking to achieve high fruit removal. When the shake pattern moves parallel to the pads, shear forces on the bark are reduced by lubricating

the surfaces between the lap pad (which laps over the main clamp pad between the trunk and the main pad) and the main pad. Sometimes with 'Valencia' trunks, however, shear forces are apparently high enough to cause bark slippage. In an effort to minimize bark damage, some shaker manufacturers have tried shaking with a linear pattern perpendicular to the parallel clamp pads. This pattern minimizes clamp pad movement parallel to the pads thereby reducing shear forces on the bark. Tests results during the 1999-2000 season indicated the linear pattern was as effective as the multidirectional pattern in removing oranges (Whitney et al., 2000b), and observations in 'Valencia' harvesting indicated bark damage was reduced with the linear pattern. Other design improvements could probably be made in the shaker head to minimize undesirable movement that causes bark damage.

**Trunk shakers and abscission chemicals.** In the past three seasons, tests have been conducted with experimental abscission chemicals to determine if they improve the orange removal performance of trunk shakers. The experimental abscission chemicals have been found to increase orange removal efficiencies of trunk shakers by 10 to 15 percentage points when the orange detachment forces were reduced 50% to 80% (Whitney et al., 2000a).

### Canopy Shakers

Canopy shakers under development have been generally classified by the way in which they proceed with harvesting. The "continuous travel canopy shake and catch" systems move continuously down the row as they shake and catch the oranges. The "canopy area shake" system stops its prime mover, positions the shaker head in an area of the canopy, and proceeds to shake that area of oranges onto the ground. After one area is shaken, the shaker is positioned in the next canopy area to be shaken. Manual harvesters work with the canopy area shake system to glean and pick up the oranges.

**Continuous travel canopy shake and catch.** USDA: This approach began with an experimental prototype developed at the USDA Fruit Laboratory, Kearneysville, W. Va. (Peterson, 1998) and funded by the FDOC. The shaker had two vertical-axis drums with nylon spokes that penetrated and shook one side of the row canopy as it moved continuously down the row at 1.2 to 2.4 km·h<sup>-1</sup>. Shaker head displacements were 11 cm at a frequency of 5 Hz. Tests during the 1996-1997 season resulted in orange removals ranging from 54% to 95% (Whitney, 1999). Orange removals were generally inversely related to canopy width in that the spokes could not adequately shake and remove oranges deep inside the wide canopies. The concept was best suited for solid, narrow hedgerows with the maximum amount of fruit in the outer canopy, and had a high harvesting capacity. Where trees were spaced far enough to develop individual canopies, the spokes did not adequately shake and remove oranges in a vertical plane near the tree row line.

**Oxbo International Corp.** This concept has been further advanced (Oxbo International Corporation, Byron, N.Y.) with development funding from the FDOC. Oxbo used two self-propelled single drum shaker and catch-frame units operating simultaneously opposite each other on both sides of the tree row. The drum was 4 m in diameter and could be adjusted in position with respect to the tree canopy. Alternate sections of the spokes oscillated in opposite directions for dynamic balance. The harvester moved down the row at 2 km·h<sup>-1</sup> and harvesting efficiencies ranged from 60% to 80% in conventional tree canopies up to 5 m wide. Low harvesting efficiencies resulted from a combination of low orange removal levels and fruit collection efficiencies.

**Korvan Industries.** The continuous travel canopy shake and catch concept has also been advanced (Korvan Industries, Inc., Lynden, Wash.) with development funding from the FDOC. They tested their first prototype during the 1999-2000 season. It was a self-propelled double drum shaker and catch-frame unit on one side of the tree row. It was operated mostly in hedgerow trees at close in row spacings and smaller size tree canopies. Limited performance data are available. For the 2000-01 season, this system will be modified to use a single drum design because the double drum configuration proved to be too large to manage effectively as a shaking device. The single drum configuration will allow for more position adjustments with respect to the tree canopy.

**Canopy area shake.** *Mongoose Harvesting Systems.* This concept was developed by Mongoose Harvesting Systems (Arcadia, Fla.) with development funding from the FDOC. The most recent version of the Mongoose had four shaker panels (with probes) mounted on the mechanical arm of a Hyundai excavator. After the probes were inserted about 1 m into the canopy, hydraulic motors moved the panels in a circular pattern to shake the canopy and remove the oranges. After shaking, the probes were withdrawn and inserted in another area of the canopy for shaking. The Mongoose can be used on various tree sizes and shapes. This versatility reduces the orange removal rate low compared with the continuous travel canopy shake methods. Orange removal efficiency was about 70% with manual harvesters gleaning the remaining fruit on the tree and picking it up from the ground.

### Canopy Pull and Catch System

**Crunkleton.** This system, patented and developed by W. Crunkleton (Avon Park, Fla.), consisted of an array of hollow metal tubes mounted on a lift mechanism. Each tube had several spring-loaded hooks. The tubes were inserted into the tree canopy and as they were withdrawn the hooks caught fruit stem and detached the fruit. With 2-m-long tubes on an experimental prototype, 67% to 81% of the oranges in the canopy volume entered by the tubes were removed by one insertion of the probes, and 91% was removed by two insertions (Whitney, 1997). It demonstrated good selectivity in harvesting 'Valencia' oranges. More recently, a larger array of tubes 2.4 m long has been constructed, but little performance data have been available.

### Fruit Pickup Machines

**Agricultural Machines, Inc.** A self-propelled fruit pickup machine was developed by Agricultural Machines, Inc. (Avon Park, Fla.) with development funding from the FDOC. It operated at 1 km·h<sup>-1</sup> and used a rod draper chain to pick up fruit from the ground and convey it to storage bin. The machine picked up fruit in place without need for windrowing except for fruit within 50 cm of either side of the trunkline, and that fruit was moved manually. Field tests during the 1996-1997 season demonstrated a down-the-row pickup capacity of 15 to 20 t/h and a pickup efficiency of 96% to 97% (Whitney, 1999). Split fruit in the storage bin on the machine averaged 3.6% to 5% and was probably due to rough handling by the conveying system. Development of the machine was discontinued because contract harvesters had little or no apparent interest in using it. Recently, however, there has been some renewed interest in development of fruit pickup machines to use with shakers of various types in grove conditions (large trees, etc.) where fruit collection efficiencies are low with catching frames.

### Grove and Tree Characteristics

Grove characteristics influence the performance of all mechanical harvesting systems. Uniform conditions usually improve their performance. Fruit collection efficiencies of all systems with catchframes would increase if all trees had taller clear trunks. The clear trunk height of many existing Florida trees is marginally 30 to 40 cm while clear trunk heights of 70 to 90 cm are desirable to achieve high fruit collection efficiencies. Taller trunk heights are highly desirable for trunk shake catch-frame harvesters for the following reasons: 1) taller trunks provide more vertical space to clamp the trunk without contacting the scaffold limbs or roots and reduce bark damage; 2) bark damage would be reduced because the cross-section of taller trunks are usually more round and less irregular in shape, and would minimize high unit pressures between the clamp pad and trunk; and 3) taller trunks allow clamping at a higher point on the trunk (more leverage) thus reducing the shaking force (unit pressure) input necessary to remove oranges. This should increase fruit removal efficiency, reduce bark damage, and increase harvest speed. Increased trunk heights would also allow the trunk shaker to effectively shake larger trees because of the increased leverage. Wheaton et al. (1995) reported good yields on orange trees that were planted and maintained with 60 cm trunk heights (Wheaton et al., 1986).

In-row tree spacings of 3 m or greater are generally preferred for the

