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Overview of Mechanical Harvesting in Florida Citrus

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***Abstract.* Florida harvests 95% of its 245,000 ha of oranges for processing. Until recently, harvesting has been a hand operation. Labor productivity averaged about 9.5 field boxes/hour (1 FB = 40 kg or 90 lb), and cost to the grower averaged about $1.65/FB to harvest the fruit (with overhead and contractor's fees) and roadside it into a highway truck for transport to the processing plant. The supply of harvest workers is now decreasing and harvesting costs are increasing. In 1994, the Florida Department of Citrus (FDOC) funded a new program to develop improved harvesting methods. At this time, eight different mechanical harvesting systems are being developed for the existing and future groves. Some systems can double labor productivity, with zero to 20% cost savings in existing groves. Others can increase labor productivity by 5 to 15 times, and reduce harvesting cost by 40% to 70% if growers own and operate them in existing and future groves. All of these harvesting systems can be used over the next 10 to 20 years as the industry transitions to nearly complete mechanical harvesting. Eventually, systems that provide high labor productivity and low harvesting cost will replace those having low labor productivity and high harvesting cost. The eight mechanical systems are explained.**

Florida produces more citrus than all other states in the United States. In 1999, the total bearing area was estimated at 315,900 ha, and 245,000 ha were oranges (Anon., 2000). Recently, oranges averaged 77% of the total production and about 95% were processed. Orange production is projected to increase unless U.S. weather, disease, labor, or economic forces act to depress production (Anon., 1993). Worldwide production and price competition in processed oranges are projected to decrease U.S. grower returns, as free-trade conditions progress.

The Florida citrus industry sponsored a Harvesting Symposium in 1993 to assess the emerging production, income, and labor supply situation for growers (Anon., 1993). A following Citrus Harvesting Think Tank resulted in a new industry Harvesting Program in 1994 to develop cost cutting and labor efficient harvesting technologies for processed oranges (Anon., 1994). The Citrus Harvesting Research Advisory Council and the Citrus Harvesting Labor Management Committee, composed of citrus industry individuals, run the Program and report to the Florida Citrus Commission. These groups defined the Program goal as reducing the cost and increasing the harvester (picker) productivity for harvesting the existing orange groves for processing. The average cost of harvesting a field box (1 FB = 41 kg or 90 lb) of oranges for processing was about $1.65 US for the 1999–2000 crop. This is the total contract cost for removing the fruit from the tree and placing it in a bulk highway truck. The average harvester (picker) productivity was about 9.5 FB (390 kg) per work-hour.

An estimated 45,000 workers are usually needed at the peak of the harvesting season (Anon. 1993). The workers have been largely single young Mexican males who migrate each year. Surveys reveal that over 50% of these individuals are undocumented workers (illegally employed). The 1996 Illegal Immigration Reform and Immigrant Responsibility Act (U.S. Public Law 104) increased the enforcement efforts to prevent employment of illegal workers and the penalties on employers. There will be a continual decrease in this traditional labor supply, and cost will increase.

In the long run, labor productivity will need to increase to more than 45 FB/h and mechanical harvesting cost will need to decrease to ≈ 50% of the hand harvest cost. In the short run, the existing juice orange groves must continue to be harvested. The tree age and size, trunk height and skirt height, between-row and in-row spacings, grove floor and bed/swale, irrigation and drainage, and clear headland conditions vary greatly over the existing groves, which were planted for hand-harvesting.

Materials and Methods

The Harvesting Program has provided development loans and evaluation services to inventors and small manufacturers for potentially beneficial harvesting approaches. A procedure for estimating the depreciated harvesting cost and the resulting harvester productivity ha been developed. If harvesting cost is reduced by more than 15% an harvester productivity is at least doubled, development may be funde Using this criteria, the Program is not funding any development wor on picker-positioner or picking-platform types of machines, or o harvesting robots.

Hand harvesting. The conventional hand harvesting method consists of using a cypress-wood ladder in trees up to 6 m tall, han "snapping" each fruit from the stem into a 41-kg picking sack that i supported at high-waist level by a shoulder strap, then emptying ful sacks into 410-kg capacity conical plastic tubs set on the groun between trees. The road siding operation is performed using a specialized grove truck. The truck has a hydraulic arm to place, retrieve an empty tubs, and a hydraulic lift to raise and dump up to 3690 kg of frui into the bulk highway trucks. Harvesting crews generally consist of 2 hand harvesters, and 1 grove truck with operator. The truck operato may also be the crew leader or supervisor. This crew may typicall harvest about 3 highway trailers of fruit in 8 h of work (1500 FB). If th fruit is destined for a pasteurized juice processor, harvesters are ofte allowed to drop all fruit to the ground, then place it in their sack. Thi increases harvester productivity by 10% to 20% in tall trees with hig skirts. Most harvesting crews are supplied to growers by harvestin contractors.

Grove conditions. The grove conditions in Florida are diverse. A estimated 12,000 growers own groves that have a wide range of tre varieties, ages, sizes, spacings (in the row and between rows), an shapes. Groves range from a few trees to about 12,000 trees in production block, and from a few to 4000 ha at one location. The grov floor (ground) conditions may be level loose sand, level firm sand loam, firm bedded sandy or rocky loam (a drainage swale of 0.3 to 0. m deep every 1, 2, 4, or 8 rows). Various swale cross-sections are used Some swales make the use of ladders, fruit pickup machines, and shake and-catch harvesters very difficult. Trees are planted in a rectangula pattern using spacings from 3 to 10 m in the row and 6 to 11 m betwee rows. Close spacings are considered hedgerows, but trees spaced 4 × m and wider will remain individual trees rather than fruiting walls fo the first 8 to 10 years of production. Tree trunks are 0.3 to 0.5 m tall, an tree skirts touch the ground. A 2.4-m-wide equipment alley is maintained between rows by mechanical hedging. Tree height is typicall maintained at 4.5, 5.4, or 6 m by mechanical topping. The wide variet of existing groves suggests that several different types of mechanica harvesters will be needed. Unfortunately, growers did not plan for th use of mechanical harvesting systems in the groves that were established after the 1980s series of killing freezes.

Fruit abscission. The fruit detachment force for oranges typicall ranges from 45 to 90 N during the harvesting season. Hand harvestin

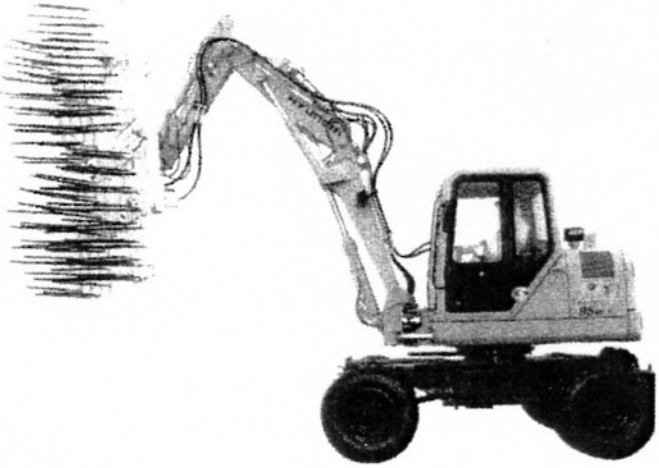

Fig. 1. Mongoose area canopy shaker.

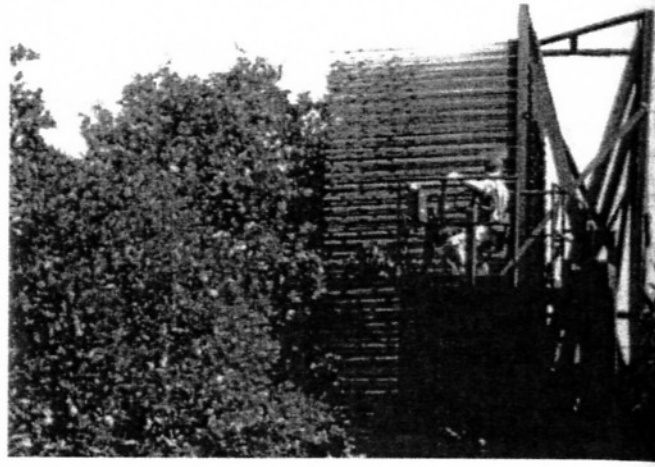

Fig. 2. Crunkelton pull-and-catch harvester.

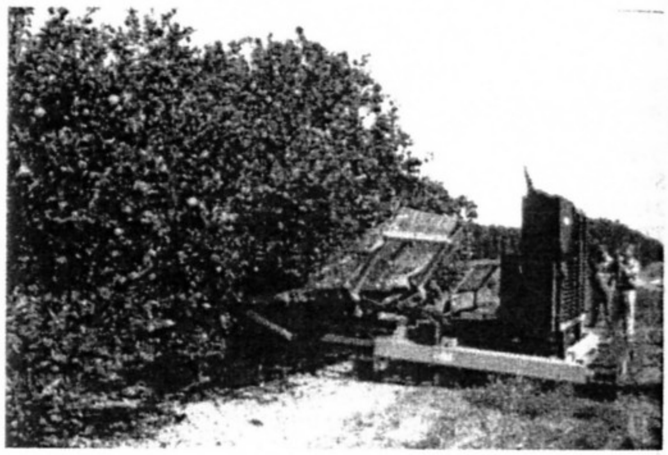

Fig. 3. FHI trunk shake-and-catch harvester.

Fig. 4. Compton trunk shake-and-catch harvester.

and mechanical harvesting would be easier and faster if this force was reduced to 22 N or less. Also, 'Valencia' oranges have bloom and developing fruit for the next crop present during much of their harvesting season in Florida. Reduction of the mature fruit detachment force, without also affecting the bloom, developing fruit, or leaves, would enable a more selective mechanical harvest for this crop. The Harvesting Program is funding research and development projects on fruit abscission compounds. Reports are available which overview the progress of these projects (Burns, 2000; Kender, 2000).

Mechanical harvesting systems. To date, eight different approaches have been selected for potential commercial use. They are: 1) canopy area shake to the ground; 2) canopy pull and catch; 3) trunk shake to the ground; 4) trunk shake and catch; 5) continuous canopy shake to the ground; 6) continuous canopy shake and catch; 7) continuous air shake to the ground; 8) mechanical fruit pickup. Each of these systems and their development through July 2000 will be briefly described. For photos, design details, and performance details refer to other reports (Anon. 1999; Brown, 2000; Neff, 2000; Peterson, 1997).

Results and Discussion

Canopy area shake-to-the ground. This harvesting system uses four groups of 26 plastic rods that are pushed into the tree canopy and shaken with enough circular stroke that most fruit are removed in 10 s. Each group of rods harvest an area about 0.6 m wide × 1.5 m high. They are positioned around the tree by a multi-jointed hydraulic arm that can provide x, y, z, and angular motions as determined by the operator. Harvested fruit are picked up by hand under the tree, and fruit still on the tree are gleaned, then placed in a grove truck.

The canopy area shaker (Fig. 1) was developed by Mongoose, Inc. (Daniels, 1999; Gaskins, 2000a, 2000b). A joint venture with Hyundai Heavy Industries, Inc., M.D. Moody & Sons, Inc., and Mongoose Inc. was announced in July 2000 to supply and support this harvesting approach.

The Mongoose system may double worker productivity and reduce harvesting cost at roadside by 10% to 30% in older groves. The system will work in a wide range of grove conditions, especially old groves. Each machine may harvest 115,000 FB during a 1500-h season.

Canopy pull and catch. This system consists of a left- and right-hand pair of self-propelled automated harvesters (Fig. 2) that travel 1.5 m, stop to harvest, then repeat the cycle. Harvesting is done using a large grid (3 m wide × 4.2 m tall) of 900 rectangular hollow tubes which are pushed horizontally up to 2.4 m into the tree canopy (Crunkelton, 1992, 1999). When they are withdrawn, small spring-loaded fingers extending from the sides of the tubes pull individual fruits from their stem. This harvest approach is probably best suited for hedgerow-style groves, although it will work when the trees are set farther apart in the row and growing as individual trees of various sizes and ages. The grove floor can be flat or bedded. Clear height at the trunk is not required. Harvested fruit is collected on a low-profile catching surface under the tree and conveyed into standard tubs or a grove truck.

With the completion of two penetrations and a move forward every 30 s, fruit removal should average 90%+, and a harvest rate of at least 65 trees/h could be achieved by the pair of machines when trees are 3.75 m apart in the row. Worker productivity could increase by 4 times and cost of harvest could decrease by 50%. At this rate, the pair of machines may harvest at least 170 FB/h, or 2.5 highway trailers of fruit in a 8-h workday. During a 1000-h harvest season the capacity may reach 200 ha.

Trunk shake-and-catch. Fast removal of 90% to 95% of the crop can be achieved in groves having trunk diameters averaging up to 200 mm. The trees should be spaced 3.75 m or more apart in the rows, so they remain separated until quite mature, allowing a large-stroke trunk shaker to effectively vibrate the canopy (Figs. 3–5). Groves planted