

## MECHANICAL SYSTEMS TO HARVEST CITRUS FRUIT FOR JUICE PROCESSING PLANTS IN FLORIDA<sup>1</sup>

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**Abstract.** Several mechanical harvesting systems have been developed for harvesting Florida citrus fruit destined for juice processing plants. Approximately 17.4 million kilograms of oranges for processing were mechanically harvested during the 1974-75 season. All systems use limb or tree shaking methods of fruit removal and the fruit is gathered by catching frames, mechanical windrow and pickup equipment, or by hand pickup crews and then loaded into grove trucks. Fruit loosening with abscission chemicals generally increases the efficiency of all harvesting systems, but especially those used in 'Valencia' oranges. However, the use of abscission chemicals requires careful timing with weather, labor and machinery, and at best, results are variable within and between groves. Commercially available machinery for mechanical harvesting has been generally limited in selection and not totally acceptable to the citrus industry. Harvest results are varied with these systems as are harvest capacity and initial cost. Total fruit recovery has been 85 to 95% under good conditions and fruit should be processed within 48 hours to prevent excessive losses from decay. Costs per box of fruit harvested have generally been higher than hand

**picking costs due to an adequate, if not over-supply of labor the past few years which has stabilized hand picking costs and reduced the immediate need for mechanization.**

Research and development of methods and equipment for mechanization of citrus harvesting has been covered in depth by previous speakers on this program (12, 14). Coppock (5) has pointed out the wide range of citrus grove conditions that a single commercial harvesting organization might encounter in Florida. Drake (8), suggested that future harvesting programs should simultaneously coordinate grove development, apparatus and methods development, and industry development. In other words, changes must occur in both the production of citrus fruit and in the receiving and processing of the fruit as well as in harvest mechanization in order for the entire process of producing a saleable product to be efficient and economical to all concerned.

Much of the current research program in Florida is directed toward putting together complete harvest systems and evaluating the various systems in terms of fruit recovered, labor required, capital investment, effects on subsequent fruit yields, and system economics.

The purpose of this paper is to discuss the combinations of equipment currently being used to make up a mechanical harvesting system and present some of the performance data to illustrate what results can be expected.

### Mechanical Harvest Systems

For reporting purposes, harvest systems are usually characterized by the methods used for fruit removal and gathering. Several systems have been used commercially in Florida, with slight variations, which account for about 16, 320 tonnes (400,000 boxes<sup>2</sup>) of citrus mechanically harvested each year for the past four seasons. This amounts to less than one percent of the total citrus crop in Florida.

#### *Handpick and Mechanical Pickup*

This is a semi-mechanical system in which handpickers remove the fruit and drop it on the ground. Using this

<sup>1</sup>Cooperative research by the U.S. Department of Agriculture, University of Florida, and the Florida Department of Citrus, Agricultural Research and Education Center, Lake Alfred, FL 33850.

<sup>2</sup>The Florida field box is defined under Sec. 601.15(3)(b) and (c) of the Florida Citrus Code as the equivalent of 90 pounds (40.8 kg) of oranges or 85 pounds (38.6 kg) of grapefruit.

method, pickers can spend 80% of their time picking or shaking fruit compared to 50% by the conventional method using a picking bag (9). The picking crew must receive an hourly wage or else "pool" their output and each picker receive the average piece rate for the entire crew. This requires skillful management to maintain the picking crew.

An abscission material may be applied to reduce the fruit bonding force but regardless of the degree of loosening attained, 100% of the fruit is removed and dropped to the ground. Handpickers can achieve an additional increase in picking rate of approximately 25% due to the fruit loosening effect of the abscission chemical (1). The less skilled pickers achieve a greater increase in picking rate than the more experienced pickers.

No field containers or special handling equipment are needed for this system which accounts for some of the pickers' increased efficiency.

No special tree pruning is required for this system except that the tree skirts must be high enough to allow the windrow equipment to pass. Weeds must be mowed or disked for the handpickers and the ground surface should be as smooth as possible for the windrow and pickup machine operations.

Considerably less leaves and sticks are removed from the tree with this system than any other; therefore, less trash must be handled by the windrow and pickup equipment.

#### *Air Shaker and Mechanical Pickup*

The air shaker harvest system (Fig. 1) has both the highest field capacity (Table 1) and the highest initial investment of any system in use. This system has harvested as many as 6,000 boxes of oranges in a day using 1 air shaker,

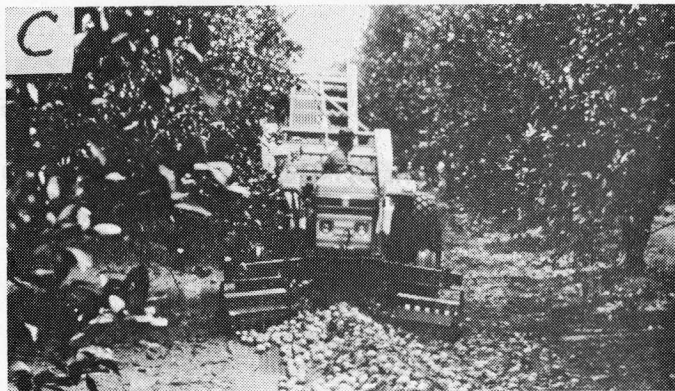
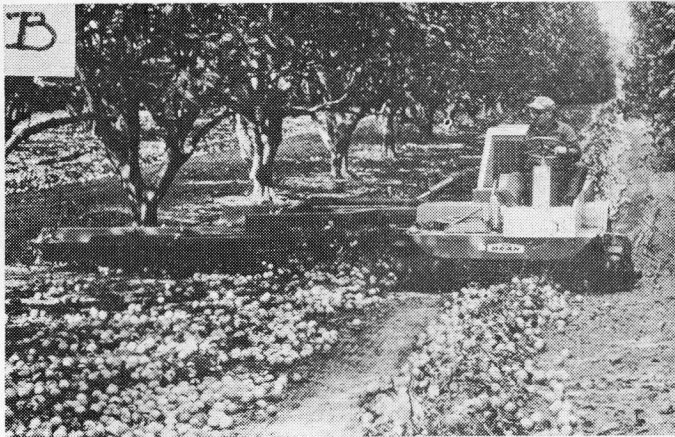


Fig. 1. Mechanical harvest system using an (A) air shaker, (B) windrow rake, and (C) pickup machine direct loading into a high lift truck.

2 windrow machines, 2 pickup machines, and 6 high-lift trucks in a grove spaced 4.5 x 9 m (15 x 30 ft) of high yielding trees with rows 0.4 km (1/5 mi) long. Such an operation requires a high degree of management skill and coordination. Normally an air shaker harvest system with a single set of machinery will harvest approximately 2,000 boxes per day with a 6-man crew.

No special pruning is necessary for the air shaker beyond the conventional hedging program used in most mature groves. Maximum tree height is 6 to 7 m (20 to 23 ft). Tree skirts must be raised to accommodate the windrowing equipment. One advantage of the air shaker in most situations is that the fruit is blown to the opposite row middle and the ground area under the tree contains less fruit and is more easily windrowed.

#### *Limb Shaker and Mechanical Pickup*

The limb shaker harvest system also has considerable latitude in how extensive the harvest operation can be (Fig. 2A). In this case, more than one limb shaker is required to match the full capacity of the windrow and pickup equipment. Usually, however, only one limb shaker is used and the remainder of the crew may be used to apply an abscission material for subsequent days harvest and glean fruit left in the tree by the shaker while the machine shakes fruit to the ground.

When trees are pruned to 3 or 4 main limbs easily visible to the operator and the abscission chemical loosens the fruit to between 4.5 to 18 N (1 to 4 lb) of detachment force the limb shaker can shake up to 70 trees per hour. An average harvest rate is 15 to 20 trees per hour. Most limb shakers are not limited by tree height, however, fruit damage increases proportional to tree height. If the ground surface is disked just prior to harvest, tall "seedling" trees

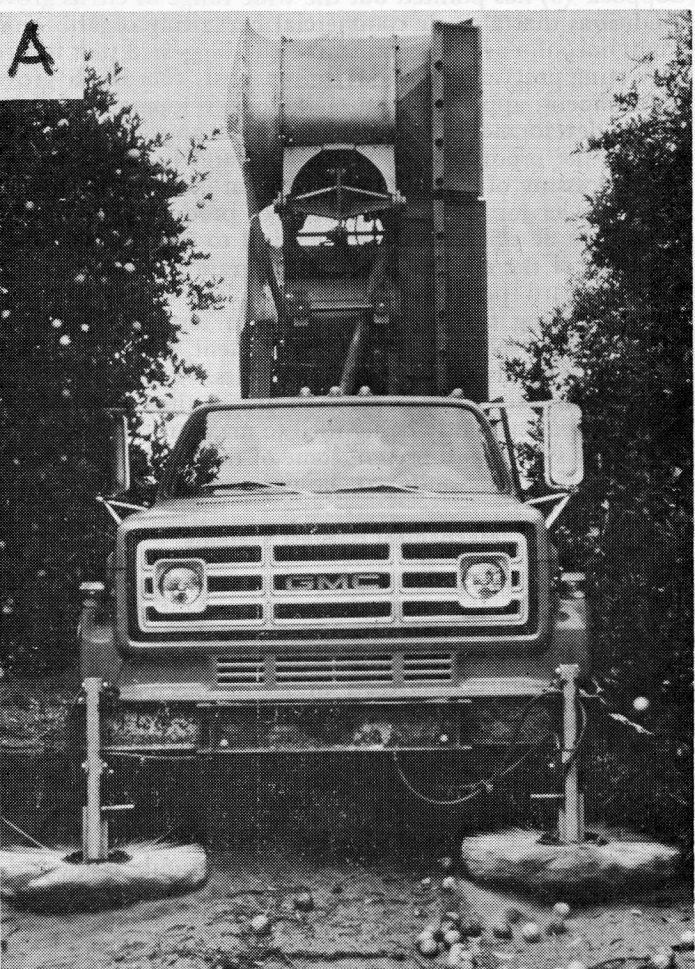


Table 1. Summary of Harvest Costs—Experimental Grove.<sup>z</sup>

Harvest method	Mach. invest.	Cost per box of fruit harvested (\$)						
		Absc.	Abandon	Removal	Rake	Pickup	Roadside	Total
Air shake mech pickup	\$154,500 <sup>y</sup> to 178,000	0.50	0.16	0.16	0.04	0.11	0.02	1.00 <sup>x</sup>
Limb shake mech pickup	141,500 <sup>y</sup> to 165,000	0.43	0.15	0.16	0.04	0.12	0.02	0.92 <sup>x</sup>
Limb shake catchframe	88,500	—	0.14	0.83	—	—	0.06	1.03 <sup>x</sup>
Limb shake catchframe	107,000	0.38	0.10	0.99	—	—	0.06	1.53 <sup>x</sup>
Handpick bag/ladder	17,000	—	—	0.55	—	—	0.30	0.85

<sup>z</sup>'Valencia' oranges, 1976 season, average yield 6.8 box/tree.

<sup>y</sup>Highest machine investment figure was used in cost analysis. See Roetheli (11).

<sup>x</sup>Cost does not reflect any reduction in yield which may be experienced in following year.

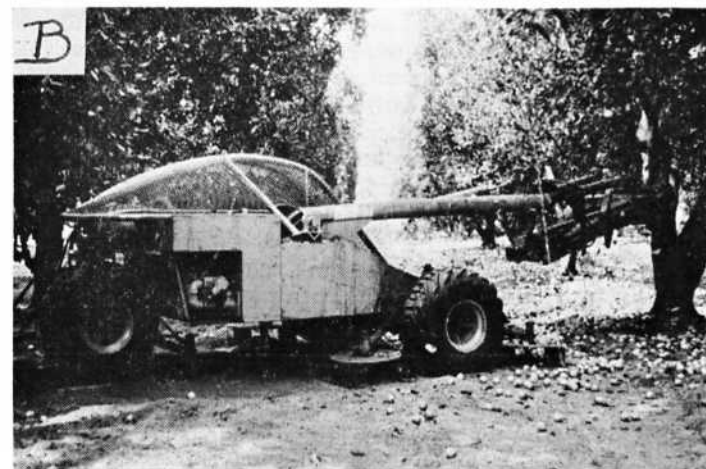


Fig. 2. (A) A self-propelled limbshaker, (B) or trunkshaker are used with rake and pickup equipment.

can be shaken with an acceptable level of fruit damage. The deep sand of the ridge section of central Florida, which does not exist in other citrus producing areas, provides an excellent cushion for falling fruit. The windrow and pickup procedures used in the limb shaker system are the same as those described for the previous two systems.

#### *Limb Shaker and Catchframe*

The limb shaker-catchframe harvest system (Fig. 3) has been under continuous development longer than any other mechanical harvesting system for citrus. A greater variety of equipment is also available to the citrus grower than with other harvest systems (12).

All of the limb shakers in use on catching frames are of the slider-crank type but vary in degree of automation as far as positioning and operation. Two limb shakers positioned on opposite sides of the tree are used simultaneously (Fig. 3). Operator visibility in positioning and attaching the shaker clamp is a key factor in harvest efficiency and prevention of bark damage.

Ground preparation is not necessary with this system but tree shaping and pruning greatly improves the effi-

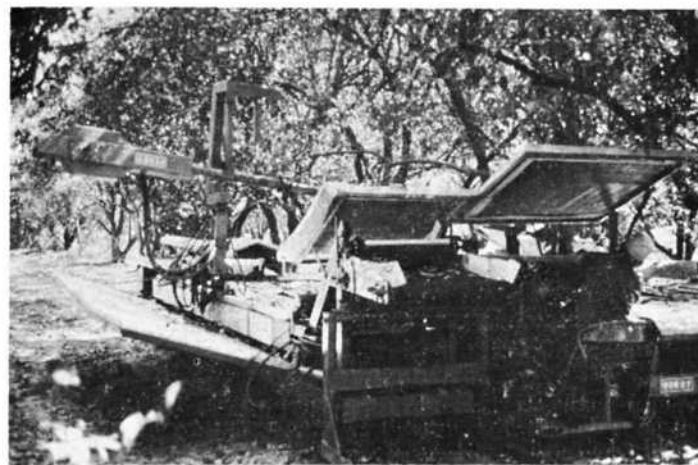


Fig. 3. Limbshaker-catchframe harvest system in use in Florida.

ciency of the system (10). Tree skirts must be high enough to allow the catching surface to project under the tree and close around the tree trunk. Tree height should be low enough (6 to 7.5 m) that fruit will fall onto the catching surface as it is removed. Deadwood pruning is also helpful in reducing "down" time spent removing limbs from the catching surface and reducing fruit damage.

The fruit handling components currently used with catch frame harvest systems are the pallet bin with tractor fork lift, and the plastic or wire tub and loader boom. Manipulating a forklift tractor with pallet bins to service two catchframes requires considerable open space in and around the trees. The forklift can carry the bins directly to the highway truck if the loading area is close, otherwise, an intermediate high-lift grove truck is necessary.

Tub or basket fruit containers are unloaded with a loader boom mounted on the high-lift truck and the empty tubs or baskets must be rolled or tumbled to the catchframes by hand. Container handling has been a continuing problem affecting the field efficiency of the catchframe system. One company using a catchframe has a supply of steel baskets stacked on the frame which drop into place as needed. Current research is aimed at improving the catchframe system to a point at which it can be used to harvest fruit for the fresh market.

#### *Trunkshaker and Mechanical Pickup*

Several trunkshaker harvest systems in Florida use abscission chemicals and mechanical windrow and pickup equipment or hand pickup crews. The commercial self-propelled trunkshaker is well developed and reliable (Fig. 2B). It must grasp the tree at least one meter above the ground to be most effective, and where trees lack a well defined trunk the shaker performs essentially as a limbshaker. The succulent bark of 'Valencia' orange trees from April to June causes a bark splitting problem when the trunk shaker is used.

#### *Other Systems in Use*

The watergun method of removal has been used by one grower for 4 seasons in combination with abscission chemicals and rake-pickup equipment.

Another firm is custom harvesting with a foliage shaker mounted on a catching frame. This system is being developed for young, brushy-type trees on bedded groves in South-central Florida.

### **General Discussion**

Growers who have mechanically harvested the same grove for 3 to 5 successive years find that once the grove has been prepared for the system they selected, pruning and ground preparation becomes minimal. Windrowing equipment cannot recover fruit from holes or swales on the ground surface nor can they perform satisfactorily in heavy weeds, vines or sod. Exposed tree roots resulting from years of improper disking techniques also impair recovery of citrus fruit from under the tree area. Gradual movement of soil from under the tree due to windrowing may cause a problem in successive years which will require moving that soil back into the tree row eventually. Old fruit drops, trash, and accumulated debris in the grove must be removed prior to harvest to insure fruit quality and extend machine life. Groves that do not produce moderate to high fruit yields are not economical to harvest mechanically.

The management and application of abscission materials as part of the harvest system has been one of the main stumbling blocks in grower acceptance of the various systems proposed. Only one compound, cyclohexamide, has been

cleared by the various regulatory agencies for use on oranges and several others have "experimental labels" for test purposes. Cyclohexamide does not work as effectively on the 'Valencia' orange variety which makes up approximately one half the Florida orange crop. The young green fruit representing next year's crop are on the tree at harvest time and are damaged or removed by the abscission chemical.

The activity of abscission materials developed thus far has been very weather dependent. If applied during a warm weather period (in excess of 16°C) they may produce fruit loosening in 3 to 4 days. However, if the temp falls below 16°C during any given day, an additional day is usually required for adequate fruit loosening. Delays caused by weather changes can be very expensive when equipment and labor are standing by waiting to harvest fruit. If the temp remains higher than expected for several days, fruit whose loosening was delayed may become loose at the same time as that which was sprayed for harvesting at a later date. This situation can cause fruit losses from excessive decay and the harvesting equipment cannot recover all the fruit that is suddenly available. A 5-day agricultural forecast by the U.S. Weather Service in Florida has been provided for the past year to help improve the management of abscission chemical applications.

All mechanical harvesting systems presently in commercial use in Florida use tree shaking methods of fruit removal with the exception of one which relies on hand pickers to separate the orange from the limb and let it fall to the ground. All catchframe systems in use on citrus employ limb shakers or foliage shakers as fruit removal devices. The trunk shaker, air shaker, and water gun are also available commercially. All of the latter methods rely on abscission chemicals to insure adequate fruit loosening for economical fruit recovery rates. The shaking methods and equipment previously described vary in field capacity, initial cost, and labor requirements but all can attain a fruit removal efficiency of 90 to 95% under specific conditions for which they are meant to be used. Operator skill is a key element in the operation of limb, trunk and foliage shakers. Field capacity of shaking equipment is expressed in trees per hour or hectares per hour because its operation is largely independent of the amount of fruit on the tree.

Gathering large volumes of oranges after they have been removed from the tree accounts for a large portion of the Florida mechanization research effort. Unlike shaking removal methods, fruit gathering efficiency is affected by fruit density. A catching frame must be capable of catching and handling 240 to 800 kg of fruit per tree without sagging or clogging. The sticks and leaves that accompany the fruit must be removed as the fruit is placed in tubs or baskets. Adequate field containers must be spotted near the catchframes or else the container handling equipment must be ever-ready to remove full containers and place empties on the catchframe. Container handling frequently becomes the limiting factor in the field capacity of a catchframe-shaker system.

Where abscission chemicals are used, some fruit drops before optimum loosening is obtained. Twenty-five to 30% of the fruit may fall before fruit removal equipment is brought into use. Catchframe equipment would not be satisfactory under these conditions and, therefore, ground pickup methods must be used. Several growers have used hand pickup crews very effectively in conjunction with limbshaker or trunkshaker removal methods. Persons lacking the physical stamina for fruit picking can perform this task satisfactorily. This method of gathering can also be used where sod, furrows, or rough terrain make mechanical rake and pickup methods impractical.

Mechanical rake and pickup equipment is capable of loading large tonnages of fruit in a single day. Methods of operation depend on fruit density, grove preparation, and equipment capacity. Where fruit density is light (4 to 6 boxes/tree), both sides of the drive row may be windrowed to the middle and picked up. However, at higher fruit density each side of the row should be windrowed and picked up separately. This means that on the second pass down the row middle, the pickup machine must handle all the trash discharged on the first pass. Frequently this causes severe problems in clogging the pickup machinery or the windrower cannot maintain a windrow on top of the trash layer left by the pickup machine. Pickup machine field capacity is inherently lower when fruit density is low.

Operator skill is very important to the success of the windrowing operation regardless of the system used. Dust can severely limit the operator's ability to see the tree trunk or fruit on the ground, therefore, it is advisable to apply a light irrigation to a grove before starting harvest operation during dry periods of the season. Speeds up to 3.2 km/h can be attained with windrow equipment under good grove conditions and fruit yields of less than 10 boxes per tree. Average rake speed is 1.6 km/h under most conditions. Pickup machinery operates at an average speed of 2 km/h in conditions of 6 to 10 boxes of fruit per tree.

Most fruit damage occurs as the tree is shaken and fruit falls through the tree to the ground or catching frame. Three to 4% damage may occur in the form of splits and punctures in early and midseason varieties and even less damage occurs with 'Valencia' oranges. Another 2 to 3% of the fruit may be damaged during the windrow-pickup operations depending on grove condition, operator skill, and fruit density.

Special grove trucks equipped with high-flotation tires and high-lift type bodies capable of transporting 2500-4000 kg of fruit are used to move fruit from a catchframe or pickup machine out of the citrus grove to a highway truck trailer. Where catchframe systems are used, a loader boom is also mounted on the grove truck to lift and empty the tubs or baskets of fruit into the high-lift body. These field containers are then reused on the catching frame.

Two grove trucks are usually required to service a pickup machine. Only one truck is necessary, however, if the pickup machine has a surge bin or storage hopper to collect fruit while the truck is unloading at roadside.

The costs of harvest systems vary with the system used, fruit density and grove conditions. Cost of any system ranges from \$0.80 to \$1.10 per box. Detailed cost and operation studies have been made over the past 10 years on systems as they were developed (6, 7, 11, 13). Additional cost data has been collected directly from growers using the systems described here as they have participated in a grower incentive harvesting plan over the past three years (2). It is difficult to compare any 2 systems directly because each is used by different people under different grove conditions. Table 1 shows the comparative costs of harvesting for one year in a single 'Valencia' orange grove using 5 harvest

systems. The analysis of data used a computer program by Roetheli (11) and, therefore, was the same assumption of machine costs and machine life as have been used in computing system costs under the grower incentive program sponsored by the Florida Department of Citrus. All mechanical harvest systems were more costly than the conventional handpicking method in this particular 'Valencia' grove.

Cost of abscission materials account for a large share of the total cost of mechanical harvesting and the cost for each system varied with the amount of material applied. Removal costs are higher with the catchframe system because 2 limb-shakers are used and the field capacity of the system is less than other systems. Abandonment costs result from fruit left on the tree or lost on the ground and not recovered.

One grove harvester using the handpick and rake-pickup system (same analysis program) had an average cost of \$1.31 per box harvesting 'Valencia' oranges at 5 grove locations (Table 2). Abscission application and material cost 25¢ per box which was considerably less than the costs shown in the experimental grove (Table 1).

This same commercial harvesting organization harvested early and midseason oranges at an average cost of \$0.98 per box for six grove locations. The cost of abscission application and material was only \$0.08 per box. This is substantially less than the costs experienced harvesting 'Valencia' oranges. Part of the reason is that the 'Valencia' orange groves averaged 5 boxes of fruit per tree and the early and midseason oranges yielded 7.5 boxes of fruit per tree. This further emphasizes the importance of choosing high yielding groves for mechanical harvesting.

Still another fruit company has used the trunk shaker and mechanical pickup system for several seasons in both early and midseason varieties and 'Valencia' oranges (Table 3). Their harvest cost was \$0.74 per box compared to \$1.28 per box for 'Valencia' oranges. The abscission costs were 3.5 times more per box of 'Valencia' oranges than for early season fruit. It should also be noted that average yields were 1.6 times greater in the early season varieties. 'Valencia' oranges may not be as economical to mechanically harvest as the earlier maturing varieties if fruit yields are lower, but if capital and machinery are to be substituted for hand picking labor at the beginning of the harvest season, then the labor will not be available when 'Valencia' oranges mature. The machinery overhead used in the analyses are based on using the equipment throughout the season.

Most processing plants are not equipped to handle any large, continuous volume of fruit that may have larger quantities of trash and unsound fruit than normally encountered with handpicked fruit. Work has been done on several methods of trash and cull fruit separation, both in the field and at the processing plant (3, 4). With adequate preharvest grove preparation and conscientious labor to operate harvest equipment, a good quality orange can be delivered to the juice processing plant but abscission chemicals and mechanical handling do weaken the fruit peel and

Table 2. Harvest costs for handpick and mechanical pickup system (\$/box) 1974-75 season.<sup>a</sup>

Variety	Yield bx/T	Absc.	Removal	Rake	Pickup	Roadside	Overhead	Suprv.	Total
E & M <sup>b</sup>	7.4	0.08	0.38	0.13	0.15	0.09	0.13	0.02	0.98
Val <sup>c</sup>	4.9	0.25	0.46	0.14	0.16	0.10	0.17	0.02	1.30

<sup>a</sup>Machinery investment for this system ranged from \$87,000 to \$95,500 (11).

<sup>b</sup>Average for 6 groves of 'Hamlin,' 'Pineapple,' or 'Parson Brown' oranges.

<sup>c</sup>Average of 5 'Valencia' groves.

Table 3. Harvest costs for trunkshaker and mechanical pickup system (\$/box) 1974-75 season.<sup>a</sup>

Variety	Yield box/T	Absc. <sup>w</sup>	Removal	Rake	Pickup	Roadside	Overhead	Labor	Total
E & M <sup>y</sup>	7.3	0.15	0.08	0.03	0.05	0.03	0.10	0.30	0.74
Val <sup>x</sup>	4.6	0.53	0.12	0.05	0.06	0.03	0.17	0.32	1.28

<sup>a</sup>Machinery investment for this system ranged from \$121,000 to \$153,000.

<sup>y</sup>Average for 3 groves of 'Hamlin' or 'Pineapple' oranges.

<sup>x</sup>Average for 2 'Valencia' groves.

<sup>w</sup>Labor to perform this operation is included in this figure.

processing should take place within 48 hours to prevent unnecessary fruit losses.

Mechanical harvesting operations are presently not delivering enough fruit to really see what problems, if any, will be encountered at the processing plant but certainly some changes will be required, if and when, mechanization takes place.

Rising costs of machinery and energy sources have become a serious consideration in the degree of mechanization that can be adopted. Anticipated shortages of picking labor have not materialized for reasons outside the control of the citrus industry and the need for full harvest mechanization has not been as critical as 10 years ago. The balance between labor availability and cost vs. materials, energy and capital is ever changing and will affect future research on harvest mechanization.

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