Reprinted from *Proc. Int. Soc. Citriculture.* 87-91. 1978.

# HARVESTING AND MARKETING

CHAIRPERSON: JAMES H. DUNCAN

## MECHANICAL HARVESTING AND HANDLING OF CITRUS FRUITS[1]

G. E. COPPOCK
*Florida Department of Citrus,*
*Agricultural Research and Education Center,*
*P. O. Box 1088, Lake Alfred, FL 33850, USA*

*Additional index words.* Machines.

*Abstract.* **Continual labor and economic problems have stimulated the development of mechanical harvesting and handling technology for citrus. Mechanical handling methods are widely used, but mechanical harvesting methods have gained only minimal acceptance.**

**Mechanical aids to assist hand harvesting improve conditions for the workers but in most cases the worker's productivity increase is not enough to justify the extra investment in equipment. Mechanical harvesting is better suited for processed fruit because the fruit is usually damaged too much for fresh-market use.**

**Contact (stripper and spindle type) machines and mass removal (shaker type) machines have been tried for mechanical harvesting: however, the recent development of abscission chemicals to lower the fruit removal force makes mass removal machines more attractive. Performance of these machines in Florida has been marginal except under some specific grove conditions. Their performance has been best in early and midseason oranges** (C. sinensis **L. Osbeck) and grapefruit** (C. paradisi **Macf). These cultivars mature and are harvested before spring growth and a new crop is set. Attempts to harvest late season Valencia oranges have been only partially successful because of the presence of bloom or small immature fruit along with the mature fruit.**

**Mechanically harvested citrus for processing is gathered from the ground with a mechanical rake-pickup system or collected on catchframes. Allowable storage time before utilization is influenced by the extent of fruit damage, fruit maturity, weather conditions and level of fungus infestation at harvest. Usually fruit collected on catchframes has a longer storage time.**

**Trends in the world citrus industry toward increased processed products, a better life for the workers, and increased control of tree growth indicate that a climate more favorable to harvesting and handling mechanization is on the horizon.**

Citrus harvesting and handling may follow trends established by several other fruits and by the staple food, fiber, and feed crops which already have been mechanized. A concerted effort over two decades to develop mechanical harvesting for citrus has failed to produce an entirely successful method. The fruit is still largely individually selected and hand-picked.

Harvesting and handling are the operations of removing fruit from trees and delivering it to the point where it is packaged or processed into products. A large number of unskilled, seasonal workers are employed in removing fruit from trees. Competition for these workers from other local industries which offer more desirable working conditions has created a potential labor deficit for many growing areas in the industrialized nations of the world. This competition plus minimum wage and other labor legislation has increased harvesting and handling costs until they are approaching the cost of production. Mechanization is expected to give partial relief, especially for those cultivars harvested for processing where some fruit damage can be tolerated.

The factors influencing mechanization are extremely complex and have ramifications extending into all facets of citrus production and utilization. One prime factor standing clearly in the forefront is that the tree must be preserved for future production. This imposes a restriction on mechanization which has not had to be faced in the mechanization of field crops. The Valencia orange cultivar imposes the additional restriction of having to remove mature fruit with minimal injury to the immature fruit that is on the tree. Also, fruit for the fresh market must be handled with considerable care to prevent spoilage at the market place but fruit for processing can tolerate more damage. Other important factors are: a) age, shape, and height of trees, b) terrain and soil type, c) season and climate, d) type and availability of labor, e) type of management, and f) psychology of the industry.

The objective of research to develop mechanical harvesting and handling technology for citrus has been to reduce or eliminate the 'stoop' labor and drudgery in hand-harvesting in a manner that will be economically feasible.

Research has been directed toward specific areas. Hand labor used in hauling the fruit from the tree to packing house or processing plant has been largely eliminated with mechanical equipment (1). Hand labor used in picking has not been reduced appreciably with man-positioning machines, but the work has been made easier. The hand labor used in picking has been reduced experimentally with mechanical fruit removal means. Economic success with these means had been limited until the recent discovery of several abscission chemicals that loosen the fruit on certain cultivars (22). The discovery of abscission chemicals to loosen mature Valencia oranges with minimal harm to the immature fruit has provided a promising way to selective harvest this cultivar.

### Hand Harvesting Aids

A man using the bag and ladder is the most widely used method of harvesting citrus fruit. It has been tailored to meet the special needs of different cultivars and the fresh and processed fruit outlets. The workers (pickers) are usually paid for each box or unit picked rather than on a hourly basis. This makes the method well suited for the employment of unskilled seasonal labor. However, the work is arduous and is associated with considerable drugery. In large trees, a Florida picker spends 75% and 60% of his

[1]Florida Agricultural Experiment Stations Journal Series No. 1317. Cooperative research by the Florida Department of Citrus, AREC, University of Florida, and the U.S. Department of Agriculture, Lake Alfred, Florida.

total harvest time picking (reaching and detaching fruit) oranges and grapefruit, respectively. He can pick 70 to 80% more fruit when he does not have to use the ladder (3). In California the picker spends 75% and 85% of his total harvest time picking oranges and lemons, respectively (15). This potential for gain has stimulated interest in man-positioning machines.

Man-positioning machines to position one picker in a tree and to automatically convey the fruit into bins or containers have not been successful, economically, because increases in productivity have not justified the machine cost (14). Attempts to lower equipment cost per picker by increasing the number of pickers have resulted in a correspondingly lower gain in picker productivity. Where fruit is picked for processing, there has been a steady trend away from the use of picking bags and toward dropping the fruit on the ground and picking it up later. Good pickers would rather use the picking bag to avoid double handling, however poor or inexperienced pickers can gain by this practice. The productivity of the pickers has been increased about 25% by loosening the fruit with abscission chemicals but it has been difficult to convince the pickers to accept a lower per unit pay scale to pay for the chemical.

## Abscission Chemicals

The discovery of abscission chemicals to loosen fruit on the tree greatly increased the potential for mechanical fruit removal and improves hand-picking. Several chemicals loosen fruit but they all have certain inherent limitations. A recent paper has reviewed in detail available chemicals and their uses (22).

Several problems are encountered in using abscission chemicals. The fruit does not always loosen evenly on the tree. When the tightest fruit is loosened to a level desired for the efficient use of some mechanical harvesters, a heavy fruit drop results. This detracts from the effectiveness of the harvesters that collect the fruit on catchframes, but it is beneficial to shaker systems designed to put fruit on the ground for mechanical pick-up.

Adverse weather can also affect abscission chemicals. Most chemicals must remain on the fruit for at least a few hours to be taken up by the fruit and sudden rains within two hours usually result in complete loss of activity. Under desert conditions, air humidities are often so low that for some abscission chemicals to be effective at all, they must be applied at concentrations double or triple those applied under humid conditions. Tree vigor is also an important consideration with all abscission chemicals and the chemical should not be applied or applied with caution to trees which are noticeably weakened from such factors as disease, insects, drought, or freezing temperatures.

Low temperatures will delay or reduce the effectiveness of abscission chemicals. The exact temperature ranges have not been established for all abscission chemicals, but field observations indicate that little loosening occurs at temperatures below 60°F (16°C). Loosening may subsequently occur with the arrival of warmer weather. Low temperature retardation of loosening is frequently a problem in Florida with winter harvesting of early and midseason oranges. Valencia oranges are harvested in spring and summer when such low temperatures are rarely encountered but then the spring rains become a problem by washing off the chemical before it can be active. High temperatures have generally not hindered the activities of abscission chemicals.

Under Florida conditions most chemicals which have been useful for fruit loosening also cause peel injury. The injury is inconsequential for processing fruit unless applied rates are too high causing severe peel damage.

The Valencia orange, in addition to having both immature and mature fruit crops at the time of harvest, also undergoes a period commonly referred to as 'regreening' when the fruit becomes less responsive to the chemical. This is especially true if the rootstock is rough lemon. In Florida this period occurs during May and June and is thought to be associated with juvenility factors resulting from active growth of the tree.

## Mechanical Harvesting

Machines that have been tried for harvesting citrus have been described in detail in a separate publication (21). They can be classified as contact machines and mass removal machines according to their method of fruit removal.

*Contact machines* employ either a spindle or a comb-like mechanism to detach the fruit. They consist of a picking head, housing the detachment mechanism, and a positioning mechanism to place the head in the tree. The thick foliage and limb interference of the tree canopy have limited the fruit removal with these machines to about 70% (6). The positioning mechanism, common to all harvesters of this type, is the principal factor affecting initial cost and harvest rate. The combination of high cost, low fruit removal efficiency and a harvest rate of only 5 to 10 six-m high trees per hour has discouraged the development of these machines.

*Mass removal machines* employ some type of external shaking force which is transmitted to the fruit through the limbs or foliage. This force is generated by a mechanical vibration source that attaches onto the trunk, limb or foliage of the tree, or by oscillating air or water pulses which shake the foliage.

The recent development of abscission chemicals to loosen the fruit has made the mass removal machines more attractive. Performance of these machines in Florida has been marginal except under some specific grove conditions. Their performance has been best in early and midseason oranges (*C. sinensis* L. Osbeck) and grapefruit (*C. paradisi* Macf). These cultivars mature and are harvested before spring growth and a new crop is set.

Trunk shakers attach onto the trunk of the tree and operate at frequencies ranging from 10 to 16.67 HZ (cycles per sec). They have been observed to harvest 40 to 60 trees per hour when the fruit is satisfactorily loosened with an abscission chemical. In most operations the fruit is shaken to the ground and picked up later. These shakers are suited for trees which have single trunks, and where shaking can usually be accomplished with a single attachment to the trunk. Bark damage can be a problem at times in Valencia oranges during the spring growth period.

Limb shakers are similar to trunk shakers except they attach on to the major tree limbs about one-third of their length out from the trunk. They operate on inertia principle which makes them well suited for mounting on catchframes (6). Limb shakers operate at lower frequencies 2.5 to 5.83 HZ and have a lower harvest rate than trunk shakers. Operating independant of catchframes they have achieved a harvest rate of 17 to 45 trees per hour in oranges depending on tree shape and looseness of the fruit (17). Their performance is not as dependent on an abscission chemical as most other shakers, but loosening the fruit does increase the harvest rate and has only a small effect on removal efficiency. Longer stroke limb shakers offer in effect an 'override system' in case the chemical fails to loosen the fruit adequately for easy removal. However, this is sometimes accomplished at the expense of increased wear and tear on the machine and trees.

Foliage shakers transmit a vertical or horizontal shaking motion to the fruit by clamping to the smaller branches (foliage), or by utilizing an oscillating air or water stream

to deflect the foliage, thereby shaking the fruit. These machines produce relatively low frequency, shaking action ranging from 0.67-3.33 HZ.

Foliage shaker employing a vertical shake principle may have potential for the selective harvest of Valencia oranges (11). Selectivity between the mature and immature fruit is accomplished by fruit weight differentials. This principle exercises good control over the shaking motion (in the vicinity of shaker attachment) imparted directly to the fruit, which is a very important feature in selective harvesting. Inside fruit at some distant from the attachment is difficult to remove. The need to position the shaking mechanism over the tree makes the machines harvest rate low (5-10 trees per hr). The machine is not as dependent on an abscission chemical as trunk shakers but its performance could be improved by the use of one.

A foliage shaker employing an oscillating air stream (0.83 to 1.67 HZ), usually referred to as an 'air shaker' has the highest harvest rate (70-120 trees per hr) of any mass removal machine, but its performance is heavily dependent on an effective abscission chemical (19). Some foliage is damaged by the air velocity (160-240 km/hr) and sometimes by high rates of abscission chemicals. Under some conditions this damage has resulted in reduced fruit yields the next year (20).

An oscillating water stream produces a shaking action similar to that of the air shaker. Water at rates up to 1892 *l*/min (liters per minute) is supplied from an established irrigation system or from other suitable sources. However, the large water supply hose which must be dragged behind the machine limits the harvest rate to below that for the air shaker, and the water stream causes more damage to the fruit by knocking it against limbs. Also, the water causes the fruit to deteriorate faster on the ground. As with the air shaker, its performance is heavily dependent on effective loosening of the fruit.

*Selective harvest.* Valencia orange cultivar has a young crop of immature fruit on the tree when the mature crop is harvested. The immature fruit increases in diameter from 3 mm at the beginning to 38 mm at the end of the 8-week season (4). To harvest the mature fruit, the fruit removal device must remove a high percent of the mature crop with minimal damage to the immature crop. Present mass removal harvesting machines remove enough of the immature fruit to cause a reduction in subsequent fruit yield except possibly near the beginning of the season. The amount of reduction depends on the weight and condition of the immature crop (7). Use of the abscission chemical, Release[R], lowers the subsequent yield reduction. However, when a high mature fruit removal is required, the inability of the chemical to consistently loosen all the mature fruit to a low level reduces the machines ability to select between the two crops. Limb shakers used with high application rates of an abscission chemical seems to have reasonably good potential for selective harvest, but the economic conditions will have to change before this system can be acceptable.

## Fruit Handling

Mechanically harvested fruit has been either dropped onto padded catchframes or allowed to drop on freshly plowed ground where it is collected and hauled to the processing plant. The method used depends on whether the fruit is for processing or for the fresh-market, and also on whether the fruit collection machinery is an integral part of the harvesting machine.

*Collection.* Collection and handling equipment has been discussed in detail in a separate publication (18). Catchframes are usually used as an integral part of a harvesting machine. When used in conjunction with an abscission chemical, close control of the chemical application must be exercised to minimize preharvest fruit drop. Usually the fruit is conveyed to containers or short-term storage bins. The use of catchframes slows the fruit removal operation over operating independently since the catchframes have to be moved from tree to tree. Pruning to raise the tree skirts about 60 cm above the ground is usually necessary except in older plantings where the skirts are naturally high enough to accommodate the machinery. The fruit handling components currently being used in Florida with catchframe systems are the pallet bin with tractor forklift, 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 truck is necessary.

Tub or basket fruit containers (409 kg capacity) are unloaded with a loader boom mounted on the high-lift truck and the empty ones must be rolled or tumbled by hand to the fruit collector bin of the catchframes. Container handling is a problem affecting the field efficiency of the catchframe system which has not been entirely solved.

A fruit rake and pickup machine have been used in Florida to collect and handle the fruit in conjunction with any type fruit removal equipment. The fruit is raked into a windrow; picked up and loaded into a field truck equipped with a high-lift body and hauled directly to a highway truck. Preharvest fruit drop from abscission chemicals is not a problem but fruit already on the ground from natural drop must be eliminated before harvest to prevent lowering fruit quality. Ground pick-up methods allow each component of the fruit removal and handling operation to be operated separately and at its maximum rate. However, both operations must be closely coordinated so that fruit does not remain on the ground too long, resulting in unacceptable levels of decay. Some ground leveling is usually beneficial by improving rake and pickup efficiency.

Both catchframes and pickup machinery have cleaning equipment to remove trash. Trash consists largely of leaves, stems, and dead limbs on the catchframes, but the rake and pickup machinery must also contend with grass, soil, and debris removed from the ground. Under some conditions, when hand labor is available, the fruit may be picked up by hand and placed into containers. When this is done the workers grade the fruit as they pick it up, thus eliminating the need for field cleaning.

*Fruit condition.* Mechanical harvesting and handling generally causes more injury to the fruit than hand harvesting (9, 12). The damage is in the form of split fruit, internal and exterior bruising, and superficial peel injury. The extent of damage varies widely from the influence of harvesting and handling methods, weather conditions, fruit maturity, tree size, and cultivar. Also fruit picked up from the ground may be mixed with old naturally dropped fruit if it is not cleared from the ground before harvest.

The allowable storage time between harvest and utilization is governed by the extent of fruit damage, fruit maturity, weather conditions, and level of fungus infestation at harvest. Mechanically harvested oranges for processing in Florida has an allowable storage time of about 36 hours in warm humid weather. Usually fruit collected on a padded catchframe has a longer storage time than that collected from the ground. Present abscission chemicals burn the peel and tend to speed up fruit deterioration. Florida law sets the content of unwholesome fruit acceptable at the processing plant. Grading out a large amount of unwholesome fruit to make it acceptable is time consuming

and labor intensive and is to be avoided.

Mechanically harvested oranges in Florida often contain a large amount of trash and under certain conditions has fruit with stems attached. Most of this material is either removed in handling in the field or at the point of utilization. It is important that this material be removed as soon as possible in the handling operation to reduce the probability of it damaging the fruit. Abscission chemical use reduces the number of attached stems significantly (5).

Harvesting trials with tree shakers have been made in Florida (9), California (2), Israel (10), and Australia (8) on citrus for the fresh-market. Trunk shaker harvest in California is reported to have good potential in desert grapefruit. In Florida oranges, the damage level was too high for industry acceptance.

*Sources of damage.* One source of fruit damage is in its removal from the tree. Without abscission chemicals, shakers operating with a relatively long stroke and low frequency cause large limb displacements subjecting the fruit to possible collision with surrounding limbs and fruit. Trunk shakers, with their short stroke and high frequency, do not expose the fruit to as much danger of being damaged as do the limb shakers. With abscission chemicals, fruit is removed with lower shaking intensity with either shaker, therefore reducing their differences in potential fruit damage.

Sources of fruit damage other than fruit removal include the impact of fruit with limbs as it falls through the tree, the impact with catchframe or the ground and handling the fruit to the point of utilization. In Florida considerable damage has occurred in raking the fruit to the middles in high fruit densities (above 300 kg per tree) especially with thin skinned cultivars. Research is now underway to compare this method with one where the fruit is raked into a windrow under the drip line of the tree. This will reduce the ground fruit density in half but will require two passes of the pickup machine per middle.

## Harvest Systems

A complete system of harvesting and handling may include all or part of the following operations: 1) preharvest tree and ground preparation, 2) fruit removal and 3) fruit collection and handling. All or part of these operations may be performed mechanically or in combination with hand labor as conditions dictate. The wide range of varietal and cultural conditions found in citrus make it improbable that any one system will ever be suitable for all conditions, thus making the development and use of a variety of machines necessary.

Several systems have been used on a semi-commercial basis in Florida which account for about 16320 tonnes of oranges mechanically harvested each year over the 4 seasons from 1973 to 1977. This amounts to less than 1% of the total citrus crop in Florida. Fruit removal methods employing hand-pickers, air shaker, or limb shaker were used in one or more of the systems in conjunction with either catchframes or ground pickup fruit collection methods (13).

*Management* of mechanical harvesting systems has many risks. When an abscission chemical is applied, the harvest operation is immediately governed by the action of the chemical which can upset the entire harvesting timetable if it fails to loosen the fruit. The fruit has more damage than hand harvested which makes it necessary that it be processed shortly after harvest to prevent spoilage. The harvesting manager is faced with a logistic problem of coordinating harvesting with the processing plant. This must be accomplished in spite of possible machine breakdowns, and adverse weather. His problem is amplified by the fact that in many organizations he must work in overlaping management areas.

*Cost of harvesting* varies with the system used, fruit density, and orchard condition. Several systems have competed favorably with hand harvesting for processing fruit under specific conditions, primarily in tall, high yielding trees. Fruit recovery ranged from 90 to 98% and in most cases it was not economical to glean the fruit that is left using hand labor. Therefore, the fruit has to be abandoned and its value charged to the cost of mechanical harvesting. This places mechanical harvesting at a disadvantage when competing with the approximate 100% recovery obtained with hand harvesting. The cost of fruit abandonment varies with prevailing fruit prices so that in years of low fruit prices the mechanical systems are more economical. Usually years of low fruit prices also have the largest crop and this contributes to better economy for mechanical harvesting.

## Trends and Opportunities

Trends today on the world citrus scene indicate that a climate more favorable to the acceptance of mechanized harvest methods is on the horizon. A larger proportion of world citrus production is going into products. Approximately 80% of all Florida citrus is now being processed and the proportion is rapidly increasing in other countries such as Brazil and Australia. This should enhance mechanical harvesting since it has been more successful in fruit for the product outlet. The pressure of government, church groups, and organized labor for higher pay and better working conditions for seasonal workers and the competition from other industries is expected to increase in the industrialized citrus growing areas. This will continue to affect availability and cost of harvest labor.

On the research scene, great strides have been made in loosening citrus fruit with abscission chemicals and in controlling tree shape through hedging and topping. Also, many new and improved innovations have been made in harvesting machinery and methods. These developments have enhanced the efficiency of harvesting methods.

Many opportunities still exist to further improve citrus harvesting methods. More uniform loosening of the fruit is needed from abscission chemicals to lower the energy required for fruit removal and to increase fruit removal efficiency. This might be accomplished by better spray coverage, improved chemical action on the fruit or methods to reduce the effect of rain immediately following application. Another opportunity is the elimination of the characteristic peel burn caused by present abscission chemicals. This would enhance harvesting for the fresh-market. Improved methods are needed to control citrus tree growth making it possible to reduce machinery requirements and increase harvesting efficiency. This may be possible through improved hedging and topping methods or by using dwarfing rootstock or by growth regulation chemical. Future machinery development may depend somewhat on developments that occur in the abscission chemical and tree growth control areas. Improved innovations are needed to reduce the complexity and increase reliability of the harvesting machinery.

With the combined efforts of engineers and plant scientist working together, economical mechanical harvesting and handling systems are expected to become a reality for processing fruit. The prospect for fresh market fruit is not clear and may be limited to the mechanical aid approach.

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