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COLLECTING AND HANDLING MECHANICALLY REMOVED CITRUS FRUIT[1]

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Abstract. **Citrus fruit mechanically detached from the tree is either collected and handled by catchframe systems that catch the fruit or it is allowed to fall to the ground where it is raked into a windrow and picked up. Fruit that falls to the ground generally receives more damage than fruit caught on catchframes and is utilized for processed products. Therefore, the method of collecting and handling of mechanically removed citrus is influenced by the use for the harvested fruit. Several basic concepts of catching frames and associated handling equipment have been investigated. Most of them are designed for use in conjunction with a limb shaker for fruit removal. The catchframe method of collecting fruit requires that the tree skirts be higher than when collecting fruit with the ground pickup method. A variety of machines that rake fruit into a windrow and machines that pick up fruit have been designed and evaluated. An oblique type rake that gathers fruit into a windrow for pickup is usually the most successful in selected groves when the ground has received adequate preharvest preparation. A pickup machine using a rod draper chain picks up the fruit and loads it directly into a grove truck. Both the rake and pickup machines are commercially available.**

Mechanical citrus harvesting systems have been developed that employ either contact (by use of strippers and spindles) or mass removal (by shakers) for removing the fruit from the trees (13). Since citrus fruit is easily damaged and has a short storage life after harvest, the collection and handling of the fruit after removal is a vital component of the system. The fruit must be efficiently gathered, loaded on a grove truck and transported to the roadside as an acceptable product. Since 1960, several methods for collecting and handling citrus to be processed have been tried in a wide range of grove conditions in Florida.

Although some contact removal equipment retrieves the fruit as it is detached from the tree, it has not been as successful as mass removal equipment. Only those fruit handling methods suitable for use in mass removal harvesting systems are covered in this paper. These methods can be classified into two general types: (1) ground pickup—where the fruit is allowed to drop to the ground (which usually has been cleaned and prepared before harvest) and is then picked up in a sequence of operations and (2) catchframe—where the fruit is caught on a catching surface as it falls from the tree in the removal process. Method 1 is independent of the fruit removal method used and each sequence of the handling operation is independent of the other. Method 2 requires that the collecting equipment be present while the fruit is being removed. When catchframes are used the fruit removal device is an integral part of the machine. Each approach has advantages and disadvantages depending on the grove conditions, ultimate use to be made of the fruit and the quality of available labor and management. This paper discusses the basic principles and efficiency of the various components employed in the two general methods of fruit collection and handling.

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Ground Pickup Methods

Ground pickup methods of collection and handling have been used successfully in harvest systems for such crops as almonds, walnuts and pecans. These small nuts are difficult to collect but are not easily damaged. In contrast, citrus fruits are large and readily susceptible to damage. Oranges and grapefruit will withstand a drop of 6 m onto soft, cultivated soil without being ruined for processing if they are processed within 36 to 48 hours, depending on temperature and humidity (8). In orange groves, where the soil under the trees had been recently cultivated, from 1 to 5% of the fruit was damaged (14) mostly from hitting limbs as it passed through the foliage. The large mass of citrus fruit produced per hectare (40,000 to 70,000 kg) presents a storage and transportation problem once it is harvested because of the short allowable storage period before the fruit has to be processed.

Several of the rake and pickup principles used successfully in machines for harvesting nut crops were modified and employed in machines for harvesting citrus. Also, several new principles have been developed into workable machines. The ground pickup method employed in citrus consists of raking or windrowing the fruit with a machine from the grove floor into a windrow usually in the center between rows where it is accessible to another machine which picks it up and loads it onto a grove truck. Two passes are required down each row to rake fruit from both sides of the tree and place it into a double windrow for pickup (Fig. 1). It may be picked up from a single windrow. Sometimes the rake and pickup functions are performed by one machine. In the process of picking up and loading, the trash is separated from the fruit.

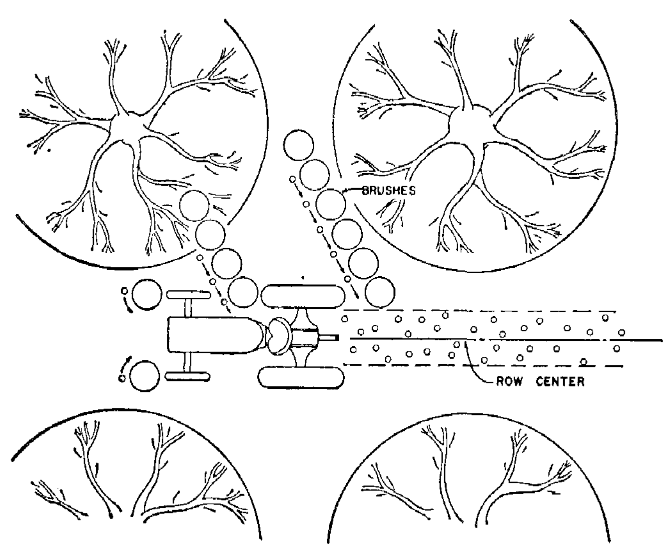


Fig. 1. Brush raking assemblies arranged with a double row of brushes to form a double windrow in the center between rows.

Raking Machines

Rakes in present use to gather fruit into a windrow are either the oblique side delivery type or the horizontal rotating brush type.

The oblique raking system consists of 1 to 3 rake assemblies that extend out toward the tree at an angle of 1.13 radians from the direction of travel (Fig. 2). The system is tractor mounted (11) or is a self-propelled, single-sided machine. The oblique rakes are designed with 3 or 4 tooth bars having rubber mounted teeth 15- to 25-cm long. The tooth length influences total rake height. Therefore, short teeth are used when possible to provide a low rake profile that can get under low hanging limbs. The amount of fruit to be raked determines the height of the rake that should be used and the rake that forms the windrow is generally higher than one near the tree trunk. Oblique rakes built for citrus have not had sufficient raking capacity in high yielding groves. Fruit damage often occurs when the rakes are overloaded as fruit is added to an existing windrow to form a double windrow or when high volumes of fruit are placed into a compact windrow. An acceptable raking efficiency can be achieved with the oblique raking system at a speed of 20 to 34 m/min provided the fruit yield is under 50 kg/m of windrow.

The brush rake consists of a series of polypropylene bristle brushes 15 cm high by 0.9 m in diam that rotate in the horizontal plane at approximately 100 rpm in the direction of fruit movement (Fig. 1). They overlap 30% of their diam and are positioned to form a line approximately 0.78 radians from the direction of travel of the machine. Each brush assembly is powered by a hydraulic motor, and the angle of contact between the ground and brush can be adjusted. A concave disk is mounted under the brush assemblies to provide independent flotation of the brush as the convex surface of the disk on the soil follows the ground contour. The overall height of the brush assemblies is 38 cm, a height that permits them to get under low hanging tree limbs.

Several brush raking assemblies, such as tractor-mounted single side, self-propelled single side and self-propelled double-sided have been built and tested. These units operate at high ground speeds (up to 54 m/min) and are better adapted to use in damp soils. They move an excessive amount of sand in dry, sandy conditions and are difficult to keep adjusted for effective fruit movement in changing soil conditions and terrain. An experienced operator is required to keep a brush system adjusted for effective raking since its efficiency is highly influenced by soil conditions, fruit load, brush speed, machine forward speed and grove terrain. The brush system is limited to a low mass of fruit (under 40 kg per m) unless a double row of brushes is used to divide the fruit load and carry it to the windrow (Fig. 1).

The end brush on the system that gathers the fruit near the tree trunk is quite effective in gathering fruit between tree roots and in soil depressions. The single brush has been added to the outer end of oblique rakes to gather fruit in the area near the tree trunk and as a wheel sweep to move fruit out of the path of tractor wheels.

Attempts to reduce fruit damage by reducing the distance fruit is raked was investigated by Churchill and Sumner (4). In their tests the fruit was deposited in a windrow at the tree dripline instead of at the center of the row for pickup (Fig. 2). Preliminary results showed that fruit received less damage when raked to the tree dripline than when raked to the center of the row.

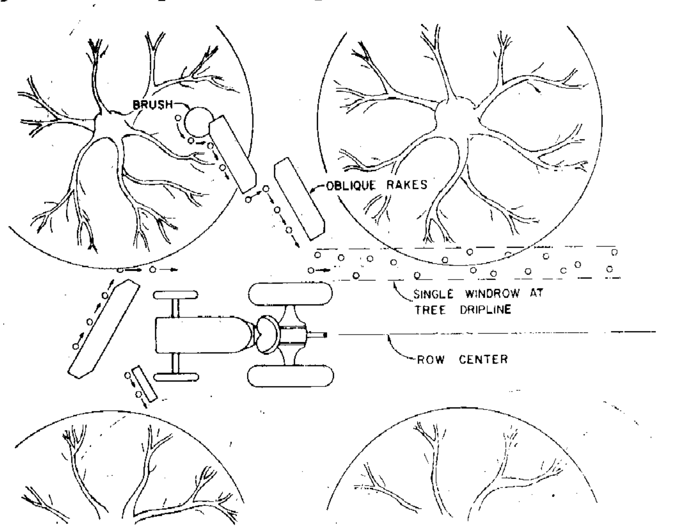


Fig. 2. Oblique rakes arranged to form a single windrow at the tree dripline.

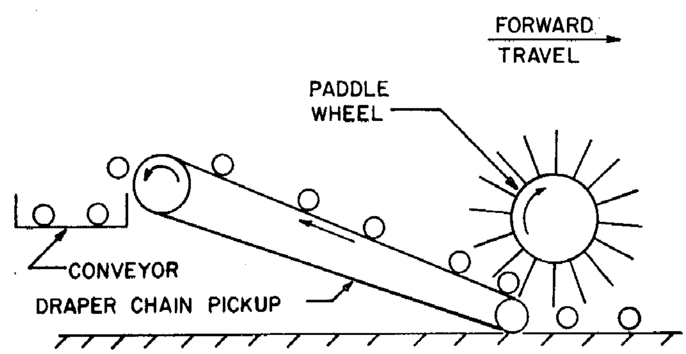
Fruit Pickup Machines

Fruit collected in a windrow is picked up by one of the following methods: (1) rod draper chain direct loading, (2) side loading onto the inside of a rod draper chain conveyor, (3) forward rotation paddle wheel and (4) reverse rotation paddle wheel (Fig. 3).

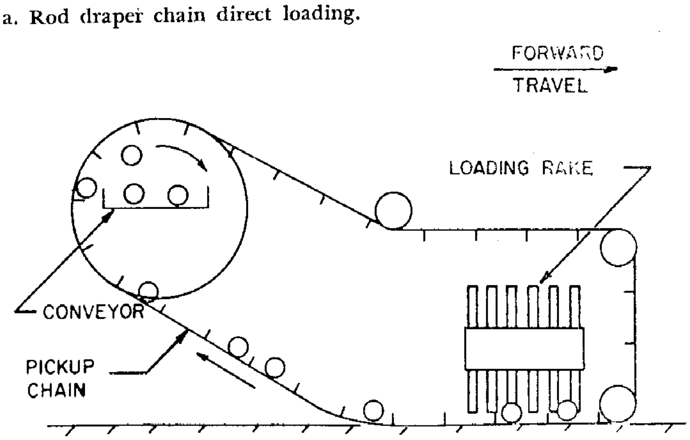
Citrus pickup machines must be capable of handling high volumes of fruit (245-600 kg/min), separating out trash from fruit and loading the fruit into a grove truck. A storage hopper is often part of the system.

Some fruit storage is desirable on the pickup machine to allow turning at the end of the rows while the grove truck is getting positioned behind the pickup machine. A storage hopper allows the pickup operation to continue while grove trucks are moved in and out of the row; this results in less delay time for unloading fruit.

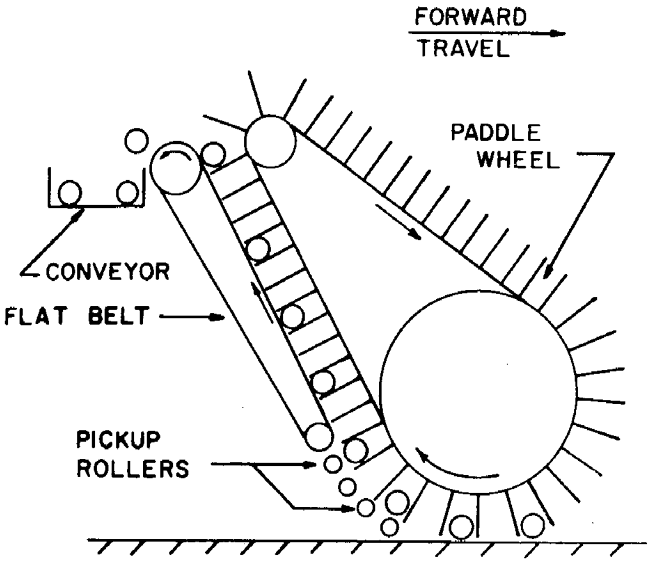
Rod draper chain direct loading. Loading fruit from a



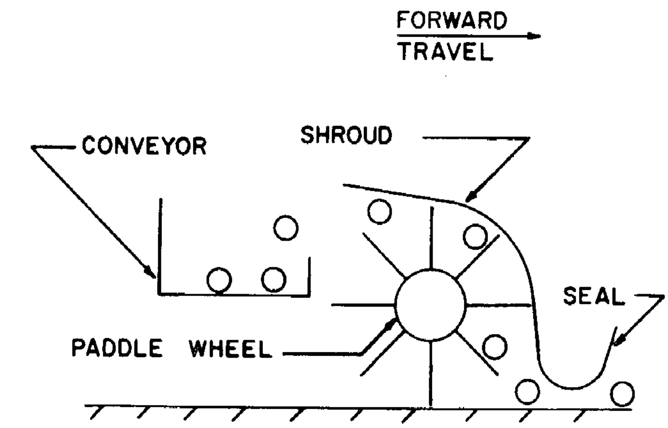
a. Rod draper chain direct loading.



b. Side loading onto the inside of rod draper chain.



c. Forward rotation paddle wheel.



d. Reverse rotation paddle wheel.

Fig. 3. Fruit pickup machines for citrus.

windrow onto a rod draper chain (Fig. 3a), similar to the method used for potato harvesting, provides a high volume machine that loads up to 1000 kg of fruit per minute with a 1.5 m pickup width. A forward rotating paddle wheel located above the pickup chain is not necessary; however, it helps keep a uniform flow of material on the pickup chain and assists fruit pickup at the end of each row. The rod draper chain with 3.96-cm pitch allows a high percentage of trash and sand to fall out of the load before the fruit drops onto the trash eliminator assembly. This pickup chain was designed to fit into a tractor mounted unit (1), a tractor drawn unit (4, 5) or a self-propelled machine (9). The tractor drawn unit loads single or double windrowed fruit, located midway between two rows, directly into a grove truck and is the most widely used pickup machine since it is commercially available. It is a straight through unit that has a high capacity cleaning belt to remove trash from the fruit.

An off-set pickup machine that has the rod draper chain direct loading principle was designed to pick up fruit at the tree dripline (approximately 2-m from the tree trunk) (4). This method reduces the distance fruit must be raked. This offset pickup machine loads directly into a 1225-kg storage hopper with a conveyor attached at the end for loading into a grove truck. The machine has a pickup rate of 200 to 400 kg of fruit per minute.

Side loading onto the inside of rod draper chain. This machine has a pickup section formed by a rod draper chain moving on the ground at approximately twice ground speed toward the rear of the machine. Fruit is raked onto the inside of the chain by an oblique or other type of rake and conveyed up to an unloading drum which transfers it to another conveyor (Fig. 3b). The experimental machine (12) that demonstrated this principle combined the rake and pickup into one unit and had a storage hopper on the pickup machine to provide high field efficiency. The pickup rate was 170 kg/min at a ground speed of approximately 9 m/min.

The side loading principle avoided the pileup of fruit into a windrow since the discharge of the rake was onto a conveyor assembly. This appeared to reduce fruit damage and increased the raking efficiency since the rake discharge was not restricted by fruit load.

Forward rotation paddle wheel. A forward rotation paddle wheel that carried fruit up a fixed grate or rotating rollers was a pickup principle (Fig. 3c) that performed satisfactorily in Florida's sandy conditions. A self-propelled pickup machine (5) using this principle had a continuous belt flap that carried the fruit up a series of rollers and against a flat belt as it was elevated to a bucket elevator. A large volume of sand was picked up with the fruit and had to be separated out by the trash eliminator belt. The type and shape of grate or rollers under the paddle wheel highly influenced the success of the fruit pickup assembly; on some components sticks and trash would plug the pickup grate. The pickup capacity of one machine using a paddle wheel was 225 kg of fruit per minute. (Fig. 3c)

Reverse rotation paddle wheel. The reverse rotation paddle wheel principle consists of a cylinder approximately 0.6 m in diameter made of highly flexible rubber paddles or fingers. The paddle wheel rotates in the opposite direction of machine travel and the fingers lift and convey the fruit between the wheel and the top shroud to deposit it onto a conveyor (Fig. 3d). The principle is limited to single layer fruit pickup and is used as a direct pickup method without a windrow of fruit. A pickup capacity of 250 kg/min was obtained at a ground speed of 14 m/min with a pickup width of 2 m. The pickup efficiency was too low (65%) in groves with disk furrows and on unlevel terrain (3). A short pickup section about 1.2 m long might prove satisfactory in the level area in the row middle and should be investigated. The reverse rotating paddle wheel pickup requires flat terrain when compared with other pickup methods. (Fig. 3d)

Fruit cleaning

The 4 pickup machines described above picked up leaves, sticks, unsound fruit, bottles and cans along with the fruit. Therefore, some type of separation of the undesirable materials from the fruit should always be incorporated into the pickup machine. A simple sloping belt trash eliminator placed under the discharge end of the fruit conveyor has been successful in removing most of the trash from the fruit on several pickup machines.

The direction of trash belt travel with respect to the direction of fruit discharge onto the trash belt was investigated by Churchill and Hedden (2) (Fig. 4). A higher percentage of trash and flattened fruit was removed when the discharge fruit conveyor belt was running in the same direction of travel as the trash eliminator belt than when it was running in the opposite direction. A trash belt inclined at approximately 0.2 radians from horizontal gave the best trash separation.

Unwholesome spherical shaped fruit is not separated from the sound fruit by the inclined trash belt. Therefore,

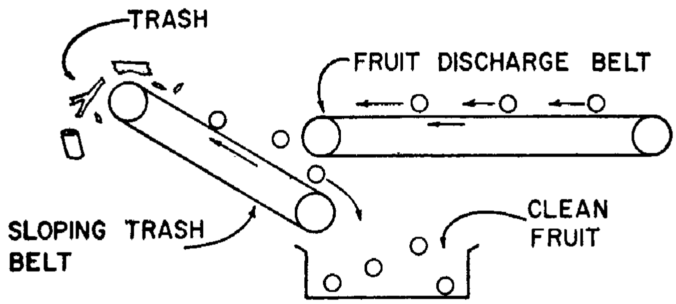


Fig. 4. Sloping belt trash eliminator.

on machines employing an incline trash belt, hand sorting is desirable and sometimes necessary when a high percentage of unwholesome fruit is being picked up.

Future Machines to Rake and Pick Up Fruit

The rake and pickup methods described above have performed satisfactorily in selected harvest conditions and will continue to be used as they are modified and refined into more reliable and efficient machines to suit a wider variety of grove conditions. Combination rake and pickup units will be used more as grove preparation such as tree pruning and ground leveling become common practice in mechanically harvested groves.

An oblique rake with longer rake teeth than are used on present machines, requiring a double pass per side in high yielding groves and providing better tooth bar height control should be designed with higher raking capacity to rake fruit into the windrow. The horizontal brush will rake the fruit in the area near the tree trunk. It will continue its use as a wheel-sweep on grove equipment such as tractors, sprayers and harvesting machinery.

The rod draper chain pickup principle will continue to be the most widely used since it is a high capacity straight-through type machine. The rod draper chain conveyors operate well in sand and trashy conditions and should be used in most fruit conveying systems.

Fruit cleaning to remove trash and other materials can be accomplished with a sloping trash belt with multi-stage cleaning units becoming necessary in groves with heavy trash problems. Hand sorting will become necessary on all pickup machines to remove unwholesome fruit when mechanical harvesting becomes a common practice. Sorting belts will be provided to facilitate the procedure. Hand sorting will be needed particularily in groves where preraking to remove unwholesome preharvest fruit drops has not been practiced.

Fruit storage of 800 kg or more should be built on the pickup machine as a surge hopper or incorporated into the conveying system on each pickup machine. This would facilitate turning at the row ends and would increase field efficiency of the machine. Unloading on the go or continuous unloading during pickup should become common on future machines.

Catchframes

The catchframe method of collecting and handling fruit is usually an integral part of a machine that shakes the fruit off and collects it as it falls from the trees. However, in the harvest of some tree fruits (prunes, apples, cherries and nuts) the two operations are performed separately. The advantages of the catchframe collecting method are: (1) the harvest is completed in one operation which may be an asset under adverse weather conditions, and (2) the collecting surface can be padded to protect the fruit from impact injury and prevent its contamination with organisms in the soil. The primary disadvantage is the restriction the collecting surface places on the fruit removal device. Limb shakers can be operated from 75 to 100% faster when independent of the catchframe. Also, the catchframe method requires that the tree skirts be pruned up higher than for the ground pickup method, and when abscission chemicals are used, a preharvest fruit drop can complicate the harvest operation.

Since about 1960 work has been under way to develop catchframes (catching surface supported by a moveable frame) for harvesting citrus fruit (primarily oranges and grapefruit for processing).

Coppock and Hedden, 1968, suggested the following general design requirements of a catchframe for citrus (1) that it: (a) catch fruit falling from a tree within the periphery of a circle with a diameter up to 7.6 m without puncturing the peel, (b) be built as low to the ground as possible to reach under low limbs, (c) form a fruit seal between frames and around the base of the tree, (d) be retractable and extendable so that frames can be moved from tree to tree, (e) be highly maneuverable in soft sandy soil, (f) turn within a 7.6-m distance at end of the grove and (g) fold to within a 3 m width for road travel. This work paralleled similar work going on in other tree crop industries (prunes, cherries and apples). Economic factors existing in those industries promoted commercial development and industry acceptance. Many of the types of catchframe equipment that had proved successful in other operations were considered for use in citrus. Such equipment included the sloping surface-parallel conveyor, sloping surface-catch dump, wrap around catchframe, horizontal conveyor catchframe and the roll out catching surface (Fig. 5).

The catchframe method of handling mechanically harvested oranges and grapefruit has some potential for harvesting fresh market fruit. Rackham and Grierson concluded in 1970 that, with improved mechanical harvesting equipment (catchframe) and techniques, fruit decay could be expected to stay within the limits accepted by the trade, particularly if postharvest fungicides were applied to the fruit (10). Presently, fresh market fruit is not being harvested mechanically but research is continuing to improve the technique.

Sloping surface parallel conveyor

The sloping surface-parallel conveyor consists of 2 separate units, one on each side of the tree that fit together to form a continuous surface under the tree (Fig. 5a). Fruit is directed toward the tree into a conveyor near the tree trunk. Early models (7) had a conveyor on only one unit and fruit from the opposite side was directed by means of sloping surfaces to the conveyor. Fruit was often lost where the catchframe units mated together since fruit would be funnelled to any opening between the catchframes and particularly at the tree trunk. Poor fruit drainage often resulted on the lower side of the frame in sloping terrain. Considerable operator skill was needed to position the tractor-drawn frames into proper orientation which was time consuming.

An improved seal between the 2 frames was possible when fruit was handled by a conveyor on each catchframe. A soft, bumper type seal on each frame enabled the frames to be pushed together without critical alignment on the tree trunk. The frames operated equally well on sloping and level terrain since they performed as independent machines. Fruit was continuously conveyed to the storage bin as it was removed from the tree, thereby minimizing damage caused by fruit colliding with fruit being collected.

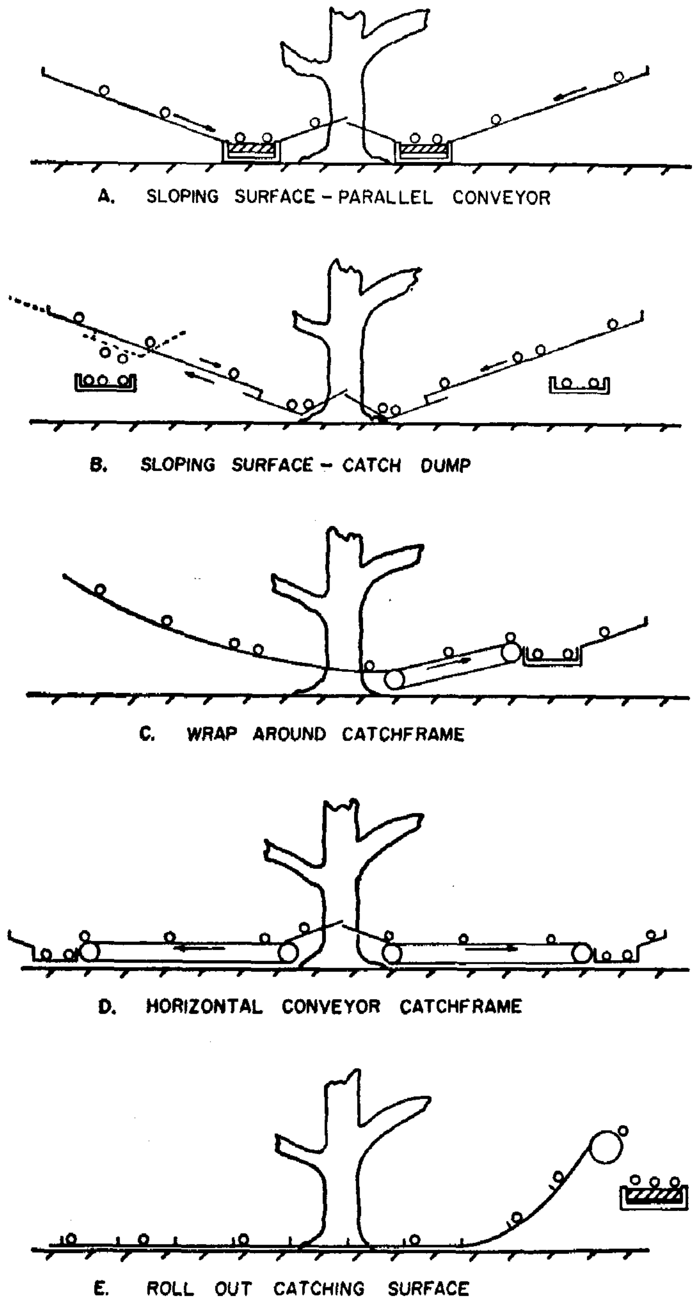


Fig. 5. Sketches of catchframe principles for collecting citrus.

One fault of the design was that because of the cross conveyor used to convey the fruit out, the machine had to operate at a fairly fixed distance from the tree row.

Sloping surface-catch dump

The 'catch dump' method developed by Coppock (6) consists of 2 units mated together under the tree to catch the fruit and direct it to holding basins on the frame near the tree trunk (Fig. 5b). The fruit is dumped into a longitudinal conveyor as the frame is retracted for movement to the next tree. The bumper type seal is made of padded panels that hinge to the frame and the portion that makes contact with the tree is fabric covered polyurethane foam. This design offers a simple fruit handling method which operates with the frame positioned any distance from the tree thus overcoming a fault of earlier catchframe design. It also enables operation on sloping terrain.

Wrap-around catchframe

The wrap-around catchframe has the appearance of an inverted umbrella. The catch surface is stretched canvas that is wrapped around the tree trunk to form a full circle. The sloping sides carry the fruit to conveyors near the trunk of the tree (Fig. 5c). The catch surface is folded up to a half circle for transport between trees.

The wrap around catching system allows the use of only one power unit and one propelling unit, thereby reducing the investment cost of the catching component. It also adapts to use in bedded groves where drainage ditches prevent passage down one side of a tree row.

Poor fruit drainage into the conveyors from the catching surface has been a problem in this system that has not been satisfactorily solved. A private company is continuing the development of this catching principle for use in citrus.

Horizontal conveyor catchframe

The horizontal conveyor catchframe consists of two units that mate together under the tree (Fig. 5d). The units have large conveyors that move the fruit away from the tree trunk and deposit it onto a cross conveyor the length of the machine. One machine of this type has decelerator strips above the conveyors to break the fall of the fruit as it comes down to the conveyors. Rigid sloping surfaces help to increase the size of the catchframes and funnel fruit to the conveyor. The horizontal conveyor catchframe gives a low machine profile at the drip line of the trees but not at the trunks of the trees when the frames are pushed together.

Roll out catching surface

The roll out catching surface principle has been used extensively in small fruit crops and nuts but has not gained acceptance for harvesting citrus. However, it was tried in citrus and may offer some advatange on rough terrain or with certain removal equipment such as the trunk shaker. It consists of a tough cloth that is attached to a roller above a conveyor (Fig. 5e). The cloth is unrolled and pulled by hand under the tree to form a low profile surface on the ground. After fruit is removed and dropped onto the cloth, it is mechanically rolled back onto the roller and the fruit is deposited onto the conveyor which is along the entire length of the machine.

The roll out catchframe is slow and requires an excessive amount of hand labor to pull out the cloths. Another problem in citrus has been the large volume and mass of fruit that must be handled as the cloth is rolled up compared to that of small fruit such as prunes and apricots. A machine employing this principle might be used successfully in groves with low yielding trees having low hanging limbs and fairly level soil conditions.

Trends in Catchframe Developments

Present trends indicate that harvest systems employing catchframes will have a place in the overall mechanization of the citrus harvest. No catchframe principle seems adaptable to all the many grove conditions found in the citrus industry. Probably future developments will be in the area of engineering the catchframes for specific harvest conditions. There may be catchframes built especially for groves on rolling terrain, another type for bedded groves, or another type for harvesting fresh market fruit. Future catchframe developments will be closely tied in with the type of fruit removal equipment used and in many instances, may dictate the principle to be used for that equipment.

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