Design and Performance of an Experimental Citrus Fruit Pick-Up Machine

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FLORIDA produces about 8 million tons of citrus fruit annually (1)*. Increasing harvest labor costs have made it necessary to develop new or improved methods and equipment to harvest this sizeable crop. The main emphasis on harvest mechanization has been upon fruit destined for processing outlets which utilize about 75 percent of Florida's citrus crop.

Many attempts have been made to mechanize citrus harvesting. These vary from simple devices such as picking tubes and other man-held picking aids to mass removal devices such as tree shakers and the oscillating air citrus harvester (2, 3). Mass removal-type machines require a high-capacity handling system. A possible harvest system is one in which the fruit are shaken on the ground, moved into a windrow, picked up, and transferred to a "high-lift" grove truck.

Objective

The objective of this research was to develop an experimental machine to pick up oranges from a windrow. It should remove a high percentage of the trash, do a minimum of damage to the fruit, and operate in grove conditions of loose sand and 8-foot hedged middles, or openings between rows.

Procedure

Pick-Up Principles Studied. Pick-up principles used in other crops were evaluated for their adaptability to citrus. Among those studied were machines to harvest potatoes, tomatoes, nuts, and prunes. Four machines were tested or observed.

First, a vacuum-type pick-up machine was built which successfully picked up oranges at rates of 20 to 30 lb per minute, one fruit at a time. Because of its low capacity, excessive horsepower requirements, noise, dust, and potential wear problems, this principle was abandoned.

A second principle observed was a

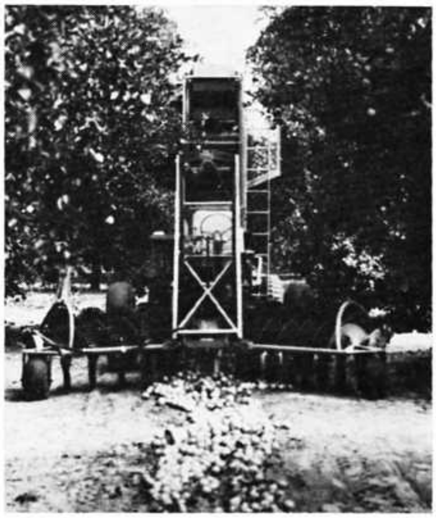

FIG. 1 Front view of USDA experimental citrus pick-up machine.

private concern's experimental machine with a flap-type rotor which rolled the fruit rearward and up a grate onto a cross conveyor. However, to prevent fruit loss below the lower portion of the grate, it had to be operated at or below the ground surface. This caused fruit damage and frequently plugged with trash.

The third machine was the USDA tung nut harvester (4), modified and tested during May, 1967. It consisted of a 34-in. diameter rubber-toothed spiral brush positioned 70 deg back from the center line of the harvester. With this lead angle, fruit was swept to the side, where the tapered end section of the brush fed the material onto a transverse elevating belt. The relative position of the brush to the ground surface was maintained by a sliding shoe at the elevating belt end and a gage wheel at the outer end. Pick-up rates ranged from 332 to 513 lb per min.

The fourth machine, tested several months after construction began on the experimental USDA machine, was a 24-in. single-row potato digger. As long as the soil was undisturbed and of average moisture content, there was sufficient soil resistance to push the windrow up onto the digger blade. The oranges in the center moved onto the chain but the trash built up rapidly on each side rail, bridging across the entire digger blade.

The tung nut sweeping pick-up principle was considered the most promising, though the tung nut harvester itself was not satisfactory for citrus. Its conveying capabilities were limited, the support frame's front casters were in a position to run over fruit in the row, and the unit was very unmaneuverable in sandy grove conditions. This principle was modified slightly in the first citrus pick-up machine design to permit fruit to be swept from each side onto a longitudinal conveyor. However, this low profile conveyor was replaced with a digger blade and rod draper chain (commonly used on potato harvesters) because of excessive sand buildup under the belt.

USDA Experimental Pick-Up Machine Design. The pick-up and handling system performed several basic functions. These were to move the fruit in line with the pick-up conveyor, to pick up and convey the fruit to a holding bin, to remove the trash en route, and to unload the bin.

Figures 1 and 2 show the experimental machine in its final design stage. A fruit flow diagram is shown in Figure 3. The spiral brushes handled windrows up to 9½ ft wide. The brushes swept the fruit to the center in line with the digger blade where it was pushed onto the rod draper chain. Most of the dirt and small trash fell through the chain before the fruit was transferred to a cleated elevator belt.

The digger blade, pick-up conveyor, elevator belt conveyor, and the entire framework above and ahead of the operator were one rigid unit pivoting about a point 33 in. below the operator. This rigid framework permitted a nearly constant relationship between the brushes and the pickup conveyor as the outer ends of the brushes moved up and down with variations in the soil surface. The digger blade was operated between 1 and 2 inches below

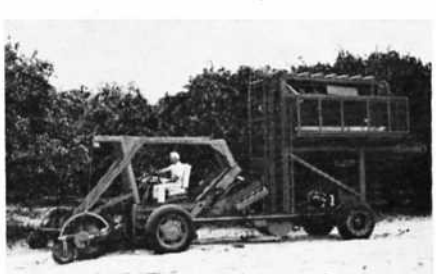

FIG. 2 Side view of pick-up machine.

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* Numbers in parentheses refer to the appended references.

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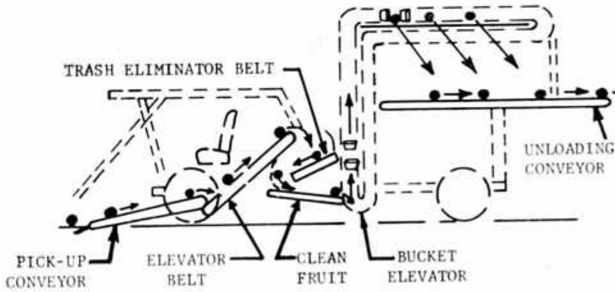

FIG. 3 Fruit flow diagram of pick-up machine.

ground level and controlled by the operator, using the brush ground clearance of ½ to 1½ in. as his depth criterion.

The cleated elevator belt dropped the fruit onto a rough-top trash eliminator belt providing a cushion on which the fruit could bounce and roll down to the clean fruit belt. The trash eliminator conveyor had adjustable "roll" and "pitch" angles. These, coupled with variable belt speed, permitted adjustments for the most effective trash separation.

Fruit on the clean fruit belt were discharged into the bucket elevator boot and elevated to the holding bin. The buckets dumped onto a horizontal area above the bin, whose width tapered to the rear to provide uniform bin filling. The pick-up machine's dimensions, speeds, component specifications, and horsepower measurements are listed in Table 1.

TABLE 1. PICK-UP MACHINE SPECIFICATIONS

Spiral brushes, 34 in. dia., 24 in. pitch	5 ft. long, 440 fpm, 1.4 hp ea.
Paddle reel, 4 paddles, 22 in. dia.	10 in. wide, 430 fpm, 0.8 hp
Pick-up conveyor, rod draper, 1.62 in. pitch	29 in. wide, 150 fpm, 2.8 hp
Cleated elevator belt with 2 in. cleats	24 in. wide, 180 fpm, 0.5 hp
Trash eliminator belt, rough-top	30 in. wide, 150 fpm, 0.3 hp
Clean fruit belt	29 in. wide, 122 fmp, 0.6 hp
Bucket elevatoar, 5½ in. deep, 23 in. long	11 in. wide, 172 fpm, 2.7 hp
Unloading belt with ⅝ in. cleats	24 in. wide, 178 fpm, 2.6 hp
Hydrostatic drive as used in picking up fruit, 0.25 mph	0.42 hp front wheels, 0.95 hp rear wheels
Hydrostatic drive, as used for highway travel (on level), 16 mph, 17 hp	
Spiral brush rubber fingers, 5 in. long, 1 dia., 1⅜ in. on center	
Length (overall)	34 ft 3 in.
Height (overall)	13 ft 4 in.
Width (overall)	12 ft 7 in.
Width (without augers)	7 ft 11 in.
Weight (empty)	13,000 lb
Tires (rear) 10.50 x 18, (front) 9.00 x 24	
Wheelbase	15 ft 7 in.
Tread width (rear) 5 ft. 10 in. (front) 6 ft. 10 in.	

A 162 cu in. gasoline engine was available for the pick-up machine power unit. A useful feature of this engine was a crankshaft-mounted gear pump. In addition, a double gerotor pump was driven from the accessory drive.

A 4.5 cu in. per rev variable displacement hydrostatic pump was coupled directly to the engine flywheel to obtain an infinitely variable ground drive. A 4.83 cu in. per rev fixed displacement hydrostatic motor drove the rear axle differential. The rear axle was a military truck front drive axle which permitted rear-wheel drive and steering.

To have front-wheel drive and still maintain clearance under the axle for the pick-up conveyor, individually-powered wheels were selected. A hydraulic front-wheel drive conversion kit designed for farm tractors was used. A pivoting front axle assembly was fabricated to accept the adjustable tread stub axles. Ground clearance was 25 in. with 9.00-24 tires.

Experimental Pick-Up Machine Tests. The data reported in this paper were obtained using oranges shaken on the ground with an inertia-type tree shaker, either tractor or trailer-mounted (5). Two methods were used to get the fruit from under the tree and into a windrow for pickup. In one method, ground cloths were placed under the trees. After shaking, two men pulled the side of the cloth under the tree toward the drive middle (Fig. 4), rolling the fruit into the middle and forming a windrow. The second method used an experimental, USDA, oblique-type, side-delivery citrus rake (Figs. 5 and 6) designed to side-shift in and out around the trees.

The pick-up machine was tested in a complete harvest system under a variety of grove conditions during the 1968-69 season. Most of the pick-up trials, however, were conducted in one orange grove (25-ft tree spacing) where the terrain was level and the trees were tall and canopied over at the top. The skirt of the foliage was 3 to 5 ft above the ground, making it convenient for the rake and pick-up brushes to operate. At this location, all the fruit was windrowed with the USDA citrus rake. The fruit was raked from under one-half of each adjoining tree row so that the equivalent fruit yield from a complete tree row was picked up at one time.

The pick-up machine was used at another grove location nearby consisting of medium height trees that were open at the top. The grove floor was undulating, with the drive middles about 12 in. below the level of the tree root crown. This condition also existed in the transverse direction so that the path of the pick-up machine was "rippled" with alternate ridges and pockets. The ground cloth windrowing system was used at this location because the terrain was totally unsuited for the citrus rake.

The pick-up machine was tested for its pick-up ability and pick-up rate under various grove conditions and with single and double half-tree windrows. Its trash-removal capability was checked in light and heavy trash conditions, and on windrows formed with the ground cloth system and the citrus rake.

Fruit samples were taken at various

FIG. 4 Workers pulling ground cloths toward row middle.

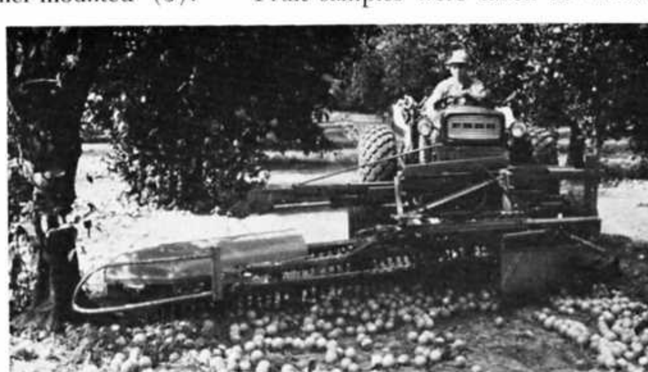

FIG. 5 USDA experimental side-delivery citrus rake.

points in the harvest system to separate effects of shaking, windrowing, picking up, and unloading on storage quality. The fruit samples were held 7 days and decay counts made at 3, 5, and 7 days. Physical damage was checked for split, punctured, and badly bruised oranges.

The handling and maneuverability in the grove and on the highway were observed. Component speeds and pressures were measured under actual operating conditions for calculating horsepower requirements.

Results and Discussion

Average fruit removal with the tree shaker was 5 boxes (450 lb) per tree. The pick-up machine picked up fruit at an average ground speed of 0.26 mph (23 fpm) in the range of 2 to 5 boxes per tree. The average pick-up rate was 408 lb per min and was not as high as anticipated due to low fruit density in the windrow. The maximum measured pick-up rate was 600 lb per min which did not overload the fruit handling system. Excessive amounts of trash in the windrow reduced the ground speed that could be maintained.

In some areas, the trash or weed buildup in the windrow caused plugging at the throat of the pick-up chain. This was particularly true when the citrus rake was used because all of the trash under the tree was brought out into the windrow. Much less trash was brought into the windrow from under the tree with the ground cloth system. A paddle reel faced with belting was installed about the digger blade to push the weed-orange-soil buildup onto the rod draper chain. In heavy trash and fruit flow, some fruit damage occurred at this point; but it was not considered excessive compared to the improved pick-up performance.

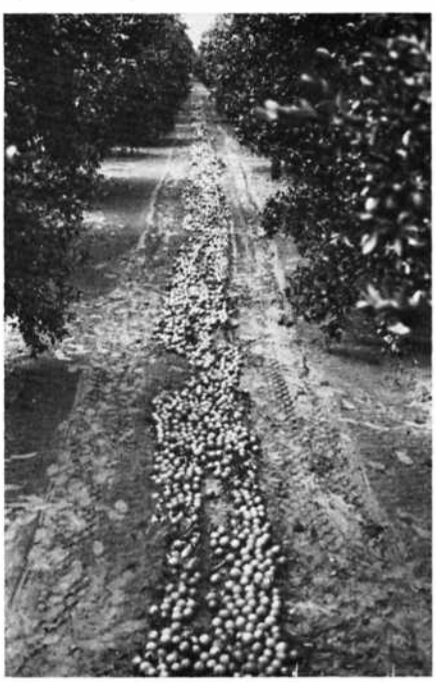

FIG. 6 Windrow formed with the USDA citrus rake.

The trash eliminator belt worked effectively under most conditions. Fruit bounced or rolled off the belt while leaves, weeds, bottles, sticks, and sand that had not fallen through the rod draper chain were carried off by the rough-top belt. A roll angle of 15 deg, a pitch angle of 30 deg, and a belt speed of 150 fpm gave best results. Occasionally, the trash belt became overloaded so that some trash escaped through to the holding bin. For groves with heavy trash, increased removal capacity would be needed.

The bin-filling system worked well under level grove conditions, but on side slopes the bin filled faster on the downhill side. The unloading conveyor functioned well and unloaded fruit at rates in excess of 4000 lb per min into the grove truck.

The decay resulting from each harvest system operation is shown in Figure 7. Normally, fruit would be processed at the canning plant within 48 hr, but for decay study purposes, the fruit was held for 7 days. The decay of the fruit (Parson Brown oranges) at 3 days sampled from the grove truck averaged 3.7 percent decay (stem-end rot and *Penicillium* mold), which was not excessive for this orange variety. Physical damage was also checked as fruit was unloaded into the grove truck. An average of 4 percent were punctured, 3 percent split, and 2 percent badly bruised. While this damage can be reduced, it did not appear to be a problem.

The 4-wheel steering capability of this machine was used to avoid tree damage from the elevated holding bin in tight groves and when turning the machine around at the end of a row. The machine handled well on the highway at up to 16 mph (maximum safe operating speed) and was driven 50 miles to the grove site on one occasion. The 4-wheel hydrostatic drive performed satisfactorily, providing infinite ground speed control while maintaining a constant component speed. The machine's long wheelbase was effective in overcoming the unusual "rippled" soil condition in the second test grove.

The pick-up machine had capacity to keep up with 6 tree shakers at the harvest rate of the shakers used for these trials. The overall field efficiency was 75 percent when unloading time, down time, turn around time, etc. were considered.

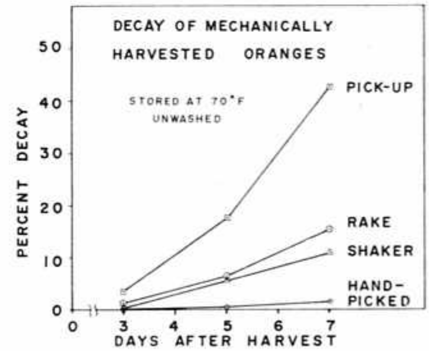

FIG. 7 Decay of Parson Brown oranges harvested with the shake, rake & pick-up system.

Summary

A pick-up machine was designed, built, and tested to pick up oranges from a windrow in a tree shaker, windrowing rake, and pick-up harvest system. The all hydraulically-operated machine provided versatility in design, torque control, speed variability, component operation at continuously changing angles, and convenient horsepower measurements. The hydrostatic drive permitted the desired infinite ground speed and 4-wheel drive. A long wheelbase and 4-wheel steering were effective in the grove and the machine handled well under all terrain and grove conditions encountered.

The average pick-up ground speed was 0.26 mph. The average pick-up rate of all trials was 408 lb per min. The maximum measured pick-up rate of 600 lb per min was matched to the fruit handling system. The trash belt removed a high percentage of the trash in average conditions, although increased removal capacity would be desirable for high-trash conditions. Fruit decay was 3.7 percent at 3 days and was within acceptable limits for the processing plant. The holding bin held a "high-lift" truck load (about 6000 lb) and could be unloaded in about one min.

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