# Design and Performance of a Citrus Rake-Pickup Machine

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THE development of mechanical harvesting systems for Florida citrus fruit has been underway for about 12 years (Coppock 1969). Several types of machines have been developed for the mass removal of fruit from trees. Fruit removed with these machines must be either caught on catching frames or allowed to fall to the ground and be picked up later with pickup equipment. The ground pickup method is particularly desirable when a high rate of fruit removal is obtained or when an abscission chemical is used to loosen the fruit and a preharvest fruit drop occurs.

Citrus pickup machines have been under development by public research agencies and machinery companies for several years (Coppock 1969 and Marshall and Hedden 1970). For these machines to function, the fruit must be in a windrow between tree rows for pickup, thus requiring separate windrow rake equipment (Sumner and Hedden 1972). A problem develops when windrowing the fruit with equipment that makes two passes between the tree rows. Fruit raked in the first pass must be in a compact windrow to allow the rake to pass down the row on the second pass. When fruit is re-raked to form the compact windrow or a large windrow is formed on the second pass, fruit damage results. An alternate method is to pick up fruit as it is raked.

The objective of this research was to design a machine that would incorporate both the rake and pickup operation in one unit, and to test it under typical grove conditions.

## MACHINE DESIGN

The machine was designed by combining, when possible, the rake, pickup, trash removal and storage principles already tested with those principles thought desirable from other observed machines. Fig. 1 shows the rake-pickup machine constructed for field testing. The oblique raking principle was used because it has proved to be an effective method for windrowing fruit (Sumner and Hedden 1972). Three oblique rake sections operated at an angle of 65 deg from the direction of forward travel and were arranged to provide a 14 1/2 ft raking width:

1 The side-shift rake (3-ft shift) was equipped with a control arm which activated a shift motor that caused the rake to retract when it contacted a tree trunk. Thus, the machine could travel between the rows of trees in a straight line. A hand-operated control valve provided an override on the system and was used to extend the rake after it passed a tree trunk. A safety "break-away" on the rake frame allowed the rake to move back 12 in. if it struck low-hanging limbs or large tree roots.

2 The front rake moved fruit from the area ahead of the pickup chain and front wheels.

3 The inner rake carried the fruit from the other two rakes and loaded it onto the inside of the pickup chain (Fig. 2).

A 2-ft long pickup section was formed by using rod draper chain (29 in. wide with a 2-in. pitch) as a track on the ground that traveled at twice ground speed in the direction of travel. Fruit raked onto the chain was lifted to a 36-in. diameter unloading drum which transferred the fruit to a cross conveyor belt. This belt then conveyed the fruit to the bin fill elevator, which lifted it to the drop chute, where it fell into the storage bin. Fig. 3 is a fruit flow diagram for this machine.

Depth control wheels, which were free to follow the ground contour, controlled the operating depth of the rakes and the height for the rod draper (pickup) chain frame. Thus, the rakes and pickup chain could float freely over uneven ground, without attention from the machine operator. The fruit pickup point was between the front drive wheels and the depth-control wheels of the chain frame.

The operator's station was located to provide a view of the pickup area as the operator looked toward the end of the side-shift rake. This location allowed him to keep his attention on the side-shift rake which was under the tree and subject to contact with low-hanging limbs. His location was also convenient for the operation of other controls.

The engine and drive system of the machine included a 162-cu-in., gasoline engine power unit and a variable-dis-

FIG. 1 The rake-pickup machine operating in the semicommercial harvest system.

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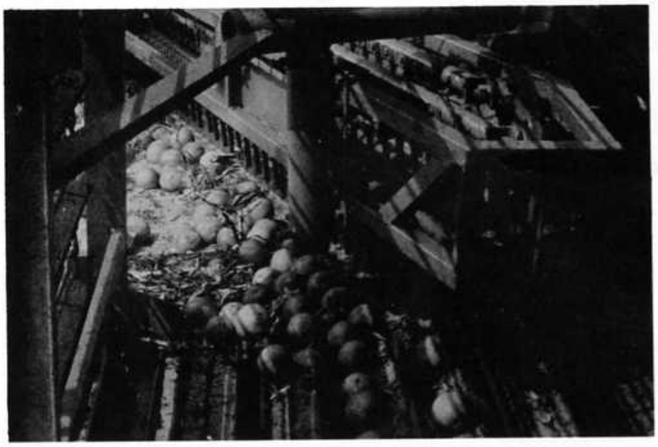

FIG. 2 Fruit pickup area. Point at which fruit is discharged from the inner oblique rake onto the chain.

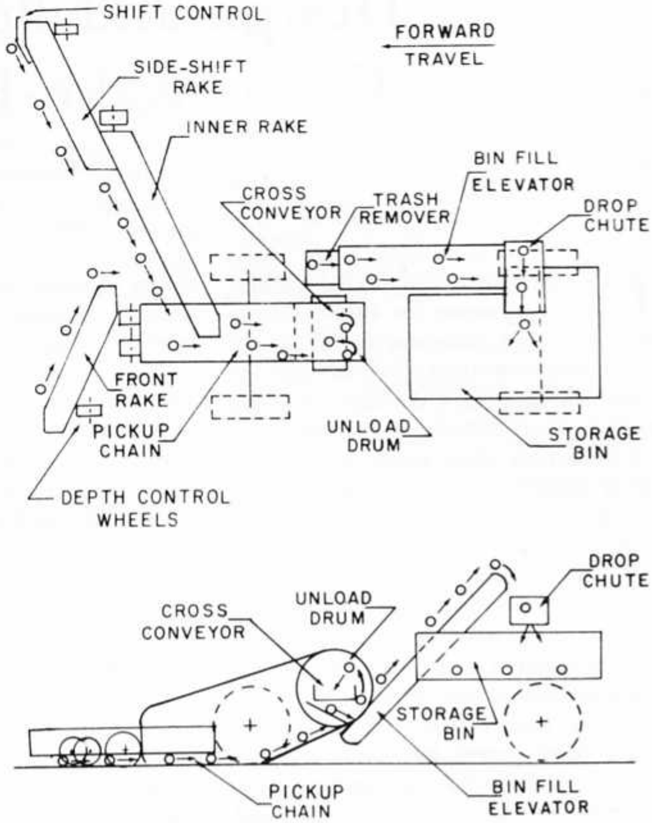


FIG. 3 Fruit flow diagram of rake-pickup machine.

placement hydrostatic drive. A four-speed mechanical transmission and transfer case driven by the hydrostatic motor provided the necessary speed ranges for highway travel in two-wheel drive and for field travel in four-wheel drive. Two front-end drive axles of the type used on military trucks, were used to provide both four-wheel steering and four-wheel drive for ease of mobility. A 30-box capacity* "lift-and-dump" fruit storage bin was mounted on the machine to maintain a low profile. The pickup machine specifications are listed below:

Height (to bin fill conveyor) . . . . . . . 8 1/4 ft
Height (to oil tank) . . . . . . 7 ft
Length (with side rake) . . . 25 ft
Width (rake extended) . 17 1/2 ft
Width (rake retracted) . 14 1/2 ft
Width (rake lifted for transport) . . . . . . . . . 8 ft
Wheel base . . . . . . . 12 1/2 ft
Storage bin capacity—30 field boxes . . . . . . . . . . 85 cu ft
Ground speed for pickup 0–2.1 mph (184.8 fpm)
Ground speed for highway travel (max) . . . . . 17.3 mph

## MACHINE TEST

Complete testing of rake-pickup machine was made as part of a semicommercial harvesting system during the 1971-72 harvest season (Hedden et al 1972). The system consisted of removing the fruit from the tree with a limb shaker, picking it up from the ground with the rake-pickup machine, and hauling it to a roadside semitrailer in a high-lift grove truck.

Tests were conducted at three grove sites during the December-to-March harvest season in the Hamlin and Pineapple orange varieties. The selected groves had fairly level terrain, and the trees were open enough to allow excess with shaker harvesting equipment. Approximately 1 200 field boxes of fruit were harvested for a total of 3 600 boxes (162 tons). Fruit was picked up the same day it was removed from the tree.

Some grove preparation was necessary, however, to allow satisfactory performance of the rake-pickup machine. Low-hanging limbs were pruned when required to let the rake get under the tree skirts and large limbs left from previous tree hedging operations were removed from the grove. Preraking and pickup was also required in some groves to remove excessive trash and decayed fruit before fruit was shaken onto the ground. Dead wood, shaken onto the ground, was picked up by hand to avoid fruit damage while raking and to reduce the amount of trash conveyed to the storage bin. Fruit near the tree trunk was raked out with a hand rake to approximately 1.5 ft from the tree trunk to make it accessible to the machine.

Samples of fruit on the ground were taken before pickup and at the processing plant for comparison to determine fruit damage caused by the pickup operation. Fruit left in the grove was also counted under predetermined sample trees. Time log data were taken during test operations to determine fruit pickup rates, fruit unloading time, and delays.

## MACHINE PERFORMANCE

The performance of the rake-pickup machine in ground speed, handling rate, and down-the-row pickup rate for each grove site is shown in Table 1.

The percentage of total field time required for picking up fruit, unloading the storage bin, making turns at the end of each row and delays determined in each of the grove sites, is shown in Fig. 4.

In Grove I (Hamlin oranges, spaced 20 by 24 ft), the sandy soil was moist, but not wet, and had only minor ground

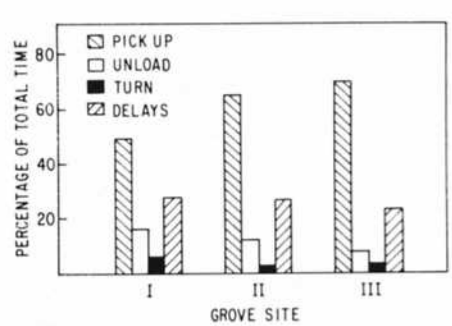


FIG. 4 Percentage of field time used in pickup, unload, turns and delays at three grove sites.

*A Florida citrus field box contains 4 800 cu in. and holds 90 lb of oranges.

**TABLE 1. PERFORMANCE OF RAKE-PICKUP MACHINE IN THREE CITRUS GROVES, 1971-72 HARVEST SEASON**

| Grove | Machine performance | | |
|---|---|---|---|
| | Ground speed, ft per min | Handling rate, boxes per hr | Pickup rate, boxes per hr |
| I | 29 | 154 | 300 |
| II | 25 | 183 | 286 |
| III | 25 | 116 | 168 |
| Average | 27 | 151 | 252 |

depressions and furrows. The ground conditions were considered good for fruit pickup. The rake-pickup machine raked, picked up, and loaded fruit into the grove truck at an average rate of 154 boxes per hr, including downtime. Field efficiency (100 X pickup time ÷ total time) was 51.3 percent. Down-the-row pickup rate, excluding delays, unloading and turning time, averaged 300 boxes per hr, and the average ground speed was 29 ft per min. The time required to unload the fruit storage bin accounted for 16 percent of the total field time and delays caused by mechanical problems, tree interference, or machine clogging from sticks and sand, accounted for 27 percent of the time.

Conditions in Grove II (Pineapple oranges) were better for raking and picking up fruit than those in Grove I. The trees were more widely spaced (25 by 25 ft), the soil was level and not wet enough to cause sand or trash buildup in the machine, and the tree skirts were high enough to cause little interference with the gathering rake. The rake-pickup machine handled fruit at an average rate of 183 boxes per hr, including downtime. Field efficiency was 64 percent. Unloading required 8.7 percent of the total time, and 25 percent of the total time was taken up by delays due to mechanical problems, dirt and stick buildup, or waiting for the high-lift truck. Machine ground speed averaged 25 ft per min and the down-the-row pickup rate averaged 286 boxes per hr in this grove.

Grove III (Pineapple oranges), was quite different from either of the previous groves in tree height, skirt height and in soil characteristics. The trees were approximately 25 ft tall, with skirts 6 to 8 ft above ground. The soil was firm, moist, and more cohesive than in the previous groves. To prevent fruit damage, the soil was disced before fruit was shaken onto the ground. As a result, some of the fruit sank into the loose soil to a depth of three-fourths of the fruit's diameter. Raking was difficult since it was necessary to move soil along with the fruit. This resulted in a buildup of soil under the pickup chain and left a mound of soil between the rows of trees. Several heavy rainfalls occurred while this test was underway, which caused the machine to clog with wet sand and a reduced ground speed was necessary. However, at the reduced speed, almost all the fruit was raked and picked up.

In Grove III, the rake-pickup machine handled fruit at an average rate of 116 boxes per hr, including delays, with a field efficiency of 69.3 percent. Unloading the fruit storage bin required 6.3 percent of the total time, and 22 percent was spent in delays caused primarily by excessive buildup of wet sand in the machine. Down-the-row fruit pickup rate in Grove III averaged 168 boxes per hr, with a range of 137 to 208 boxes per hr. The lower figure was the pickup rate after a hard rain shower. Machine ground speed averaged 25 ft per min.

The average ground speeds were about the same in the three groves; however, in Grove III, the average down-the-row pickup rate was only about 57 percent of the average pickup rate in the other two groves. The lower pickup rate in Grove III can be accounted for by: (a) Decreased tree yields, and (b) The adverse pickup conditions in Grove III, which did not allow the increase in ground speed necessary to give a fruit pickup rate equal to that in the other groves. Much of the delay time in Grove I was a result of getting the system into operation for the first time. This part of the delay time accounted for the lower field efficiency. Unloading the storage bin in Grove I required more time than for the other groves, since operators were not trained and adjustments were necessary on the storage bin dump and high-lift grove truck to improve their efficiency.

Rake capacity appears to be a limiting feature on the rake-pickup machine although the machine was able to keep up with the output of two self-propelled limb shakers. Fruit damage occurred at the point where the side-shift rake overlapped the fixed inner rake when the side-shift rake retracted to go around a tree trunk. If the machine ground speed or the fruit density became too great, fruit was carried over the rake bars and usually crushed. Pickup efficiency in the grove averaged 98.3, 97.2, and 97.1 percent, respectively, in Groves I, II, and III. Fruit sampled at the processing plant had an average of 5.5 percent more unsound fruit than was found in fruit sampled before pickup.

Trash in the form of hedge trimmings, dead wood shaken from the trees, sand, leaves, and weeds was picked up along with the fruit. Much of this trash was removed as it was conveyed by the rod draper pickup chain and at the bin fill elevator pickup point. However, some trash in the form of cans and chopped up portions of hedge trimmings was loaded into the storage bin along with the fruit and had to be sorted out at the processing plant. This trash could become a plant disposal problem, but was not a problem in regards to picking it off the plant receiving belt. Additional cleaning equipment (including a sorting belt) may be necessary on the machine, particularly for groves which have not been preraked.

The low profile, high-lift storage bin worked better as a surge bin than did the large, 60-box elevated bin used on previous machines. No unloading conveyor was required, and the bin did not interfer with trees when turning or driving the machine down unhedged tree rows. Under ideal conditions, unloading time took approximately one minute. Unloading "on the go" did not seem necessary, even though unloading the storage bin required 6.3 to 16 percent of the total operating time. Occasionally it was necessary to wait for the high lift grove truck to return from roadside and get into loading position. Some of this lost time could be regained if a larger storage bin were used.

Problems were encountered when picking up fruit in dry soil conditions, because excessive amounts of dust rose from the rake and pickup area. The operator had difficulty seeing tree trunks and suffered personal discomfort and irritation of the eyes and respiratory tracts. The problem was partly eliminated through the use of a personalized air filter system which fitted over the operator's head and shoulders.

## SUMMARY

A citrus rake-pickup machine was designed, constructed, and field tested in a semicommercial harvesting system. The machine rakes fruit from beneath the tree onto a pickup chain and conveys it

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into a storage bin. Machine performance was evaluated in three grove sites while picking up approximately 3 600 field boxes (162 tons) of oranges.

The machine had an average pickup rate of 252 boxes per hr with an average field efficiency of 61 percent. Pickup rates up to 300 boxes per hr, were obtained on level ground and dry soil conditions. Unloading required an average of 10 percent of the time and an average of 24.5 percent was spent in delays caused by mechanical failure, low limbs, or waiting for a grove truck. The average machine ground speed was 26.5 ft per min and was dependent on fruit density and grove conditions. Capacity of the pickup handling system was sufficient in all grove conditions, however, raking capacity was reduced when fruit was dense and soil conditions were adverse.

Pickup efficiency averaged 97.5 percent, and 5.5 percent of the fruit was damaged while being picked up.

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