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DEVELOPMENT OF EQUIPMENT TO WINDROW CITRUS FRUIT[1, 2]

by

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ABSTRACT. Numerous configurations of fruit gathering equipment have been designed, built and tested for handling of citrus during the last decade. However, only a few machines have been successful in the wide variation of grove conditions found in Florida. Gathering equipment range from relatively simple to rather complex machines. Their performance is highly influenced by grove and soil conditions. There are no commercial rakes being manufactured at the present time. However, several windrowing systems show promise for use in harvest operations in selected grove conditions.

INTRODUCTION

During the 1978-79 harvest season, Florida produced 6.85 million t of oranges which were almost entirely harvested by hand labor (1). Approximately 94 percent of this crop went into processed products. Mechanical harvesting equipment has been under development for the past two decades to reduce dependence on seasonal labor and reduce drudgery of hand harvest. Mass removal harvest systems using tree shakers integrated with an abscission chemical to loosen the fruit prior to harvesting has shown potential for successful harvest of fruit destined for processed products. Generally, abscission chemicals cause a large preharvest fruit drop and makes a ground fruit handling system desirable. Gathering equipment is needed to move the fruit from under the tree to a location accessible for mechanical pickup. Since 1967, several gathering devices were observed and tested by personnel of the Agricultural Research team at Lake Alfred, Florida.

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[1] Cooperative research by the Science and Education Administration, USDA, Lake Alfred, University of Florida, and the Florida Department of Citrus.

[2] Trade names are used in this publication solely for the purpose of providing specific information. Mention of a trade name does not constitute a guarantee or warranty of the product by the U. S. Department of Agriculture or an endorsement by the Department over other products not mentioned.

This report covers the development of gathering equipment for windrowing oranges. The development of pickup equipment for windrowed oranges is covered in a separate report (ARS-S-84 Jan. 1976).

WINDROWING METHODS AND MACHINES TESTED

In 1967, a USDA tung nut pickup machine shown in Fig. 1 was modified and tested with oranges on soft sand and sod (2). The gathering system consisted of a double flighted spiral conveyor screw, 86 cm (34 in.) in diameter and 2.1 m (7 ft) long, positioned at a 70° angle from the direction of machine travel. The conveyor screw was made of 2.5 cm (1.0 in.) diameter rubber teeth 13 cm (5 in.) long attached to a flat metal strip welded on the periphery of the flight. The gathering system was part of a tung nut pickup unit that mounted to the front of a tractor. It was not designed for use in soft sandy soils and therefore did not maneuver well. The gathering principle showed promise as a citrus windrowing device. However, the manufacturer abandoned the development of the machine because citrus growers were not willing to contract to purchase unproven equipment.

The Agriculture Research & Education Center at Lake Alfred, Florida built an adjustable frame angle windrowing rake in 1967. The first rake had 4 pieces of heavy conveyor belting used as reel flaps. Another design used 4 rows of rake teeth as shown in Fig. 2. The design was not a complete success since a large windrow of fruit near the discharge resulted in fruit being carried over the top of the rake reel.

In 1968 and 1969, drop sheets were used to catch the fruit as it was hand harvested onto the ground. A pair of 6-mil polyethylene sheets 3.7 x 7.6 m (12 x 25 ft) with metal stakes tied on the 4 corners to hold the sheets in place were placed under each tree by pickers. The drop sheets were pulled from the center of tree to the center between 2 rows, as shown in Fig. 3. A windrow of fruit was formed for pick up by hand or by a pickup machine.

In 1967-68, the USDA designed and built a pickup machine which gathered the fruit from a 7.9 m (9.5 ft) wide path into the throat of a 0.74 m (2.4 ft) wide pickup conveyor (3). The gathering device used on this machine was 2 spiral conveyor screws 1.8 m (6 ft) long and 0.9 m (3 ft) in diameter similar to those used on the tung nut machine, which loaded the fruit onto the pickup conveyor. However, no fruit was gathered from the area under the tree canopy. Figure 4 shows the machine in field operation. The spiral conveyor screws would move fruit in a single layer only. Single, double, and triple conveyor screws were tested and none would move multiple layered fruit as it built up near the pickup conveyor.

Figure 5 shows the USDA side delivery citrus rake mounted on the front of a tractor. This machine was developed in 1968-70 to complete the shaker, windrow and pickup harvest system (4). The rake used 13 cm (5 in.) long rubber teeth spaced on 5.7 cm (2 1/4 in.) centers and mounted on 4 reel bars attached to a 36 cm (14 in.) diameter bearing plate that rotated at 150 rpm. The rake angle was 65° from the direction of travel. Field trials at various raking angles showed that 65° was optimum for moving citrus at low ground speeds. The front pivot point on the mounting frame and two gauge wheels mounted on the rear frame determined the raking depth of the rake teeth. The rake had a 71 cm (28 in.) side shift for moving in and out of the tree row as it passed by the tree trunk which allowed the tractor to travel down the row in a straight line.

The forward travel speed of the rake was 0.8 km/h (0.5 mph) when operating in a grove that had a fruit yield of 2041 kg (5 boxes) * of fruit per tree and a tree spacing of 7.6 x 7.6 m (25 x 25 ft). A single pass with the rake formed a 0.6 m (2 ft) wide windrow. A double windrow could be formed with the rake by straddling the first windrow with the tractor and raking in the opposite direction down the same row middle. This worked satisfactorily for a row spacing of 6.1 m (20 ft). However, at other row spacings, the tractor wheel ran over the fruit raked into the first windrow.

In 1970, an oblique rake 1.2 m (4 ft) long was mounted on the right side of the USDA pickup machine to increase the effective raking capacity. The oblique rake has a greater horizontal force component acting on the fruit compared with the conveyor screw. Figure 6 shows the position of the rake on the pickup machine.

In 1971, a self-propelled combination rake-pickup machine was designed and built by the USDA engineers (5). The purpose of this machine was to combine both operations under control of one operator and a single power unit. Three oblique rake sections were mounted at an angle of 65° from the direction of travel and arranged to cover a 4.4 m (14.5 ft) raking width. The front rake moved the fruit from in front of the pickup machine to the right side of the pickup chain. A 0.9 m (3 ft) long side shift rake moved the fruit out from around the tree trunks. It operated automatically or manually and also had a safety "break-away" on the frame which allowed the rake to move to the rear 30 cm(12 in.) if it struck a low hanging limb. The inner rake moved the fruit from the other two rakes and loaded it on the pickup chain. This combination rake and pickup machine was tested as part of a semicommercial harvesting system during the 1971-72 harvest season. Figure 7 shows the USDA rake pickup machine in operation. The machine operated successfully but the trash elimination system was marginal. A skilled operator was required because of the multiple functions. The hydrostatic drive was ideal, however, additional power was needed.

During 1971, the Speedsprayer Division of FMC Corporation designed and built a prototype self-propelled windrow rake. The machine was powered with a 44 hp gasoline engine and was equipped with hydrostatic drive. It had two drive wheels in front and a single steerable wheel in the rear. When maneuvering around the tree trunks, the rear steering moved the outside rake assembly into the tree instead of away. Some problems of running over fruit were encountered if the machine had to back up to get around a tree. The windrow rake consisted of one fixed 4 bar assembly approximately 7.9 m (9.5 ft) long and one 3 bar side shift oblique rake 2 m (6.5 ft) long for gathering fruit in the tree row (Fig. 8). Both rakes used rubber mounted steel teeth. The side shift rake had a horizontal brush assembly mounted on the outboard for gathering fruit around the tree trunks. An overall height of .46 m (1.5 ft) allowed for maneuvering under tree skirts and low hanging limbs. Production models of the self-propelled rake and tractor drawn pickup machine were available for the 1971-72 harvest season. The windrow rake formed a windrow located at the center between two rows. A second pass on the opposite side formed a double windrow. Excessive fruit damage generally occurred when forming a double windrow in high yielding groves.

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*A Florida citrus field box has a volume of 4,800 cubic inches and holds 90 pounds of oranges.

In 1972, the Citrus Systems Division of Upjohn Company adapted the Koehring apple pickup machine as a front mounted citrus pickup machine attache to the tractor. Oblique rakes as shown in Fig. 9 were added to the pickup machine to gather the fruit from under the tree and place it in the path of the pickup head. Fruit in the tree row was raked by hand to a position where the rakes on the pickup machine could gather the fruit. Approximately 35,000 boxes of oranges were raked and picked up with two of these systems during the 1971-72 harvest season. Use of this machine was not continued because it had limited capacity and required hand labor to gather the fruit.

Several brush gathering systems have been built and tested for windrowing fruit. Citrus Systems Inc. built a tractor mounted brush assembly which consisted of a series of polypropylene bristle brushes 15 cm (6 in.) high by 0.9 m (3 ft) in diameter mounted on long tubes which pivoted at the front of the tractor. The outside brush assembly consisted of 3 rings stacked 1 on to of each other to form a 15 cm (6 in.) thick brush. To handle the accumulativ fruit load as the fruit moves toward the discharge point of the windrower, as many as 7 rings stacked together make up the brush assembly.

A concave disk mounted under the brush assembly provided independent flotation of each brush assembly as the convex surface of the disk followed the ground contour. The tractor mounted unit consisted of 2 tubes with 5 brush assemblies mounted to the front tube and 4 on the rear tube (Fig. 10). On the front tube, 4 brush assemblies were fixed directly to the tube and the outer brush was mounted on a swing arm which attached to the tube and allowed the brush to move in and out of the tree line. All 4 brush assemblies on the rear tube were fixed directly to the tube. The brushes were positioned to overlap 30 percent of their diameter and form a windrow at the center between 2 rows. Each brush assembly was powered by a hydraulic motor and the angle o contact between the brush and ground was adjustable.

Approximately 3 hp was required for each brush assembly. The brush wind rower could travel at a faster ground speed than the oblique rake; however, it did not operate well in unlevel groves even with independent floating brushes. The pitch and roll angle adjustment on each brush were difficult tc maintain to keep fruit from being lost between brushes when the ground conditions changed. Because of high power requirements and adjustment problems, the brush windrower had limited use. In dry soil conditions, they also movec more soil into the windrow and this did present a dust problem in the grove. The operator could not see the tree trunk at times and suffered discomfort due to irritation to the eyes and respiratory system.

Citrus Systems Inc. also built a self-propelled double-sided brush wind-rower (Fig. 11) with an arrangement of brushes similar to the tractor mountec brush system, where the brush assemblies were attached to 4 arms, 2 on each side of the propelling unit. The front arms each had 5 brush assemblies and the rear arms 4, for a total of 18 brush assemblies on the machine. The brushes were adjustable for different row spacings through vertical pivot points and the arms attached to a horizontal tube which allowed them to pivo upward for transport. This machine gathered the fruit from both sides of th row and formed a windrow in the center between 2 rows.

A self-propelled single sided brush windrower was designed and built by Citrus Systems Inc. using some of the components from the FMC Commercial windrow rake. This machine consisted of half of the self-propelled double sided brush windrower (Fig. 12).

In 1973, a "curry" type rake was designed and tested by the USDA on their combination rake and pickup machine as shown in Fig. 13. The rake was 2.1 m (7 ft) long by 46 cm (18 in.) wide. Bars were spaced 23 cm (9 in.) apart with rake teeth spaced every 6.4 cm (2.5 in.) along the bar. Two rubber fingers were mounted at the rear of each bar on the leading side of the rake teeth to keep fruit from coming out the rear of the rake. The ends of the 46 cm (18 in.) long bars were attached to double-pitch roller chain (No. 2060). The rake teeth traveled along the soil 90° from the direction of machine travel at a speed of 85 m/min (280 fpm) and moved the fruit to and onto the pickup chain. Due to the limited capacity and slow ground speed, no further testing was done.

A low profile mini rake was designed and built by the USDA in 1974 to gather the fruit from around the tree trunks and place it in a position accessible for mechanical pickup (6, 7). The rake was 1.1 m (3.5 ft) long with 3 bars of rubber fingers and 36 cm (14 in.) high for operating under low hanging limbs. It was mounted to a 4.6 m (15 ft) long tube which pivoted at the front of a tractor allowing the rake to swing about a long arc away from the tree as a skid bar made contact with the tree as shown in Fig. 14. A spring attached at the front of the mounting tube held the rake out in the tree row and the outward swing was limited by a chain stop. This allowed the rake to swing in and out as it passed by a tree. Two caster wheel assemblies were mounted at the rear of the rake frame to provide flotation and height adjustment.

A brush assembly consisting of two coils of "Mile Master" 0.27 cm (0.1 in.) diameter polypropylene filament; 44 cm (17 in.) inside diameter and 94 cm (36 in.) outside diameter attached to a 51 cm (20 in.) diameter conical disc as shown in Fig. 15 was used in place of the mini rake for gathering fruit from around the tree trunks. The same long pull tube was used and the attachment mechanism provided angle adjustment of the brush with respect to the ground surface. The brush was effective in gathering the fruit from around the tree but the effective gathering width is approximately 70 percent the brush diameter and at least two brushes were needed to move the fruit to a position for mechanical pickup.

During the 1974-75 season, a new system for gathering and picking up oranges was developed by the USDA at Lake Alfred, Florida (6, 7). This system gathers the fruit into a windrow located at the tree dripline. A dripline rake was developed consisting of 3 oblique rakes mounted to a tractor. A 4 bar oblique rake 2.4 m (8 ft) long was mounted to the front of the tractor and gathered the fruit from the row middle to the dripline of the tree. A 1.1 m (3.5 ft) long 3 bar oblique rake with rubber fingers gathered the fruit from around the tree and discharged it in front of another 1.2 m (4 ft) long 4 bar oblique rake that moved the fruit into a windrow at the tree dripline. The center of the 1 m (40 in.) wide windrow was located 2 m (6.5 ft) from the center of the tree trunk. A rubber flapper wheel sweep was mounted in front of the left front tractor tire to move the fruit from the path of the wheel. The entire rake system was hydraulically powered from a pump driven directly off the front crank shaft of the tractor.

In 1976, modifications were made to this unit by redesigning the mounting of the 1.1 m (3.5 ft) and 1.2 m (4 ft) oblique rakes (8). The rakes were attached to a frame that mounted to the right rear tractor axle and transmission housing. It had a pivot tube for raising and lowering the rakes through an arc of 110° for transport. The 1.1 m (3.5 ft) rake was mounted on slide rails for shifting approximately 0.9 m (3 ft) in and out of the tree row. The tractor mounted design provided better operator control with increased rake efficiency and speed. A forward travel speed of 2 km/h (1.3 mph) could be realized in groves ideally suited for raking. The transport position of the rakes on the tractor was much improved over the original dripline system. Figure 16 shows the windrow rake in field operation.

A tractor drawn windrow rake was developed in 1978 as shown in Fig. 17, (9). The rake had a steered rear axle and gathered fruit either to the tree dripline or by changing one rake assembly, it could gather fruit to the center between two rows. The rake arrangement was similar to the tractor mounted rake except that the left front rake on the tractor mounted system was relocated to operate behind the trailer wheels. The hitch tongue was adjustable for allowing the rake to operate in and around the trees while the tractor remained in the center between two rows. Wheel sweeps were mounted in front of the tractor tires for clearing the area ahead of the wheels. The rakes pivoted up for transport and the unit could be towed at 80 km/h (50 mph) for moving from one grove to another.

RAKE TEETH FOR OBLIQUE RAKES

The oblique raking principle has proven to be a satisfactory method for moving fruit into a windrow for pickup. A continual problem of oblique rakes has been the breakage and bending of the rake teeth. A search for rake teeth that would perform in the varying grove conditions without excessive fruit damage has been under way for the last 10 years.

Figure 18 shows 5 types of rake teeth that have been used on oblique citrus rakes in Florida. The first oblique rake was designed with a rubber tooth (Fig. 18, item 5) 13 cm (5 in.) long, tapered from 2.5 cm (1 in.) in diameter to 2 cm (0.75 in.), spaced 5.7 cm (2.25 in.) apart for minimum fruit damage. The soft rubber construction of this tooth allowed too much flexibility when raking in dry sand and resulted in low rake efficiency. A replacement steel tooth rubber mounted (Fig. 18, item 1) used on several oblique side delivery hay rakes was shortened from 23 to 13 cm (9 to 5 in.), depending on the particular rake design, to minimize rake height. Rubber tubing was slipped over the steel tooth to reduce fruit damage in some groves. The rubber mounted steel teeth spaced 5.7 cm (2.25 in.) apart gave high rake efficiency in all soil conditions tested including sod where the grove surface was reasonably level. However, tooth breakage occurred at the rubber joint (Fig. 19, items 3 and 4) if the tooth was overstressed by raking over tree roots, small branches and other obstructions. Breakage frequency was increased as the tooth aged and the rubber mount became brittle.

A small rubber mounted tooth (Fig. 18, item 4) was used on the commercially built rake for windrowing citrus. The smaller teeth deflected more than the larger teeth under load which resulted in lower raking efficiency, especially when fruit yields were high. Tooth breakage was excessive and more frequent with the smaller teeth than with the large teeth. The steel rod of the small tooth would bend when it made contact with obstructions or get deflected into other adjoining rake bars.

Spring coil teeth (Fig. 18, item 3) were tested on a rake as a replacement for the rubber mounted steel teeth. The spring coil tooth seldom broke, however, they would bend (see Fig. 20) while raking in heavy fruit loads causing the tooth to deflect into other tooth bars, especially when raking over exposed tree roots near the tree trunk. Most of the teeth could be straightened without removing them from the tooth bars. This was done by the operator about every 2 hours when operating in adverse conditions. Bending is expected to be minimal by providing more clearance between tooth bars on new rake designs.

A rubber mounted steel tooth (Fig. 18, item 2) from a different manufacturer was tried in 1979 on one of the rakes. It was easier to install on the tooth bars, had a smaller rod and had more flexibility than the other large rubber mounted steel teeth. The new teeth performed almost as well as the large rubber mounted steel teeth and the spring teeth on the same rake.

SUMMARY AND DISCUSSION

Citrus raking equipment has been developed to gather fruit to a position that is accessible for pickup equipment. The oblique raking system was developed to gather fruit from around the tree line and place it in a location for pickup with minimum fruit damage. The tooth travel is almost perpendicular to the forward travel of the rake and this minimizes the distance of travel for gathering fruit to the windrow. The oblique rake does a good job of gathering the fruit and not moving a large amount of soil along with the fruit. Different tooth lengths are used depending on the location of the rake in the system and the fruit load. Short teeth are used when possible to provide a low rake profile that can operate under low hanging limbs. Fruit damage often occurs when the rakes become over-loaded 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.

A constant problem with the oblique rakes is the breakage and bending of the rake teeth. Additional testing and improvements are needed to increase the fruit recovery efficiency and decrease the fruit damage caused during the gathering operation.

The brush type of gathering system was developed for uneven groves but was highly influenced by soil conditions, fruit load, brush speed, machine forward travel speed, and grove terrain. The brushes performed better in damp soils compared to dry sandy conditions where they move and excessive amount of soil and they are difficult to keep adjusted for effective fruit movement in different soil and terrain conditions.

Grove preparation is desirable for the raking equipment to perform to maximum efficiency. Low-hanging limbs need to be pruned and some branches removed to permit the rake and brush to gather fruit from around the trunk of the tree. At the present time, the acceptance of windrowing equipment by the industry has been limited. Hand labor is available and using mechanical means to harvest citrus has not proven to be more economical than hand labor. A commercial rake for windrowing citrus was available but due to the lack of interest and sales, it is not being manufactured at the present time. Industry and research groups are continuing to develop and improve mechanical methods for gathering citrus into a location for the pickup operation.

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