

Development of an Auger Picking Head for Selectively Harvesting Fresh Market Oranges

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THE Florida citrus industry harvested 144 million boxes of oranges (1) during the 1966-67 season. The large amount of hand labor required to harvest this crop is more difficult to recruit each year. An inertia tree-shaker and catching-frame system for harvesting citrus was developed in 1966 by Coppock and Hedden (2). This system is suitable for harvesting early and mid-season oranges utilized for processing, but it damages too much such fruit that is to be shipped fresh, and it decreases the yield of "Valencia" oranges — the only late season variety — by removing the young fruit that is developing for the following season's crop. A harvester for Valencia oranges, which make up 50 percent of the Florida orange crop, must remove the mature fruit without damaging or removing the green fruit from $\frac{1}{4}$ to 2 in. in diameter which is on the tree at harvest time. Research on an auger picking head has been aimed at developing a harvest system for Valencia oranges and for fruit that is to be shipped fresh.

Research on the auger picking head was originally started by Coppock (3), who tested a bank of sixteen, 4-in. diameter augers spaced $4\frac{1}{2}$ in. apart on a square spacing. These augers were fabricated of 35 to 45 durometer $\frac{1}{4}$ -in. thick sheet neoprene cemented together. The augers were very time consuming to make, they were not durable enough for extensive testing. The auger flights deflected primarily at the roots of the flight in the glued joint, and, for that reason, it was not certain that these augers closely simulated a molded auger. Only molded augers would be durable enough for a commercial harvest machine.

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* Numbers in parentheses refer to the appended references.

The work reported here progressed from a study of the individual auger characteristics to a study of auger arrangements to a test of a prototype auger bank. Part I, "Auger Shape, Hardness, and Diameter," reports on the effects of auger characteristics on fruit removal and foliage entanglement. Part II, "Auger Bank Configurations," reports on the effects of auger spacing, of rods between the augers, and of square and triangular auger arrangements. Part III, "Prototype Auger Bank," reports on the speed of picking and the percent of fruit removed with a 5-ft square prototype auger bank.

PART I. AUGER SHAPE, HARDNESS, AND DIAMETER

Work to optimize the auger shape and diameter necessitated development of a method to fabricate a number of different shaped augers at reasonable cost. Although it was not necessary that these augers be extremely durable, it was important that they closely simulate a molded auger.

A number of recently developed room-temperature vulcanizing (RTV) elastomers can be cast in plaster-of-Paris molds, and two of these elastomers, polyurethane and polysulfide rubber, were found suitable for casting prototype augers (Fig. 1). The molds themselves were cast in three sections using an auger of $\frac{1}{4}$ -in. thick neoprene cemented together for a pattern. Each mold was durable enough to be used for casting at least 20 augers. Silicone rubber compounds made by three different companies were tested but their tear strength was much too low to be used for casting experimental augers.

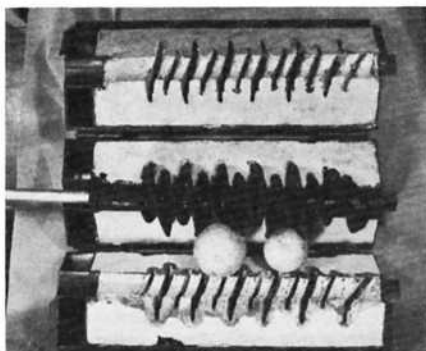


FIG. 1 A three-section plaster of Paris mold used to cast room temperature curing polyurethane augers.

Procedure

Augers of each type shown in Figs. 2 and 3 with the dimensions given in Table 1 were tested to develop an auger shape and diameter which did not entangle the foliage, would remove fruit effectively and convey it to the back of the auger bank without damage. Five different types of $5\frac{3}{4}$ -in. diameter augers (Fig. 2) were tested to determine the effect of auger hardness and shape. One type each of the $3\frac{7}{8}$ -in. diameter, $8\frac{1}{8}$ -in. diameter, and $9\frac{1}{8}$ -in. diameter augers were tested to determine the effect of auger diameter.

The $5\frac{3}{4}$ and $3\frac{7}{8}$ -in. diameter augers were both tested in auger banks of 16 augers in a triangular arrangement. The $5\frac{3}{4}$ -in. diameter augers were spaced 7 in. apart (Fig. 4c) in the auger bank and the $3\frac{7}{8}$ -in. diameter augers were spaced $5\frac{1}{2}$ in. apart (Fig. 4f). Ten of the $8\frac{1}{8}$ (Fig. 4b) and $9\frac{1}{8}$ (Fig. 4a) — in. diameter augers were spaced $10\frac{1}{2}$ in. apart in an auger bank with a triangular arrangement.

The banks with $3\frac{7}{8}$ and $5\frac{3}{4}$ -in. diameter augers had a similar amount of space — $2\frac{7}{16}$ -in. diameter — for an orange between each set of three augers. The space between each set of three $8\frac{1}{8}$ -in. diameter augers was $3\frac{1}{2}$ in. in diameter and the $9\frac{1}{8}$ -in. diameter augers had a space 3 in. in diameter between them.

The auger shafts were 10 in. longer than those tested by Coppock so that the augers protruded 40 in. from the drive unit. More fruit could be reached with the longer auger shafts; however, the augers usually ran into a limb or became entangled before penetrating their full length. At least one tree was picked with augers of each type after

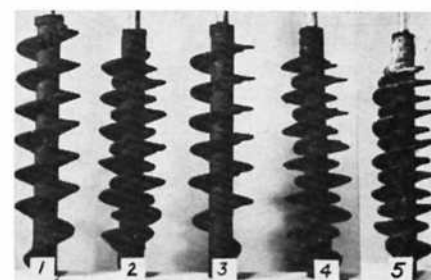


FIG. 2 Five different types of $5\frac{3}{4}$ -in. diameter augers tested. Types 1 and 2 were cast out of polysulfide rubber (30 durometer hardness) types 3, 4, and 5 were cast out of polyurethane (60 durometer).

TABLE 1. SALIENT DIMENSIONS OF EXPERIMENTAL PICKING AUGERS TESTED

Auger No.	No. of auger flights	Durometer hardness	Pitch of flights	Major diameter of largest auger flight	Major diameter of smallest auger flight	Minor diameter
(Fig. 2)						
1	1	30	2 3/4	5 3/4	---	2
2	2	30	2 3/4	5 3/4	3 3/4	2
3	1	60	2 3/4	5 3/4	---	2
4	2	60	2 3/4	5 3/4	3 3/4	2
5	2	60	2 3/4	5 3/4	4 3/4	2
(Fig. 3)						
6	1	60	2 1/2	3 3/4	---	1 1/2
7		(Same as No. 4 in Fig. 2)				
8	4	60	5	8 1/8	7	2 3/4
Not shown	4	60	5	9 1/8	7	2 3/4

* There were two flights of both diameters of this auger.

they had been adjusted to run at their optimum rotational speed. Each was evaluated for its effectiveness in removing the fruit and the extent to which it entangled the foliage.

The auger bank was positioned and then moved into the tree radially with a "scissors" positioner while the augers all rotated in the same direction (CCW looking at the front of the auger bank). The augers were then pulled out of the tree as they were rotated in the opposite direction and repositioned to enter the tree again.

Results and Discussion

Effect of Auger Hardness Auger types 1 to 5 are arranged in Fig. 2 according to the degree that they tended to entangle the foliage. Type 1 entangled the foliage most often, and types 4 and 5 entangled the foliage the least often. The softer (30 durometer) polysulfide rubber augers (Types 1 and 2, Fig. 2) did not slip through the tree foliage as easily as the harder (60 durometer) polyurethane auger (types 3, 4 and 5). The foliage tended to cling and wrap around the polysulfide augers.

The hard and soft augers removed the fruit equally well. In fact, all five of the 5 3/4-in.-diameter auger types removed nearly 100 percent of the fruit once the fruit was entrained within the bank of augers. Each of these auger types appeared to grasp the fruit equally well, and each was equally aggressive in pulling the fruit into the bank of augers.

Effect of Auger Shape Auger shapes having a second smaller diameter flight between the main flight (Types 2, 4 and 5) entangled the foliage less than the single-flight augers. This effect was much more pronounced when the two auger shapes made of the polysulfide rubber were compared. The smaller flight increased the effective diameter of the auger shaft as "seen" by the foliage, and a large diameter shaft has less tendency to wrap up in the foliage than a small diameter shaft.

Auger shape did not have any effect on fruit removal. However, auger type 5 with the largest second flight did not convey the fruit to the back of the auger bank as well as the other two shapes of polyurethane augers (Types

3 and 4). The large fruit was often in firm contact with three augers all of the time and consequently would simply idle in one place. Apparently it is necessary that the fruit have some room to "fall" for the fruit to be conveyed.

The two most effective 5 3/4-in. diameter auger shapes tested (No. 3 and 4, Fig. 2) were compared in two additional tests. Sixteen augers of each type were tested with a 7 1/2-in. center distance between the augers in a triangular auger arrangement. At the time of the first test (October 4, 1967), the fruit was small and had a high removal force. This fruit tended to wedge between the flights of the single-flighted auger (Type 3) causing the foliage to be twisted around the auger. The smaller flight of the double-flighted augers (Type 4) prevented the fruit from wedging between the flights and, consequently, these augers removed much less foliage. At the time of the second test (November 3, 1967), the larger fruit with a lower removal force prevented the fruit from wedging between the flights of the single-flighted augers and resulted in both types of augers entangling the foliage about the same amount. Usually there was little difference between the operation of these two auger shapes; however, the double-flighted auger always operated as well if not better than the single-flight auger.

Effect of Auger Diameter Increasing the size of the augers caused them to crowd the foliage and entangle it. The 9 1/8-in. and 8 1/8-in. diameter augers entangled the foliage so severely that they were not rated for fruit removal even though there was more room between these augers for the fruit. Instead of going into the foliage, larger augers would push it to one side and remove only a small portion of the fruit. Any foliage pulled into the bank of augers was usually damaged and entangled to a much greater extent than with the smaller augers.

The 5 3/4-in. diameter augers entangled the foliage once every six or seven times they were extended into the tree but could effectively be used to remove the fruit. The smallest augers (3 3/8-in. diameter) very seldom entangled the foliage and effectively removed the fruit.

PART II. AUGER BANK CONFIGURATIONS

Using the optimum 5 3/4-in. diameter augers tested (Fig. 3) and the 3 3/8-in. diameter augers, a number of different auger bank configurations (*i.e.*, spacial arrangements of the augers) were tested. These configurations included triangular and square arrangements of the augers, three different auger spacings, and the placing of rods between each three augers in the triangular arrangements (Fig. 4). The 8 1/8 and 9 1/8-in. diameter augers were not used in this test but are included in Fig. 4 so as to show all the configurations that were ever tested. One-half a tree was picked with each auger bank of sixteen augers and the auger configuration rated for fruit removal, foliage entanglement, aggressiveness, and conveying of the fruit.

In these tests, the augers were rotated in the same direction all of the time the auger bank was moving in and out of the tree. Previously the augers were often reversed when pulled out of the tree to untangle the foliage. This was time consuming, and one of the primary objectives was to develop a configuration that would remove the fruit without entangling the foliage. The 5 3/4-in. diameter augers were rotated at approximately 250 rpm or 376 surface feet per minute and the 3 3/8-in. diameter augers worked best at 330 rpm or 334 surface feet per minute.

The auger configurations were defined as being closely spaced, intermediately spaced, or loosely spaced as determined by the amount of space between the augers for the fruit. A 2 7/16-in. diameter cylinder was the largest that would fit between the closely spaced augers; a cylinder between

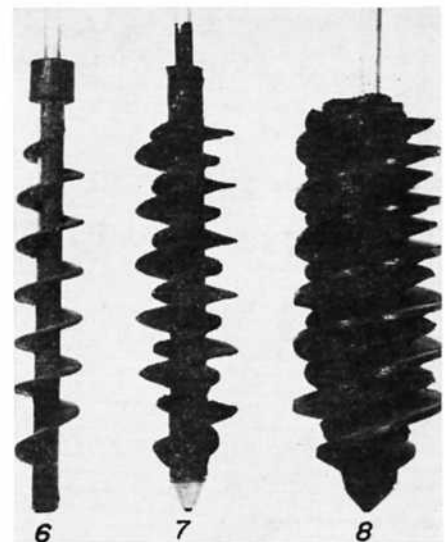


FIG. 3 Three different sizes of augers tested: a 3 3/8-in. diameter auger; the optimum type of 5 3/4-in. diameter auger, and an 8 1/8-in. diameter auger. A fourth size, 1 in. larger in diameter than the largest auger shown, was also tested.

TABLE 2. OPERATING CHARACTERISTICS OF AUGER CONFIGURATIONS TESTED

Auger diameter, in.	Auger center distance,° in.	Fruit removal	Entanglement of foliage	Aggressiveness	Conveying of fruit
5 3/4	7 tri (C)	Excellent	Substantial	Excessive	Good
5 3/4	7 1/2 tri (D)	Satisfactory	Negligible	Satisfactory	Good
5 3/4	8 tri (E)	Poor	Negligible	Satisfactory	Poor
3 3/8	5 1/2 tri (F)	Excellent	Negligible	Satisfactory	Good
3 3/8	6 tri (G)	Satisfactory	Negligible	Satisfactory	Good
3 3/8	7 tri (H)	Very poor	Negligible	Satisfactory	Poor
3 3/8	4 1/2 sq (I)	Excellent	Substantial	Satisfactory	Good
3 3/8	4 15/16 sq (J)	Satisfactory	Negligible	Satisfactory	Fair
5 3/4	8 tri (K)†	Satisfactory	Negligible	Too little	Poor
3 3/8	7 tri (L)†	Satisfactory	Substantial	Too little	Poor

° Center-to-center distance between augers. "Tri" indicated triangular auger arrangement with three-point fruit contact; "Sq" indicates square auger arrangement with four-point fruit contact. The letter in parenthesis is the number of the configuration shown in Fig. 4.

† These arrangements had 3/4-in. diameter rods centered between each three augers.

2 7/8 and 3 in. in diameter would fit between the intermediate spaced augers, and a cylinder 3 1/2 in. in diameter would fit between the loosely spaced augers.

Results and Discussion

Auger Spacing Fruit removal was inversely related to the space between the augers through which the fruit could slide out of the auger bank. Closely spaced auger configurations C, F, and I (Fig. 4) removed all of the fruit which entered the auger bank (Table 2). Closely spaced configuration K (Fig. 4) did not remove all of the fruit, probably because of insufficient auger contact on the fruit. Configurations D, G, J, and L (Fig. 4) with intermediate spacing removed most (90 percent or more) of the fruit which entered the auger bank but did not remove the fruit as quickly as the closely spaced configurations. The loosely spaced configurations E and H (Fig. 4) removed only about two-thirds of the fruit which entered the auger bank.

The maximum triangular spacing of any size augers between 3 3/8 and 5 3/4 in. in diameter which will result in most of the fruit being removed is given by the following equation:

Auger spacing = (Auger diameter + 3 in.) cos 30 deg. This equation was derived from the geometry of configurations D and G (Fig. 4) and simply gives the spacing which will allow a 3-in. diameter cylinder to be placed between the augers.

Too close spacing of augers caused them to entangle foliage. Closely spaced 5 3/4-in. diameter augers entangled the foliage because there was not enough room between the augers for the foliage. Crowding of the foliage was also evidenced by a greater amount of power required to drive the closely spaced 5 3/4-in. augers than the intermediate or loose spacing. Neither the intermediate nor the loose spacings of the 5 3/4-in. augers entangled foliage.

The auger configurations, which crowded the foliage, entangled the foliage less if the augers were extended into the tree very slowly. This gave them a chance to pull the foliage to the back of the auger bank and straight-

en it out thus resulting in less foliage crowding. Moving the augers radially into the tree also decreased the foliage entanglement. Any branches crossways of the augers had much more tendency to entangle.

The aggressiveness of an auger bank was defined as the tendency of the

auger bank to pull foliage into it. Auger aggressiveness was generally related to how crowded the foliage was in the auger bank. Both the 5 3/4-in. augers on a close triangular spacing and the 3 3/8-in. augers on a close square spacing were aggressive auger banks.

Effect of Auger Arrangement and Rods Between Augers Fruit removal was affected relatively little by whether the auger configuration included rods or whether the augers were arranged in a triangular or square pattern. Configurations with 3 3/8-in. augers removed the fruit slightly slower than configurations with a similar spacing of 5 3/4-in. augers, probably because of a smaller area of contact between rotating augers and the fruit. For this reason, the 3 3/8-in. diameter augers in a triangular arrangement did not remove the fruit as rapidly as the square arrangement, and

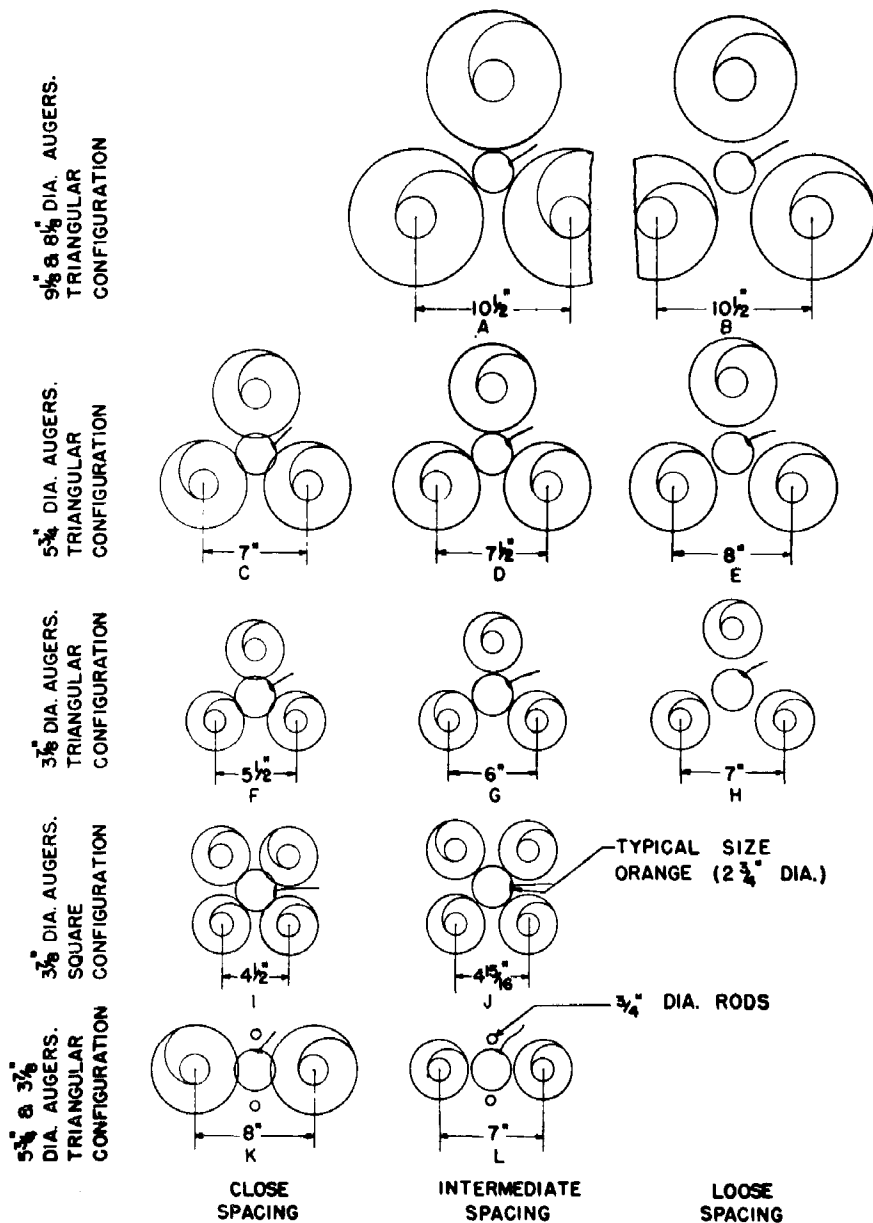


FIG. 4 Schematic drawing of the different auger configurations tested. Each schematic represents one of the fruit-removing "holes" in an auger bank. In a particular auger bank, all of the "holes" were the same geometrically, but some of the holes would be oriented differently than others.

