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SHAKER-PICKUP HARVEST SYSTEM FOR EARLY AND MIDSEASON ORANGES

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Abstract. **Early and midseason oranges were loosened with an abscission chemical, removed from the tree with a limb shaker, picked up from the ground with a windrowing pickup machine, roadsided, and transported to the processing plant. Performance and compatability of components, harvesting costs, and effects of the system on the fruit were determined in 3 grove areas.**

The cost of harvesting (tree to processing plant) varied from 70 to 88¢ per box in groves yielding 6 to 11.5 boxes per tree. The abscission chemical did not reduce fruit bonding force as much as expected and in some cases was not economically justified. A larger amount of foreign material and unwholesome fruit was delivered to the processing plant than is usually encountered with hand harvesting but was acceptable under State Inspection Standards.

The shaker-pickup harvest system is one of several systems proposed for mechanically harvesting citrus fruit. Components of the system have been under development at the Agricultural Research and Education Center-Lake Alfred for several years (1, 2). Their development has progressed to a level at which they could be field tested in an integrated harvesting system. In the past, meaningful independent component evaluations have been difficult because the components are dependent on each other, i.e., a pickup machine must have fruit on the ground before its performance can be evaluated.

The purpose of this study was to evaluate the tree shaker-pickup system and its components operating under a variety of grove, fruit, and weather conditions during the 1971-72 early and midseason orange season. The criteria for evaluating the system were performance and compatability of components, harvesting costs, and effect of various fruit and tree conditions on the system.

Materials and Methods

Harvesting experiments with 2 varieties of oranges were carried out in the following locations and orange varieties:

1. Lynchburg (Coca Cola Co.) 'Hamlin,' 20 x 24 ft. tree spacing.
2. Florida Gold (Coca Cola Co.) 'Pineapple' 25 x 25 ft. tree spacing.
3. Winter Garden (Southern Fruit Dist.) 'Pineapple' 25 x 25 ft. diamond tree spacing.

Average fruit yields for the 3 groves were 7.3, 10.3, and 8.1 boxes per tree, respectively. The groves were selected because of their suitability for the use of limb shakers and the windrow-pickup machine. A tree skirt clearance of 20 inches was necessary for operation of the rake-pickup machine and the grove was required to be relatively flat, with only negligible grass, weeds, and pruning residue. No extensive tree pruning nor land preparation was necessary in the groves selected for these experiments.

Each grove area contained 3 plots with enough trees to yield approximately 400 boxes per plot. Two plots were sprayed with Acti-Aid (cycloheximide) at concentrations of 10 and 15 ppm (20 ppm at Winter Garden) respectively, and the third plot was left unsprayed as a control. Fruit samples were pull tested until it was judged that the chemical had achieved its maximum fruit loosening, (usually 5 to 7 days after spray application).

Two self-propelled limb shakers designed and constructed at the AREC-Lake Alfred were used in the harvest system. One shaker had an 8-inch

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[2]Mention of commercial organizations or products in this report is solely to provide specific information. It does not constitute endorsement by the U.S. Department of Agriculture over other organizations or products not mentioned.

stroke and was operated at a maximum frequency of 250 cpm (cycles per minute) and the other had a 6-inch stroke and was operated at 350 cpm (cycles per minute). Each shaker required a single operator and all trees were shaken from one side. Time and motion studies were made of the limb shakers. The rate of harvest and percentage of fruit removed were determined and amount of fruit damaged in the fall from tree to ground was estimated by sampling 4 square areas (3 ft. x 3 ft.) under 6 randomly selected trees in each plot. A grove laborer was employed to rake fruit out to approximately 1 ft. around each tree trunk for better windrow rake performance. He also gleaned fruit not removed by the shaker from the tree skirts.

A combination windrow-pickup machine developed at the AREC-Lake Alfred was used to gather the fruit and load it into a conventional hi-lift grove truck. The windrow pickup machine moved the fruit from under the tree skirt on one side, onto a pickup chain, where it was elevated into a 30-box capacity hopper. The 2-inch pitch rod draper pickup chain allowed sand and much of the trash picked up with the oranges to fall through the chain onto the ground. When the hopper was full, the machine was stopped and the fruit dumped into a hi-lift grove truck and transported to the roadside loading area. The windrow-pickup machine had an effective raking width of 14 feet and could be retracted 3 feet in length to clear low limbs and tree trunks as it progressed down the row. Time and motion data, work rates, and split fruit counts were taken throughout the 3 harvest tests.

Semi-trailers containing the harvested fruit were accompanied through the receiving lines of the respective processing plants to obtain quality data from the State Inspection Service under Department of Citrus regulations. A double sample was taken by the State controlled sampler and the percentage of unwholesome fruit was determined by the State Inspector. The amount of trash and unwholesome fruit removed by the grading personnel in the respective receiving lines was observed and recorded by catching and weighing the pickouts before the fruit passed through the State test sampler.

A complete cost analysis was made of the respective harvest operations using estimated machine costs and the actual field performance data. The straight line depreciation method was used in determining fixed charges for equipment. The performance data were used to determine cost per hour of operating time and converted to cost per box. Fruit losses were based on a value of 50¢ per pound-solids.

Results and Discussion

The abscission chemical, in general, did not produce the degree of fruit loosening experienced in previous seasons. Fruit loosening in the plots sprayed with the 15 ppm concentration of Acti-Aid was rarely below 7 lbs. pull force. The average pull force in the unsprayed control plots was 13.65 lbs. Standard deviations in the pull force for the sprayed treatments were generally large, indicating considerable variation in response of the fruit to the chemical. The abnormally warm winter season and lack of tree dormancy might have caused some of the variation in chemical response.

Efficiency of fruit removal was not appreciably affected by the abscission chemical but the rate of harvest was increased because it took less time to harvest 90% or more fruit in the sprayed plots. The average percentage of fruit removal for all plots was 95.4%. There were fewer stems attached to fruit harvested from the abscission plots by a ratio of 4 to 1 between the unsprayed control and highest application rate of abscission material.

The harvest rate of each shaker ranged from 51 to 87 boxes of fruit per hour or 6 to 14 trees per hour; the highest harvest rate occurred in the 15 ppm abscission plots. An average of 30% of the operators time was spent shaking limbs but 53% of his time was used in positioning the shaker boom and in grasping the limb for shaking. Ten percent of shaker operating time was required in moving the shaker transport and 7% was spent raking fallen oranges from the area in front of the wheels. Shaker positioning time could be reduced by pruning the trees so as to make the limbs more accessible and reduce the number of main limbs which must be shaken. The average number of limbs shaken per tree varied from 4 limbs per tree in a Winter Garden 'Pineapple' grove (where the work rate was highest) to 8 limbs per tree in the Florida Gold 'Pineapple' grove.

The percentage of fruit that was split in being shaken from the trees or from falling on the ground varied between groves. The splitting was related to tree height, ground conditions, and fruit type. An average of 4.0% of the fruit was split in the Lynchburg 'Hamlin' grove (which had a thin skinned fruit) and 1.6% was split in the Florida Gold 'Pineapple' grove (which had a

thicker skinned fruit). The highest percentage (5.7%) was split in the Winter Garden 'Pineapple' grove where the trees were tall and the soil compacted easily.

The varying grove conditions of soil, moisture, trash, and tree skirt height resulted in considerable variability in windrow-pickup machine performance. In the Lynchburg 'Hamlin' grove, the sandy soil was moist, but not wet, which offered excellent ground conditions. Heavy dew delayed the pickup operation until approximately 10:30 a.m. each morning. The pickup machine operating in the Lynchburg 'Hamlin' grove passed by an average of 43 trees per hour or picked up 298 boxes per hour at a continuous "down the row" rate without delays. Rows were 33 trees long. An average of 2.9 minutes were required to turn the pickup machine around at the end of each row. Including the delay and unloading time in the pickup machine operation, 51.3% of the total operational time was spent picking up fruit, 15.6% was spent in unloading the fruit hopper, and 33.0% was spent in delays or downtime due to mechanical problems, tree interference, or sticks and sand clogging the machine.

Conditions at the Florida Gold 'Pineapple' grove were better than at Lynchburg for picking up fruit. The trees were more widely spaced (25 x 25 feet), the soil was level and not wet enough to cause a buildup in the machine, and the tree skirts were high enough to cause little interference with the gathering rake. The pickup machine handled fruit at an average sustained rate of 289 boxes per hour at a grove speed of 30.3 trees per hour. Of the total operating time, 69.3% was spent picking up fruit, 9.3% was spent unloading the fruit hopper, and 21.4% of the time was taken up by delays due to mechanical problems, dirt and stick buildup, or waiting for the hi-lift truck.

The Winter Garden 'Pineapple' grove was quite different from either of the previous groves in tree structure and soil characteristics. The trees were approximately 25 feet tall with tree skirts 6 to 8 feet above ground. The soil was firm, moist, and much heavier than in the other groves. Several heavy rainfalls occurred during the experiment which made the machine clog easily with wet sand and slower ground speeds were necessary. The fruit pickup rate at Winter Garden averaged 183 boxes per hour for the 3 treatments and the machine speed was 31 trees per hour. These average figures, however, cover a wide range of 23 to 39 trees per hour and 145 to 229 boxes per hour. The lower figures were pickup rates after a heavy rainfall. Of the total operating time, an average of 69.3% was spent picking up fruit, 6.8% was spent unloading the fruit hopper, and 23.9% was spent in delays due mostly to excessive buildup of wet sand in the machine.

The highest pickup rate was achieved in the Lynchburg grove. However, almost as much fruit per hour was picked up at the Florida Gold grove while passing only 70% as many trees because of the higher fruit yield (approximately 2.5 more boxes per tree) of the Florida Gold trees.

The capacity of the windrow rake appears to be a limiting feature on the pickup machine, although the machine as a whole was able to keep up with the output of the 2 self-propelled limb shakers. Fruit damage occurred in the windrow rake at the point where the retractable portion of the rake overlapped the fixed portion as it retracted to go around a tree trunk. If the ground speed of the machine of the fruit density on the ground became too great, fruit was carried over the rake bars and was usually crushed. However, this condition seldom occurred because of the wide speed range built into the machine. In comparison to the large 60-box elevated hopper used on previous machines, the low profile, lift hopper worked very well as a surge bin. Unloading the surge bin while continuing to pick up fruit did not seem necessary though unloading required 7 to 15% of the total operating time. Some of this lost time might be eliminated if no surge bin were used and if fruit were loaded directly into a hi-lift truck, however, an additional truck would be required. Some trash in the form of cans and chopped up portions of hedge trimmings was loaded along with the fruit and had to be sorted out at the processing plant. This trash could become a plant disposal problem; however, it was not a problem as far as picking it off the sorting belt was concerned.

Grove truck hauling rates were not obtained in all cases but one hi-lift truck kept ahead of the pickup machine most of the time. A round trip to the road truck averaged 8.3 minutes at Lynchburg where the semi-trailer was located 0.35 mile from the grove area. In all other tests (Florida Gold and Winter Garden), the road truck loading area was located at the ends of the pickup rows so that no road travel wes necessary. When the Lynchburg road travel time of 3.3 minutes is deducted from the total round trip time (8.3 min.), an average time if approximately 5 minutes remains for the grove truck to leave the grove, unload, and return to the pickup machine.

Data used in the cost analysis, outside of

actual performance data, are estimates generally agreed upon by the personnel conducting this test, since historical data are never available for a new machine. Table 1 lists some basic assumptions and the resultant hourly machine costs used in evaluating this shaker-pickup system. Using these cost data, the per box cost of the harvest system components and fruit losses for the 3 harvesting treatments in the 3 test groves are shown in Table 2. The costs range from 70 to 88 cents per box depending largely upon the effectiveness of the abscission chemical which influenced tree shaker harvest rate and fruit removal.

The results of the Lynchburg test (Table 2) show large variations in shaking, grove loss, and plant loss costs. The higher shaking cost of the unsprayed control treatment resulted from more time being required to achieve the desired fruit removal from the tree. The higher grove loss cost of the control treatment resulted from partial removal of unwholesome fruit as the fruit was picked up in the grove by a sorter in the hopper of the pickup machine. The result was a higher cost for grove loss and a lower plant loss cost in comparison to plots treated with abscission chemicals.

Results of the Florida Gold test (Table 2) indicate a decided advantage for the treatment receiving no abscission agent application. The total cost advantage of the control treatment compared to the 10 ppm abscission treatment was the cost of applying the 10 ppm abscission treatment which in turn provided no increase in harvest rate or removal efficiency. Results are unfairly biased against the 15 ppm abscission treatment compared to the control. Principally, grove loss costs are responsible for this. Harvest rate for the 15 ppm treatment plot was 77 boxes per hour for each limb shaker compared to 67 boxes per hour for the control plot. This increased harvest rate apparently resulted in reduced fruit removal for this test. The figures in Table 2 also indicate larger amounts of fruit left in the Florida Gold grove and a decreased amount of unwholesome fruit in the official plant test when compared to the 10 ppm treatment control plots. Both factors occurred as a result of grading out unwholesome fruit in the grove. These factors are reflected in an approximate 9 cents per box higher grove loss cost for the 15 ppm test plot as compared to the 10 ppm treatment and the control plots. The zero cost for plant grading means that at the receiving line there was no increase in sorting labor required over the conventional setup.

During the harvest of the Winter Garden plots, heavy rainfall occurred while the control and 10 ppm abscission treatment plots were being harvested. The plot with 20 ppm of abscission agent showed a decided cost advantage for fruit removal and grove loss cost when compared to the 10 ppm treatment plot and the control plot. The canopy of the Winter Garden trees had many long willowy fruit hangers making a high percentage of fruit removal virtually impossible without the use of the abscission agent. The abscission action on the 10 ppm test plot was not as good as desired because more fruit was left on the trees in comparison to the 20 ppm test plot. Consequently, the grove loss cost was higher. This test indicated that the abscission agent must do an excellent job in order for reductions in shaking cost and grove loss cost to offset the additional cost of applying an abscission agent. Harvesting the 10 ppm test plot resulted in a total cost of 88.2¢ per box. This higher total harvest cost is a result of the additional cost for

Table 1. Data used in analysis of ASPT system.

System component	Initial cost ($)	Life (yr)	Annual usage (hr)	Fixed cost ($/hr)	Operating cost ($/hr)	Overhead cost ($/hr)	Total cost ($/hr)
Limb shaker	10,000	5	550	4.32	7.38	1.76	13.46
Pickup machine	20,000	5	450	10.57	9.30	2.98	22.85
Hi-life truck	10,000	8	800	2.22	5.63	1.18	9.03

Table 2. Operation costs for the shake-pickup system.[z]

Location	Lynchburg-[y] 'Hamlin'			Fla. Gold 'Pineapple'[y]			Wtr. Garden 'Pineapple'[y]		
Treatment (ppm)[x]	0	10	15	0	10	15	0	10	20
	Operation Cost - cents/box								
Abscission	0	6.5	8.6	0	6.4	8.3	0	10.3	12.2
Shaking	24.1	19.3	20.4	20.5	21.3	18.1	27.3	23.1	16.1
Rake-pickup	11.5	11.2	12.1	13.6	14.0	11.6	15.3	15.3	15.3
Roadside loading	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
Grove loss[w]	16.6	11.0	8.4	13.1	12.6	22.1	17.6	20.0	12.8
Plant loss[w]	1.4	9.0	5.4	3.8	3.7	5.1	--	--	--
Plant grading	2.0	2.0	2.0	0	0	0	0	0	0
Hauling	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
Total Cost	75.1	78.5	76.4	70.5	77.5	84.7	79.7	88.2	75.9

[z]Detailed analysis of these costs is contained in mimeo report AREC-LA-72-18, Lake Alfred.

[y]657, 720, and 567 boxes per acre respectively.

[x]Cycloheximide (Acti-Aid) was used as an abscission agent.

[w]Based on a fruit price of 50 cents per pound-solids.

spraying and little reduction in shaking cost plus high grove loss costs when compared to the control treatment.

The quality of fruit delivered to the canning plant was determined by official sample of the State Inspection Service according to Department of Citrus regulations. On the basis of unwholesome fruit, the Lynchburg test was marginal; the Florida Gold and the Winter Garden tests were well within tolerance. There was more trash in the loads from the Lynchburg and Florida Gold test plots than in other average loads of fruit arriving at the processing plant. Trash in the loads of fruit from Lynchburg ranged from above normal to excessive as a result of pruning residue on the ground and lack of cleaning equipment on the rake-pickup machine. A subjective estimate of internal fruit damage (not considered in unwholesome fruit count) indicates that this could be a major problem area. This type damage results from fruit falling on the shaker itself, on compacted soil, or on tree limbs as well as damage caused by the windrow pickup machine. Grove preparation before shaking or improvement of the raking action to lessen the fruit piling effect in front of rake could reduce this damage.

The rake-pickup machine was operated fewer hours per day than the shakers because of wet soil and wet fruit in the early morning hours. When operating, the rake-pickup machine depended on the hi-lift truck being available to allow it to unload. In order to keep the harvesting system operating, it is necessary that each machine component in the system have more capacity than the preceding component. In these tests, the truck could have hauled more fruit on a continuous basis than the windrow-pickup machine averaged; the windrow-pickup machine had more per hour capacity than the 2 shakers, etc. Allowing for some failures in the system, this complement of machinery, in similarly selected groves, appears capable of producing 900 to 1000 boxes of roadside fruit per 10-hour work day. This estimate is based on 65 boxes per hour average harvest rate (for each of 2 shakers) and an average windrow-pickup machine capacity of 175-200 boxes per hour with 5 men operating the total system.

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