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Limitations of Single- and Multi-man Platform Harvesting Aids

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The use of mechanical aids in harvesting apples for the fresh market has been evaluated over the past several years. Effectiveness of picking with a ladder and with single- and multi-man positioning devices was measured in terms of both man minutes per hundredweight of fruit harvested and physical damage to the fruit. Through work sampling techniques, times were determined for component activities of the total work cycle for each of the harvesting methods. None of the methods eliminated the removal by hand of fruit from the tree. The substantial time required for the hand-picking part of the operation, the high cost of machines per unit of fruit harvested, and the trend to increased production led to the view that future research should emphasize development of satisfactory methods for mass removal of fruit from apple trees.

Contents

Portions of this report were presented in Paper Number 70-651 by A. G. Berlage, R. D. Langmo, and G. E. Yost at the 1970 Winter Meeting of the American Society of Agricultural Engineers. Permission to publish those parts appearing in the Paper has been granted by the Society and the authors.

Limitations of Single- and Multi-man Platform Harvesting Aids

A. G. Berlage, R. D. Langmo, and G. E. Yost*

Introduction

During the past seven years, the Wenatchee, Washington, field station of the Agricultural Engineering Research Division, USDA, has made various harvesting time studies. These studies, conducted in the Wenatchee area, have been part of a cooperative research program with the Department of Agricultural Economics, Agricultural Experiment Station, Oregon State University, and the Washington State University Tree Fruit Research Center. Both commercial and experimental aids have been tested in a continuing program to improve the harvesting efficiency of fresh market apples and pears.

Apple production is expected to increase as orchardists strive for higher yields per acre in an effort to maintain or, hopefully, decrease their cost per unit of product. The potential exists for yield increases [1][1] up to five times the Washington State average [2] of 10 tons per acre (approximately 570 boxes per acre).

In seeking this production, the conventional tree shape, rootstock, and planting distances are changing. Size-controlled trees are planted closer together. Resultant high yields of these plantings will increase the demand for a very efficient harvesting system if the crop in a given area is to be harvested in the two-week period normally available.

In the development of harvesting aids, a major requirement is to increase the individual picker's daily output. To accomplish this, non-picking operations must be minimized or, ideally, eliminated. A problem analysis indicated that replacement of the ladder-climbing operation with a mechanized picker-positioning device should improve the harvesting efficiency. Likewise, replacement of the fruit-carrying operation with a conveyor system was expected to decrease the non-picking functions. As a result of these expectations, a variety of platform aids have been designed and field tested.

Conditions for studies were controlled as closely as the naturally varying environment permitted. Each individual field study is reported separately. The results are discussed on a combined basis.

Single-man Harvesting Aids

A comparison was made between four machine-assisted harvesting methods and the conventional ladder/bag system [3]. All machines were of the self-propelled type (Figure 1), and each accommodated a single operator who hand-picked the fruit and directed the movements of the machine through hand- and foot-operated controls. Design differences between the machines involved mainly the way in which the operator was positioned and the method of fruit handling, bin filling, and bin handling. Table 1 lists and describes the machines and their harvesting methods.

Procedure

The test procedures were designed to minimize the number of test variables and maximize the amount of relevant data. The picker-operator was chosen for his mechanical aptitude as well as his picking ability. The same man was used on each

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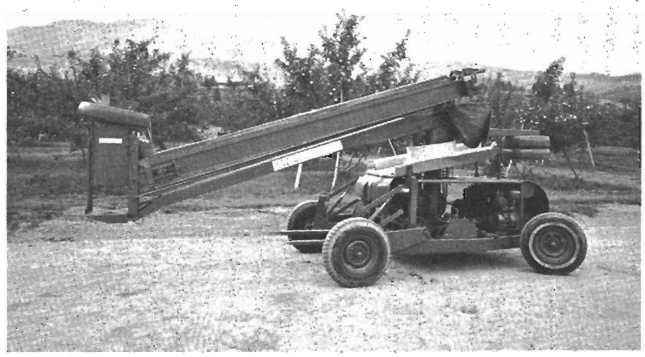
Cooperative research by the Agricultural Engineering Research Division, U.S. Department of Agriculture; the Agricultural Experiment Station, Oregon State University; and the Tree Fruit Research Center, Washington State University.

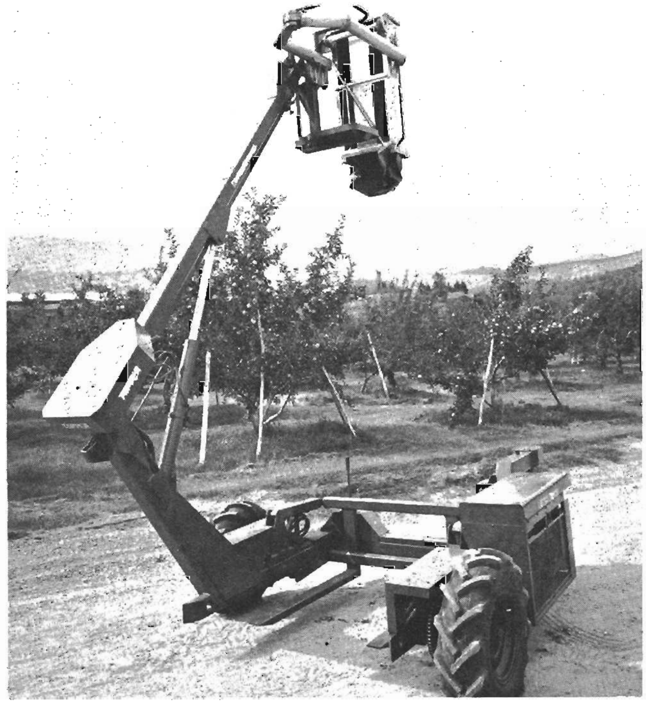
[1] Numbers in brackets refer to appended references.

Machine A



Machine B

Machine C



Machine D

Figure 1. Single-man harvesting aids.

machine, to eliminate the usual variation between pickers. Several familiarization runs were made by the picker on each machine during the days prior to the test week. Following each test period, an additional familiarization run was made on the machine to be used in the next test.

All harvesting was done in the same orchard. The travel rows were on a diagonal, with Red Delicious and Golden Delicious trees alternating down the row. This pattern placed a Red Delicious in one row opposite a Golden Delicious in an adjacent row. Tree spacing in the row, and row spacing, were 28.25 feet. Only the Golden Delicious were picked, thus providing for a better bruise evaluation. Three bins of fruit were picked for each method.

An attempt was made to choose trees as similar as possible with respect to tree size, fruit size, and fruiting density. These variables in combination were difficult to control and recognize prior to picking, and excessive variations which became apparent during any one test were noted in the time study results.

Each harvesting method was randomly assigned a test day. During each test, 80 fruits (four trays of 20 fruits each) were randomly removed from each bin throughout its filling period and placed in plastic fruit separator trays within a cardboard container. The samples were identified, weighed, and placed in cold storage for later bruise analysis. Each bulk bin of fruit was weighed, and

Table 1. Machine Descriptions

	Machine A	*Machine B*	*Machine C*	*Machine D*
Harvesting Crew Size	1	1*	1	1
Number of Wheels (Driven)	3 (2)	4 (2)	3 (1)	3 (2)
Fruit Picking System	Hand-picked into bulk bag	Hand-picked into circular receiver	Hand-picked into powered conveyor	Hand-picked into bulk bag
Bin Carried on Machine	No	Yes	Yes	Yes
Fruit Transfer	Machine carries bulk bag to bin	Fruits drop from conveyor to tilted tray	Fruits roll from conveyor to bin filler	Picker swings bulk bag over bin
Bin Filling Method	Bulk transfer from bag to bin	Individual fruits drop from ramp thru deceleration strips into bin	Rotating distributor with automatic level sensing device	Bulk transfer from bag to bin
Fruit Distribution within Bin	Picker maneuvers machine to position and empty bag where desired	None*	Uniform	Picker maneuvers bag supporting pivot arms to position and empty bag where desired
Vertical Positioning of Operator	Hydraulically operated boom with control platform	Hydraulically operated boom with control platform	Hydraulically operated boom with control platform	Hydraulically operated boom with control platform
Boom Swing	Approx. 20° either side of center	360°	None	None
Harvesting Pattern	Machine maneuvers in, out, and around to pick complete tree	Machine moves straight down row to pick half of each tree in quarter tree segments	Machine maneuvers in, out, and around to pick complete tree	Machine maneuvers in, out, and around to pick complete tree
Maximum Platform Height	12′ 6″	16′ 6″	11′ 9″	12′ 3″
Powered Pruning Equipment	Yes	Yes	Yes	Yes

* Normally a ground man is used to pick the lower fruit and level fruit in the bin. Occasionally an extra man on the ground must operate a hydraulic valve to allow bin-carrying forks to be lowered when bin is filled. Since machine maneuverability is limited, system efficiency is increased if the extra man positions an empty bin in the row and re-positions the lower valve after the empty bin is raised on the forks. His time was not included in the time study.

the net weight of fruit harvested per test was recorded.

All fruits below the six-foot level were harvested prior to each test. This put all machines on an equal basis, since Machine B was not designed to harvest low-level fruit. In turn, when harvesting with ladder and bag, the picker was required to do essentially all ladder-picking. Resulting data was favorable to the machine system, since a man picking with a bag obtains his highest rate when picking from the ground.

Two simultaneous time studies were made. One was to determine the overall harvest rate per bin of fruit. The second, and more intensive study, determined the time devoted to picker activities, which are defined in the Appendix. A fruit-damage study further evaluated the various fruit handling methods.

Production Time Study

In this phase of the harvest study, the time period began when the picker touched the first fruit and ended when the last fruit entered the bin. Any delays, such as rest or coffee breaks, were subtracted from the overall recorded time per bin. The summarized field data is presented in Table 2.

The average diameter of fruit in Bin 10, harvested by Machine C, was considerably smaller than the average fruit count of 100 apples per packed box experienced with the other test bins. For this reason, the average harvest index of Machine C was computed for only two bins (Numbers 11 and 12) rather than the three bins used on all other methods.

Figure 2 shows the percent decrease in overall harvesting time for each of the four machines, compared to ladder picking. The percentage values are obtained from the following equation and the harvest index data in Table 2.

$$\text{Decrease in Harvesting Time} = 100\left[1 - \frac{\text{Machine Average Harvest Index}}{\text{Ladder \& Bag Average Harvest Index}}\right]\%$$

Table 2. Time Study Data

Harvest Method	Bin Number	Average Fruit Diameter (inches)	Average Fruit Count[a]	Time Required to Fill Bin[b] (minutes)	Net Fruit Weight Per Bin (pounds)	Harvest Rate (lbs/min)	Harvest Time: Study Index (man-min/cwt)	Harvest Time: Average Index (man-min/cwt)
Ladder-Bag	1	2.92	100	81.68	892	10.0	9.16	
	2	2.89	100	66.20	878	13.3	7.54	8.30
	3	2.75	113	71.92	877	12.2	8.20	
Machine A	4	2.95	100	72.00	884	12.3	8.14	
	5	2.93	100	71.28	900	12.6	7.92	8.00
	6	2.91	100	73.73	929	12.6	7.94	
Machine B	7	2.83	113	78.92	909	11.5	8.68[c]	
	8	2.88	100	72.43	896	12.4	8.08	8.14
	9	2.85	100	68.82	900	13.1	7.65	
Machine C	10	2.67[d]	125	73.28	904	12.3	8.11	
	11	2.92	100	57.78	898	15.5	6.43	6.53[e]
	12	2.85	100	60.22	909	15.1	6.62	
Machine D	13	2.95	100	57.35	884	15.4	6.49	
	14	2.93	100	60.73	899	14.8	6.76	7.05
	15	2.85	100	68.92	871	12.6	7.91	

[a] Number of fruit per packed shipping box.
[b] Delay times have been subtracted.
[c] Since the Red and Golden fruit could not be harvested at the same time, it was necessary for Machine B to pick alternate tree halves as it moved down the row. Data analysis assumes one-man operation, even though a ground man was needed for occasional tasks.
[d] Total number of fruit per bin was obtained for Machine C only. Fruit size difference was noted by the number of fruit per bin, which was 3226, 2323, 2464, for Bins 10, 11, and 12 respectively.
[e] Bin 10 was not used to obtain the average index time.

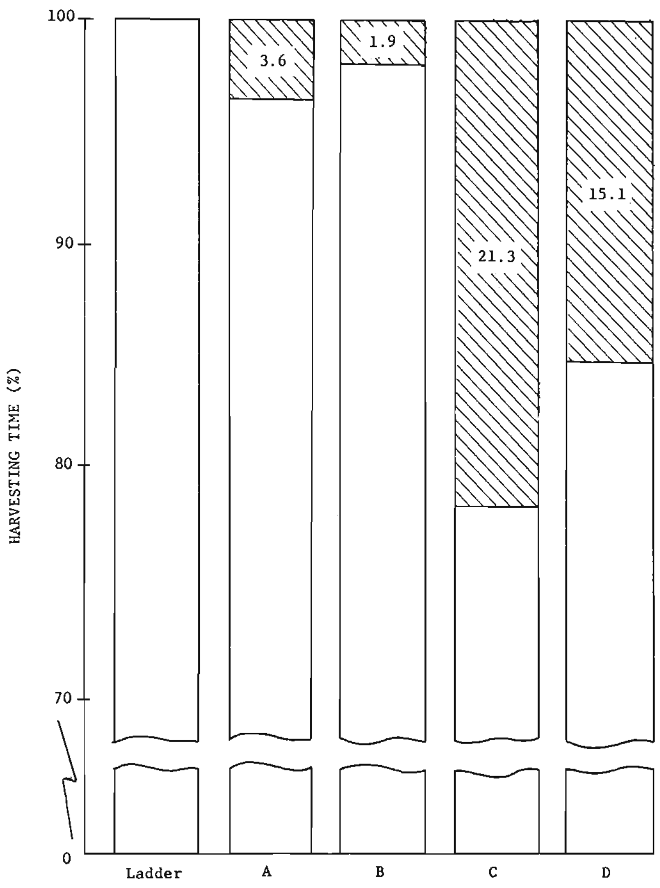


Figure 2. Machine vs. ladder and bag harvest time. Number is percentage decrease with harvesting aid.

Although not part of the actual study, it was interesting to note that for Bin 11 (lowest harvest index—6.43 man-min./cwt), the harvest rate on a fruit-per-minute basis was 40.2 fruit/min. Bin 10, with the smallest average fruit diameter, yielded 44.0 fruit/min. On a per-fruit basis, it appeared that Bin 10 was picked more rapidly than Bin 11. It was actually filled at a slower rate, as indicated by the harvest index of 8.11 man-min./cwt. This emphasized the importance of reporting time study results on both a total weight and number or size of fruit basis.

Also, it was observed that when unrestricted picking with both hands was possible from a machine, maximum picker output ranged between 55 and 60 fruit/min., a rate about twice that normally obtained by the ladder method. This indicated that it is unrealistic to expect more than a 100% increase in harvesting rate with equipment that positions the picker near the fruit. Even then, the only way that a 100% increase could be maintained was by continuous, unrestricted picking with both hands.

The greatest harvesting rate (pounds/min.) increase in this study of ladder vs. machine picking was 42.2% revealed in the comparison of Bins 1 and 11.

Work Sampling Time Study

Additional studies were made by a work sampling technique, in order to obtain time estimates for the component activities essential to the total job of harvesting. Activities needed for picking by ladder and with machine assistance necessarily differ, but for both methods the main duties were picking, positioning to pick, and transferring materials. For timing and analysis, these groups were further divided into work elements fully described in the Appendix. Periodic observations (eight per minute) provided an estimate of the number of times during the picking process that the work elements were being performed. This frequency of work element occurrence was converted to percent of total cycle time, and man-minutes per bin and per hundredweight of apples picked. These results are shown in Tables 3 through 6.

Comparative times for actions needed to pick fruit are in Table 3. With the aid of either Machine A, C, or D, the operator picked fruit faster than he did from the ladder. Savings were 7.4% with Machine A, 8.8% for Machine C, and 14.4% with Machine D. The operator, while working with Machine B, spent 6.23 man-minutes per hundredweight, or about 12% more time than was needed for fruit removal by the ladder method, which was 5.56 man-minutes per hundredweight.

Table 3. Comparative Picking Activity Times for Different Harvesting Methods

Method	*Picking Time (man-min/cwt)*	*Percent Savings Over Ladder*
Ladder	5.56[a]	......
Machine A	5.15	7.4
Machine B	6.23	–12.1
Machine C	5.07	8.8
Machine D	4.76	14.4

[a] Of the 5.56 man-minutes required to pick 100 pounds of apples, 0.17 minutes were spent picking from the ground as the picker moved to and from the ladder.

Comparisons in Table 4 were restricted to operator-positioning activities when preparing to pick fruit. For the ladder method, this included the time for both moving on the ladder and changing the location of the ladder. Machine movements were subdivided into those for positioning in the tree for localized picking, and those for moving around the tree to select a new picking area.

Inspection indicated that, within the limits of this study, none of the machines had an extensive advantage over the positioning movements required with the ladder. Machine B, designed for more open orchard conditions, required more time to position than the ladder. Most of the disadvantage occurred in moving within the tree. In-and-out movements were restricted because the chassis was intended to move in a straight line within lanes between trees, thus restricting maneuverability. Machines C and D performed with an equal savings of about 7% in man-minutes of positioning time per hundredweight. Though equal in total savings, Machine C took the least time for positioning in the tree, and Machine D was most effective in moving around the tree.

Table 4. Times by Different Methods for Positioning Man and Equipment in Preparation for Picking, Compared in Man-minutes Per Hundredweight

Method	*Move on Ladder*	*Reset Ladder*	*Position in Tree*	*Position Around Tree*	*Total*	*% Savings Over Ladder*
Ladder	0.80[a]	0.65	......	......	1.45	......
Machine A	......	......	1.16	0.24	1.40	3.4
Machine B	......	......	1.43	0.30[b]	1.73	–19.3
Machine C	......	......	1.07	0.28	1.35	6.9
Machine D	......	......	1.20	0.15	1.35	6.9

[a] Of the 0.80 man-minutes required for "move on ladder" for each 100 pounds of fruit picked, 0.06 was spent moving on the ground as the picker positioned himself to harvest the small amount of fruit reached from the ground.

[b] The design of this machine is not suited to moving around the tree; hence, this element consists of moving straight along the row.

Advantages demonstrated by particular machines indicated that positioning ability was enhanced by having a compact platform and fruit receiver, conveniently located controls, and a power supply that was responsive, smooth, and fast.

A final group of work elements was required to transfer fruit to field bins and, in the case of Machines B, C, and D, to exchange a full bin for an empty one. Man-minutes determined for the several methods are shown in Table 5.

Only Machines B and C had a handling time less than the ladder method. These two machines, unlike the others, were designed to mechanically transfer fruit from the operator to a bin carried by the machine. Machine C was most effective in changing bins, performing this function in about 1/10th of a minute per hundredweight of fruit harvested. Machine D was equally capable in changing bins, but required more total time because of the need to periodically empty the fruit-holding bag into the bin.

Handling bins was an added duty for mechanical-aid picking, since it was not a part of conventional ladder harvesting. However, time for changing the bin was much less than the time required to travel to and from a stationary bin to discharge fruit, as was the case for ladder picking and for Machine A that did not carry a bin. Also, the ability of the picking aid to position the bin fork entries

Table 5. Comparative Times Required for Transferring Fruit and Handling Containers by Each Harvesting Method, in Man-minutes Per Hundredweight

Method	Adjust Bag	To Empty	Empty	Return to Next Activity	Change Bins	Total	% Savings Over Ladder
Ladder	......	0.19	0.33	0.23	......	0.75	......
Machine A	0.34	0.43	0.43	0.26	......	1.46	–94.7
Machine B	0.14[a]	......	......	......	0.20[b]	0.34	54.7
Machine C	......	......	......	......	0.10[b]	0.10	86.7
Machine D	0.17	0.29	0.35	0.10	0.11[b]	1.02	–36.0

[a] No bag was employed on Machine B. The time listed under "adjust bag" was required to clear fruit that occasionally got caught between the receiving ring and the discharge conveyor.

[b] "Change bin" for Machines B, C, and D included moving with a full bin to the change area, releasing the full bin, picking up an empty bin, and returning to the picking area. Though a man on the ground briefly assisted with the bin change on Machine B, his time was not included.

Table 6. Summary by Time and Percent for Alternative Methods of Picking Apples, Compared in Man-minutes Per Hundredweight

	Picking Activities		Positioning Activities		Fruit Transfer and Bin Change		Total Harvest Time	Savings Over Ladder
Method	(man-min.)	(% of cycle)	(man-min.)	(% of cycle)	(man-min.)	(% of cycle)	(man-min. per cwt.)	(%)
Ladder	5.56	71.6	1.45	18.7	0.75	9.7	7.76	......
Machine A	5.51	64.3	1.40	17.5	1.46	18.2	8.01	–3.2
Machine B	6.23	75.1	1.73	20.8	0.34	4.1	8.30	–7.0
Machine C	5.07	77.8	1.35	20.7	0.10	1.5	6.52	16.0
Machine D	4.76	66.8	1.35	18.9	1.02	14.3	7.13	8.1

for quick pick-up by a fork-lift tractor should simplify hauling the full bins out of the orchard.

Production times for the three main categories of activities for each harvesting method are summarized in Table 6. The percentage figures show the proportion of time required by the activities for a given method, and hence, aids in selecting potential areas of improvement. For example, the elimination of the "fruit transfer and bin change" activity, which required only 1.5% of the total work time for Machine C, would have little impact on overall efficiency. In contrast, potential for improvement could be substantial through reduction or elimination of the 20.7% "positioning" time.

Review of the work sampling study results indicated that for all categories of harvesting activities, either Machine C or Machine D performed best with respect to the use of man-minutes per hundredweight of fruit. With the component activity time available, it was possible to synthesize the operation of a hypothetical picking aid that would employ the best characteristics of Machines C and D. Such a selection resulted in the following combinations:

	Per Hundredweight	Percent
Picking, Machine D	4.76 man-minutes	78.3
Position in tree, Machine C	1.07 man-minutes	17.6
Position around tree, Machine D	0.15 man-minutes	2.5
Fruit transfer and bin change, Machine C	0.10 man-minutes	1.6
TOTAL HARVEST TIME	6.08 man-minutes	100.0

The projected output at 6.08 man-minutes per hundredweight saves 21.6% in time, when compared to ladder-picking total time of 7.76 man-minutes per hundredweight cited in Table 6. A comparison, based on the average of 8.30 man-minutes per hundredweight for the three ladder-picked bins reported in Table 3, saved 2.22 man-minutes per hundredweight, or 26.7% in the total picking cycle. Even with this synthesized aid, the actual picking time was only 78.3% of the total harvest time, leaving over 20% of its time for non-productive positioning and handling activities [7].

Bruise and Skin Break Study

The 80 fruit samples from each test bin (240 fruit samples per method) were evaluated the

Table 7. **Bruise Study Data**

Harvest Method	*Bin No.*	*Number of Bruises per Size Category Size of Bruise (inches in diameter)* Less than 1/2	1/2 – 3/4	3/4 – 1	1 – 1-1/4	Greater than 1-1/4	*Skin Break*	*Number of Unbruised Fruit in Fruit Sample*
Ladder & Bag	1	163	12	3			1	13
	2	115	13	2			2	20
	3	101	8	1			3	23
Machine A	4	170	34	5		1	1	5
	5	165	27	3	2		2	13
	6	102	31	4			1	16
Machine B	7	144	118	101	49	6	11	0
	8	162	151	72	13		10	0
	9	161	110	54	22		10	1
Machine C	10	77	8	3			2	24
	11	106	22	1			6	15
	12	68	25	2	1		5	26
Machine D	13	295	33	7	5		8	3
	14	273	44	7	7	2	6	3
	15	170	36	9	3	2	2	14

week following the field studies. Results of the damage studies are summarized in Table 7.

Excessive fruit damage noted in Bins 13 and 14, harvested by Machine D, was attributed to high engine RPM. At the higher speed, the increased oil flow to the hydraulic system made machine movement somewhat jerky, especially the boom action, when lowering the bag into the bin for dumping. It was also difficult to achieve a smooth upward movement of the boom when the bag was being dumped. When the machine motion was slowed and smoothed, the harvest index increased (Table 2, Bin 15), but the total bruises and skin breaks were considerably reduced (Table 7, Bin 15).

Figures 3 and 4 show the total number of bruises and skin breaks for each harvest method. Very small bruises (less than ½ inch) usually are

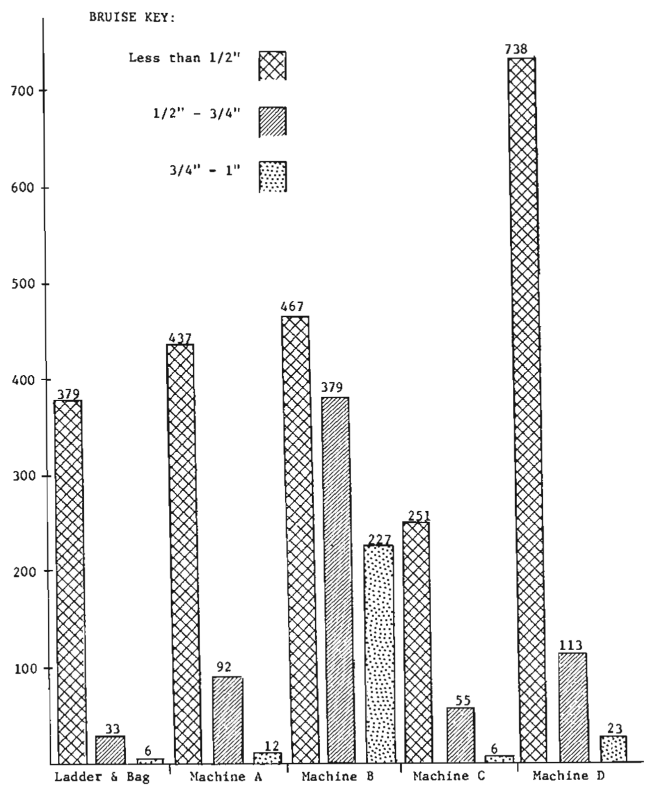


Figure 3. Total number of bruises up to one inch found in 240 fruit sample for each three-bin study.

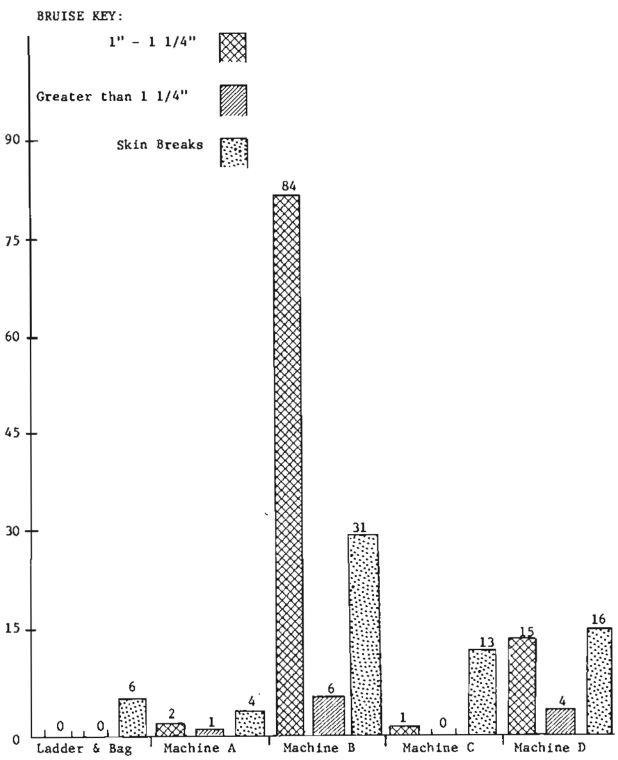


Figure 4. Total number of bruises over one inch found in 240 fruit sample for each three-bin-study.

not considered objectionable. However, when occurring in excessive quantities, they detract from the fruit appearance.

The ladder and bag, Machine A, and Machine D utilized essentially the same fruit-handling system. This batch accumulation and dumping system appeared to produce a greater quantity of the very small bruises caused by fruit against fruit impact (less than ½ inch).

The fruit-handling system of Machine C separated and conveyed the fruit to the bin, thus reducing the quantity of small bruises occurring in the batch handling systems. Skin breaks, though moderate in number, probably occurred when fruit occasionally rolled on fruit as it was distributed in the bin.

The conveyor on Machine B moved the fruit in small batches, rather than individually, and it did not come equipped with a means of lowering the fruit into the bin. To reduce the potential of fruit damage, plastic foam pads were installed at points where bruising seemed likely to occur, and a frame with deceleration strips was placed over the bin opening to slow the fruit as it dropped into the container. Periodically it was necessary to manually raise the deceleration unit as the bin filled. Apples in Bins 7, 8, and 9, harvested with Machine B, had more bruises over ½ inch in diameter, and skin breaks, than fruit handled by the other systems.

The skin breaks were either stem punctures or impact breaks. One can only surmise that, if fruit separation can be maintained until final placement occurs in the bin, stem punctures may be reduced. Fruit rolling over stationary fruit oriented with stems up, and fruit sliding past other fruits, as in batch dumping, also provide many opportunities for stem punctures. The impact breaks and large bruises can only be reduced by additional care in handling and improvement in the design of parts that contact the fruit.

Tree Size Influence on Harvesting Efficiency

For subsequent comparison with harvesting of other tree sizes, a time study was made on standard Red Delicious trees using the conventional ladder/bag system and a commercial man-positioning aid with an experimental fruit and bin handling system [4]. Starting time began when the picker detached the first fruit from a tree, and ended when the last fruit removed from the tree had entered the bin.

All ladder, machine, and picker movements per tree were included in the total time. Since only a comparison of picking time per tree was desired, travel time between trees and bin handling time was omitted. The same picker was used throughout the trials. Tree size, shape, and yield were similar. Results for comparison are in Table 8.

Table 8. Time Study Summary for Ladder/Bag vs. Platform Picking Time for Red Delicious Standard-Sized Trees

Ladder/Bag System (man-min./cwt)	*Platform Aid (man-min./cwt)*	*Platform Time Savings (%)*
11.5	9.7	15.6

The same picker was used to harvest standard, semi-dwarf, and dwarf Red Delicious apple trees with the conventional ladder/bag method. A 12-foot ladder was used on the standard trees. Picking time began when the picker removed the first fruit, included necessary ladder moves and trips to the bin, and ended when the bin was filled with the last bag of fruit. The results are shown in Table 9.

The average harvesting time (9.6 man-min./cwt) for the combined semi-dwarf and dwarf trees, compared to standard trees, provided a 15.8% decrease in harvesting time. Table 8 shows that harvesting standard trees with a platform aid provided a 15.6% decrease. This comparison indicated that planting more small trees per acre reduces the harvesting time without added mechanization.

Table 9. Effect of Tree Size on Harvesting Time

Tree Size	*Harvesting Time (man-min./cwt)*	*Harvesting Time[a] Decrease (%)*
Standard	11.4[b]	......
Semi-dwarf	9.5	16.7
Dwarf	9.7	14.9

[a] Harvesting time decrease as a percent of the standard tree time.

[b] Note the almost identical Red Delicious harvesting time in Table 8 for the same picker in similar-sized trees with similar fruit yield.

A comparison, employing four experienced pickers with varying levels of skill, was made for picking standard-sized trees with ladder and bag and dwarf tree-walls with a bag, but no ladder.

For all four pickers the average harvesting time decrease on dwarf trees was 26.7%. No mechanization was required to obtain this decrease. Data from the comparative study appears in Table 10. These results, extended by other observations, indicated that the productivity of all pickers, regardless of their ability, was increased when they changed from conventional standard-tree picking to ground picking in high-density, size-controlled, tree-wall plantings [3, 5, 6, 11].

Table 10. Effect of Tree Size on Harvesting Time

	Harvesting Time (man-min./cwt)		*Harvesting Time Decrease (%)*
Picker	*Standard*	*Dwarf*	
B	10.59	6.90	34.8
D	9.04	7.16	20.8
E	7.28	5.75	21.0
H	7.62	5.50	27.8

An excellent picker was chosen for an additional comparison study [6] between picking into a bag or into a trough while working from the ground along a tree-wall. When picking with the bag, fruit transfer from bag into bin was accomplished by the picker in the conventional manner. When picking into the trough, a complete fruit-handling and bin-filling system was assumed to be part of the proposed harvesting aid. The picker only removed the fruit from the tree and placed it in the trough illustrated in Figure 5. The trough was always adjacent to the picker, and perpendicular to the tree row so as not to interfere with or restrict his reach into the foliage.

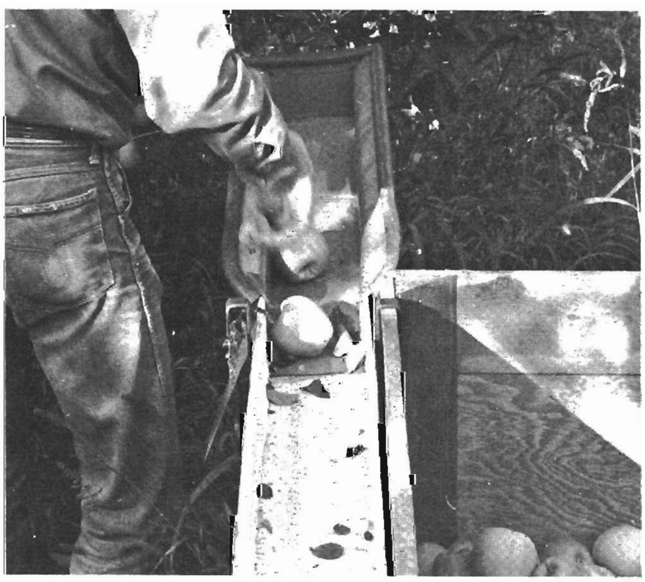


Figure 5. Mobile trough and bin receives fruit picked from a dwarf tree-wall planting.

Table 11 shows that picking into the trough, located at the picker's side, took more time than picking into the conveniently located bag. Non-picking time decreased 92.4% due to elimination of the fruit-carrying operation.

Table 11. Tree-wall Time Study Results for a Skilled Operator Picking by Alternative Methods

	Working Time in Man-min./cwt		
	Picking	*Non-picking*	*Total*
Pick into bag	4.16 (79.8%)	1.05[a] (20.2%)	5.21 (100%)
Pick into trough	4.84 (98.4%)	0.08[b] (1.6%)	4.92 (100%)
Optimum system	4.16 (98.1%)	0.08 (1.9%)	4.24 (100%)

[a] Includes moving along row when not picking, carrying fruit to bin, emptying and leveling fruit in bin, and returning to row from bin.
[b] Includes moving along row when not picking.

The optimum system in Table 11 combines the best characteristics of the two methods. To achieve this theoretical level of productivity, the freedom of picking from the ground was combined with the convenience and unrestricted movement of a front-mounted, waist-high fruit receiver which fed into an automatic fruit-handling system. Such an optimum system provided an 18.6% reduction in overall harvesting time (approximate increase of 2½ bins per day for this extremely fast picker) instead of the 5.6% reduction obtained with the side-mounted trough.

The same picker harvested standard-sized trees with ladder and bag. These results are shown in Table 12. The non-picking time (29.9%) was relatively low for the standard trees, and was evidence of the capability of this picker. His moves were well-planned. When picking the tree-walls from the ground, he reduced his overall standard-tree picking time by 23.7% with the bag, and by 28.0% with the trough. The synthesized optimum system reduced overall picking time by 37.9%.

Table 12. Standard-Tree Time Study Results for a Skilled Operator Picking with Ladder and Bag

	Working Time in Man-min./cwt		
Ground Pick	*Ladder Pick*	*Non-picking*	*Total*
1.34 (19.6%)	3.45 (50.5%)	2.04 (29.9%)	6.83 (100%)

Multi-man Harvesting Aids

Aids with Mechanical Fruit-Handling Systems

Picking into a conveyor from a continuously moving platform aid was compared to conventional picking [5]. The first trial was conducted with two women picking at different elevations from one side of a prototype harvesting aid (Figure 6A). Dwarf Golden Delicious apple trees in a tree-wall planting, with a tree spacing of 6′ x 12′, were harvested in this trial.

When picking from the ground with the picking bag, both pickers carried their full bags to a common bin. The time study data was recorded as a two-picker team (K & L) output for both ground and machine picking. The results are shown in Table 13.

The decrease in harvesting time of 25.8% was encouraging, since it was obtained with a platform in dwarf tree-walls. Other studies (Tables 9 and 10) had shown that bag-picking of dwarf trees always provided a decrease in harvesting time compared to ladder/bag picking of standard trees. The smallest decrease (Table 9) was 14.9%.

The difference between standard and dwarf tree-picking performance in Table 9 was used to extrapolate a ladder/bag, standard-tree harvesting time for the picker team on the prototype machine. This revealed a theoretical 36.9% decrease in harvesting time of the mechanical aid compared to picking standard trees. With this potential in mind, a more sophisticated platform aid was developed and tested.

A four-picker, fixed-platform, self-propelled, self-steering harvesting aid (Figure 6B) was designed for tree-walls with fruit up to nine feet high [8]. The principle of the aid was to provide each picker with a continuous supply of fruit and reduce the human effort to that of fruit removal and disposal in an adjacent conveyor.

Table 13. Time Study of Bag vs. Conveyor Picking of Golden Delicious Tree-Walls

Picker	*Picking into Bag from Ground*[a] *(man-min./cwt)*	*Picking into Conveyor from Aid*[b] *(man-min./cwt)*	*Harvesting Time Decrease (%)*
K & L	15.5	11.5[c]	25.8
H	5.5	4.9[d]	10.9

[a] In addition to the actual picking time, the bag-picking includes walking to and from the centrally located bin, emptying the bag and leveling the fruit in the bin, and moving along the row while not actually picking.

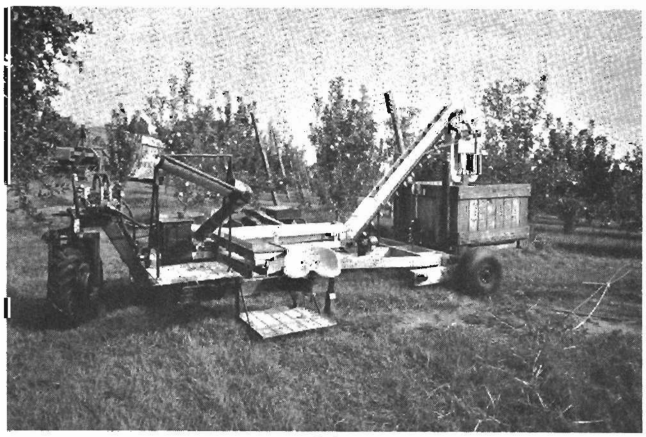
[b] Since the pickers and separated fruit were being moved by the platform aid, the conveyor-picking time includes picking only. Idle or waiting time, recorded separately, has been excluded.

[c] Average results for two pickers on a two-man machine.

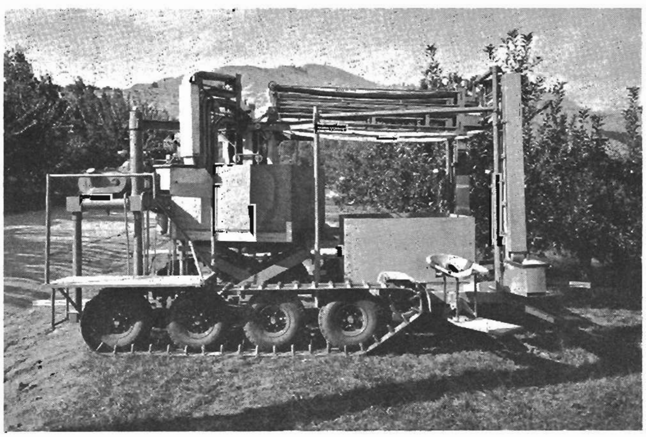
[d] Selected results for one picker in a four-man machine.

During the harvesting operation the unit slowly (5 ft./min/average) and continuously moved two seated and two standing pickers between the faces of adjoining tree-walls. Each picker hand-picked the fruit from his fruiting zone 2.5 to 3 feet deep and 3 to 4 feet high. Each fruit was placed on a positive-transfer conveyor [9] and separately delivered to and distributed in a central bulk container which was carried on the machine. Machine steering, fruit conveying, and bin handling operations were automated. Bin removal required that the left-rear (standing) picker depress a toggle switch to accomplish release at the bin.

Experienced pickers were used to compare the harvesting time between picking with ladder/bag and the four-man platform. Selected data for the fastest picker (H) in the four-man crew is shown



6A



6B

Figure 6. Self-propelled harvesting aids designed to accommodate two pickers (6A) and four pickers (6B). Each machine has a mechanical fruit-handling system to move fruit from the picker to a carried bin.

in Table 13. Note that the average time for the conventional bag harvesting of K & L was almost three times greater than that of H. Harvesting from a continuously moving aid provided the women (K & L) with a harvesting time decrease of 2.37 times that incurred by the man, thus emphasizing that aids are of marginal value to pickers experienced in the conventional picking methods.

Both women were picking essentially 100% of the time from one side of the two-station prototype platform. Continuous movement forced picking *if* the fruit supply was continuous. The four-man crew, picking from both sides of the four-station platform, was subjected to highly variable fruiting conditions. During the selected portion of the four-man platform study for Picker H, 46% of his overall harvesting time was recorded as non-productive waiting time. A crew platform must operate at a speed acceptable to every member of the crew. The larger the crew, the more inefficient the operation, due to natural tree and fruiting variations.

A 1966 cost analysis of the four-picker aid indicated that a retail price of approximately $12,000 would be necessary for that level of automation. At $3,000 per picker, the cost would be less than four one-man platforms with fruit- and bin-handling components.

Aids without Fruit-Handling Systems

To reduce the investment per picker for harvesting aids, the expensive hydraulic and electric components may be eliminated from the fruit- and bin-handling functions. If fruit is picked into the conventional bag, and only the ladder is replaced with a towable or self-propelled platform, a more feasible machine cost may be obtained. For this approach, catwalk-type platform systems were built and tested.

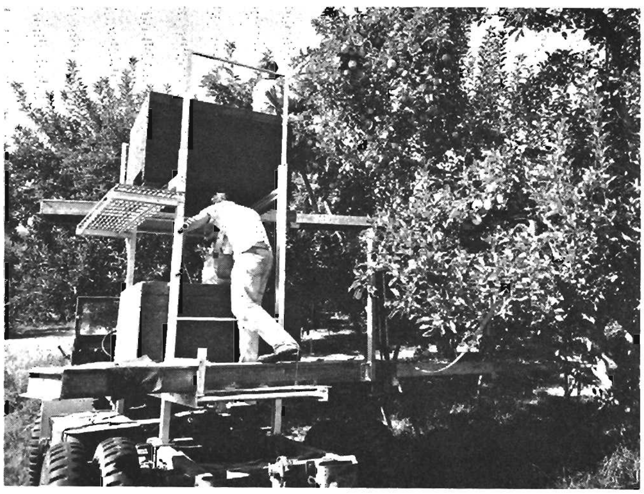
Two one-way telescoping platforms [6, 10], illustrated in Figure 7A, were mounted at elevations of 4.5 and 9 feet on a truck chassis. The truck was moved when all fruit within reach of the 10-foot extension catwalks had been picked. Two inexperienced pickers, using picking bags, harvested standard-size Red Delicious trees from the platform and from 10-foot ladders. The pickers emptied their bags in separate bins on the platform as well as on the ground. Table 14 shows the summarized results of the one-way telescoping platform time study.

Table 14. Time Study of Ladder vs. One-way Telescoping Platform

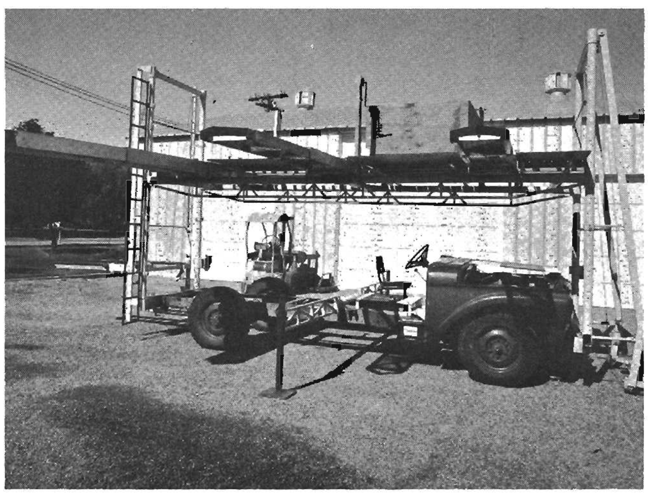
Picker	*Ladder (man-min./cwt)*	*Platform (man-min./cwt)*	*Savings over Ladder[a] (%)*
A	16.36	19.95 (lower catwalk)	–21.9
B	17.98	13.42 (upper catwalk)	25.4

[a] Increase or decrease of harvesting time as a percent of ladder/bag time.

Picker A incurred a considerable increase in harvesting time when picking from the lower catwalk. Time study data showed that an average of 10% of his overall time was waiting time. This was due to the heavier yield of fruit at the upper elevation on the trees being picked, and demonstrated the need for more flexibility than is offered by fixed-elevation platforms. The "simple" platform becomes more expensive when elevating mechanisms are added; thus, in many cases, negating the ad-



7A



7B

Figure 7. Two prototype self-propelled picker platforms. The two-man machine in 7A has catwalks at two elevations that can be extended in one direction. Three catwalks, each extendable to both sides of the machine shown in 7B, are placed at one elevation to serve two pickers.

vantage gained by a small improvement in harvesting efficiency.

In an effort to reduce the waiting time of either picker in the platform crew, three two-way telescoping catwalks [6] were mounted on a common platform as shown in Figure 7B. In addition to increased picking flexibility, the two-way catwalks allowed a 50% reduction in platform movement because of the ability to work both sides of a drive row. It was anticipated that by providing one catwalk in excess to the number of pickers in a crew, and by adding the two-way feature to each catwalk, idle time would be essentially eliminated.

The previous study of the one-way catwalks did not include the time for bin handling on the platform. Since bin handling is not an integral part of the ladder/bag picking operation, the necessity to handle bins on the platform was purposely ignored during the one-way study. In the two-way catwalk study, the bin-handling operation was included, because pickers must devote some time to the bin-changing activities.

The platform was set at an elevation of six feet for the time study. The two platform pickers were instructed in the proper sequence of picking paths. A third picker, operating from the ground, picked the fruit to six feet, supplied empty bins to and removed full bins from the platform by means of hand-operated winches and cable lift forks, and moved the truck when each set of half-trees was picked. All three pickers were also timed while picking similar trees in the same block with eight-foot ladders. Table 15 summarizes the combined harvesting time for the three-picker crew.

Table 15. Time Study of Ladder vs. Two-way Telescoping Platform for Three-man Crew

Ladder (man-min./cwt)	*Platform (man-min./cwt)*	*Savings over Ladder (%)*
8.6	10.2	–18.6

As was previously stated, this two-way study included bin-handling time for the platform system. Even though increased flexibility was obtained with the two-way system and the extra catwalk, the necessity of handling bins with the platform system made it less efficient that the conventional ladder/bag system.

Discussion

The generalized results of all the foregoing field trials were basically the same. Harvesting from a platform aid provided experienced ladder-pickers with overall reductions in harvesting time ranging from 0 to 26%. Inexperienced ladder-pickers obtained reductions up to 50%. Similar reductions, as well as slight increases, in harvesting time have been reported in many other research studies [12-20].

Instead of lifting the picker to the fruit of standard-sized trees, the European approach to increasing harvest labor productivity has been to lower the fruit to the ground-based picker by planting and maintaining smaller trees [21]. This method is emphasized because the most consistent decrease in harvesting time for all pickers occurred when comparing the ladder/bag system of picking standard trees to picking size-controlled, high-density plantings from the ground with a bag. The minimal non-picking time (10%-20%) incurred while picking high-density tree-wall plantings from the ground [6] remains impractical to recover with any form of mechanized aid.

Part of the non-picking time can be recovered by keeping the bin near the picker at all times with an "economical" bin carrier. The additional expense of attaching a fruit-conveying and bin-filling system to the bin carrier cannot be justified, due to the small productivity increase potentially available [22]. The average non-picking time (15%) incurred in tree-wall plantings, although theoretically available for picking, cannot be completely eliminated. Even the "economical" bin carrier (approximate cost $200) mentioned above must be moved along the row. This non-productive moving time offers little advantage, since it simply replaces a large percentage of the potential savings in time normally spent carrying fruit to the stationary bin. The small gains actually available limit the feasibility of additional investments.

The comparative reduction in overall harvesting time obtained by the slower or less-experienced picker when picking from a platform may result in a misleading evaluation. As an example, in the past the ladder/bag picking rate of six bins per nine-hour day (1.5 hrs./bin) was considered a good rate throughout the Pacific Northwest. As the labor situation changes, inexperienced pickers make up more of the available labor force. If these pickers harvest at the ladder/bag rate of two bins per day (4.5 hrs./bin), and increase to four bins per day (2.25 hrs./bin) when picking from a platform, a 100% rate increase (50% reduction in overall harvesting time) is indicated [15].

Actually, the grower has provided a machine for the picker while the picker has, in turn, provided the grower with an increase in overall harvesting time of 50% above the previously acceptable 1.5 hours per bin. Even though harvesting from a platform increased the inexperienced picker's efficiency, his total output may not be as great as that of the experienced picker using the conventional ladder and bag. If experienced pickers willing to use ladders and bags are not available, and the grower chooses to invest in platform aids, he cannot be assured of maintaining the daily output previously obtained with experienced ladder/bag pickers.

An aspect that must be considered is the eventuality that no labor willing or able to adequately utilize the ladder and bag system will be available. In this case, supplying the labor force with mechanical aids may present the only currently acceptable method for harvesting fresh-market tree fruits with a labor market which otherwise could not be considered for the task. Such a situation would only increase the cost per hundredweight of fruit harvested.

The major limitation in the use of platform harvesting aids is the picker. His physical ability to remove fruit from the tree and place it in a receiver, combined with his endurance limit, determines the minimum possible harvesting time.

Another limiting factor is the non-uniformity of fruit distribution throughout the tree. Picker movement past a non-fruiting area results in non-picking time. Multi-picker platforms require uniform fruit distribution if maximum efficiency is to be maintained by each crew member [5, 19].

The extent of picker positioning required in a platform system presents still another limitation. A platform which requires three- or even two-dimensional positioning will result in more non-picking time for a given fruit distribution than a fixed platform moving continuously along a uniformly fruiting surface.

Low yields require excessive machine and picker motions, thus creating additional non-picking time. These limitations may combine to produce a high percentage of non-productive operations.

The cost of currently available commercial platform harvesting aids ranges from $700 for a tractor-mounted, one-man platform to $20,000 for a nine-man (eight pickers plus machine operator), self-propelled, multi-level platform with fruit and bin handling system. In comparison, commercially available grape and cane-berry harvesters may range from $28,000 to $38,000. Tree fruit catching frames with limb or trunk shakers vary from $12,000 for a tractor-mounted, wrap-around machine, to $40,000 for a two-unit system with bin storage on the frames.

Future expectations for platform aids are less than encouraging. Current technology allows us to automate all functions but the controlled removal and collection of the fruit. When human labor is used to remove and collect individual fruits, maximum automation of all the non-picking operations cannot increase the harvesting rate enough to justify current machine costs. In citrus, the B.E.I. (Break-Even Investment) for a single picker platform aid providing a 20% reduction in overall harvesting time (25% productivity increase), with 1,000 hours annual harvest usage, is about $970 [22]. With a 33⅓% reduction in harvesting time (50% productivity increase), the B.E.I. would approach $2,580.

The dominant Northwest apple varieties are Red and Golden Delicious. Each has an optimum harvest period of 10 days. The individual harvest periods overlap. In any given area the overlapping period would never exceed 19 days. At 10 hours per day, this is a maximum of 190 hours of harvest usage. Unless a grower has other crops to provide a longer harvest season, the B.E.I., as a harvesting machine only, should not exceed $490, on the assumption that each picker's overall harvesting time will decrease by 33⅓%.

Platform aids, with fruit- and bin-handling attachments removed, may be used for extended periods during the pruning season, although far fewer machines would be needed. If a decrease in harvesting time of 33⅓% could be maintained by inexperienced pickers using platform aids throughout the short harvest season, the picking crew could be reduced to two-thirds of the number needed when using ladders and bags. Such an investment in platform aids currently available would not be feasible [7].

Comments

The current trend toward high-density plantings of size-controlled trees [11, 21, 23, 24] will provide increased yields per acre. More fruit in a given volume of orchard will tend to reduce the picker's non-picking time, and thus improve his picking efficiency. This slight improvement will not offset the need for additional pickers to hand-harvest the increasing yields per acre within the optimum harvest period. Even without a yield increase, additional inexperienced pickers will be needed to simply maintain the same daily harvest output obtained previously with experienced harvest labor.

The smaller trees will allow more of the fruit to be picked from the ground with only a picking bag. All fruits above seven feet will have to be picked from a ladder or some form of platform aid. More careful handling of future fresh-market apple production will be required, due to the increased number of Golden Delicious trees planted in recent years [25]. This variety is more susceptible to physical damage than Red Delicious.

The lack of consistent and decisive improvements in harvesting efficiency when picking from platform aids points to the need for long-range research on completely mechanized harvesting systems. These systems must be compatible with the high-density orchard of the future. The inclusion of farm workers under the Fair Labor Standards Act, increasing Social Security, and prospects of other social legislation covering housing, unemployment insurance, and collective bargaining will continue to increase harvesting costs.

The higher yields of the future orchards will provide a greater volume of product. This increased production will allow for mass removal of fruit with subsequent mechanized, high-volume sorting, into fresh-market and processing categories.

Cooperative research between horticulturists and engineers must continue. Research with regard to tree training should lead to mass removal of fruit in high-density plantings with minimal bruising. Reduction of fruit removal forces through the application of abscission chemicals is an important phase of this research. A determination should be made of the optimum location of the larger structural support limbs, so as to minimize the frequency of contact with falling fruits. The feasibility of complete or partial encapsulation of fruit and/or limbs should be studied.

Small improvements may continue to be made on stop-gap measures such as man-positioning and single-fruit removal aids. These developments will provide limited, short-term solutions as available labor decreases and crop yield increases. Long-term solutions will be obtained from research directed toward acceptable mass removal harvesting systems.

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Appendix

Work element descriptions for picking apples with a ladder and with machine assistance:

I. Ladder Picking.

A. Picking activities:

1. "Ground pick" is made up of those actions of the picker, working from the ground, that include reaching for fruit, removing fruit from the spur, and moving the fruit to the bag and releasing it. If these actions are performed while the worker is walking, they are still counted as picking.
2. "Ladder pick" is the same in definition as "ground pick," except that the operations are performed while the worker is on the ladder.

B. Positioning man and equipment in preparation for picking:

1. "Move on ground" includes walking as the picker changes his location at a tree. No picking is performed simultaneously with this type move. Moves to and from the fruit disposal area are not a part of this type move.
2. "Move on ladder" includes traveling up or down the ladder when no picking is being done.
3. "Reset ladder" includes picking up and carrying or walking ladder to a new location within the set of trees being picked. It does not include the longer transportation of moving to a different set of trees.

C. Transferring fruit and handling containers:

1. "Move to bin" includes walking from the picking point to the bin to dispose of fruit in the picking bag.
2. "Empty" consists of emptying fruit into the bin, re-setting bag ropes, and leveling of fruit within the bin.
3. "Return to tree" includes walking to the work area.

II. Machine Picking.

A. Picking activities:

1. "Pick" includes reaching for fruit, removing fruit from the spur, and moving it to the bag or rereceiver. All these actions are performed with the operator in the carriage of the machine. If this picking is done simultaneously with movements of the machine, the work is recorded as "pick".

B. Position machine in preparation for picking:

1. "Position in tree" includes those side-to-side, vertical, and in-and-out moves of the machine within and outside of the tree that properly place the operator for picking. Position is recorded only if picking is not taking place during the move.
2. "Position around tree" involves moves about the periphery of the tree that take the picker to a new work location.

C. Transferring fruit and handling containers:

1. "Adjust bag" includes manipulation of the bag to facilitate filling or emptying it.
2. "Move to empty" includes traveling to the bin or positioning the bag-holding device over a bin carried by the machine.
3. "Empty" involves those activities required to move the fruit from the bag into the bin.
4. "Return to tree" is the time needed to move from the location of empty to the work area.

D. Change bin:

1. "Move to bin disposal" consists of machine travel with a full bin to the area where the bin will be released.
2. "Changing bins" includes those actions required to release the full bin, travel to the location of an empty bin, and getting the empty bin in position on the machine.
3. "Return" is the travel time needed to get back to the picking area.