ECONOMICS OF MECHANICAL TREE FRUIT HARVESTERS

Darrel Good
Assistant Professor
Department of Agricultural Economics
University of Illinois

Eddy LaDue
Associate Professor
Department of Agricultural Economics
Cornell University

Lance Davey
Former Graduate Student
Department of Agricultural Economics
Cornell University

Introduction

Mechanical fruit harvesters have been commercially available to New York growers for ten years. However, adoption of mechanical apple harvesters has been relatively slow because of (1) the availability of relatively inexpensive hand labor, (2) the lack of a suitable fresh fruit harvester, and (3) the wide variation in tree size, apple varieties, farm size and production practices which make operation of a mechanical harvester physically and/or economically infeasible.

A number of mechanical harvesters, however, are currently in use in the processing apple growing area of Western New York. Interest remains high in mechanical harvesting due to increasing difficulty in attracting harvest labor and in meeting governmental regulations relative to labor management. The purpose of the study reported here was to assess the economic performance of mechanical harvesters in operation in Western New York during the 1975 harvest season. The data are used to calculate mechanical harvesting costs and to identify factors of importance in determining the likely profitability of investment in a mechanical apple harvester.

The Survey Farms

Fifteen apple growers (all located in Wayne County, New York) provided mechanical harvester performance and cost data for the 1975 season. The survey farms ranged in size from 64 to 1400 acres of fruit and averaged 287 acres (222 acres of apples, 55 acres of cherries, and 10 acres of other tree fruits). An average of 93 percent of the apples produced on these farms was sold for processing and 41 percent of the processing apples were machine harvested in 1975.

All of the machines used on the survey farms are capable of harvesting apples, although two were not used for apples in 1975. Thirteen of the fifteen machines are also capable of harvesting other tree fruits such as cherries, peaches, prunes, and pears. Twelve were actually used for cherry harvest in 1975.

Harvester Performance

The extent of use and performance of harvesters in 1975 varied considerably from farm to farm (Tables 1 and 2). On average, the harvesters were used 27 days in apple harvesting and 12 days for cherry harvesting. An average of 50.7 acres of apples was harvested by each machine, but machine harvested acreage ranged from 10 to 120. Similarly, the total quantity of apples harvested ranged from 1,958 to 63,280 bushels and averaged 23,663 bushels. An average of 10.6 trees was harvested per operating hour, yielding 127 bushels per hour. On average, 3.6 hours were required to harvest an acre of apples.

For cherries, quantity harvested ranged from 22,000 pounds to 381,233 pounds per machine and averaged almost 200,000 pounds of which 36,728 were custom harvested for other growers. On average, 4.7 hours were required to harvest an acre of cherries.

Mechanical Harvesting Costs

Total mechanical harvesting costs were computed by (1) calculating total annual overhead costs for each machine and allocating between apples and cherries on the basis of hours spent harvesting each crop and (2) adding the recorded operating costs for each crop. Total annual overhead is assumed to consist of a charge for capital recovery and interest, an allowance for insurance and housing and a further allowance for periodic overhaul or rennovation of the machine.

The formula for calculating the annual charge for capital recovery and interest is:

$$R = A/\left[\frac{1 - (1 + i)^{-n}}{i}\right] + SV\,(i)$$

where: R = annual charge for capital recovery and interest
A = amount to be recovered
i = annual interest rate
n = recovery period
SV = salvage value.

Table 1.
Mechanical Harvester Performance on Apples
Survey Farms, Wayne County, New York, 1975

Characteristic	Average	Range
Harvest Period:		
Begin	Sept. 15 (12)[a]	Sept. 8 - Sept. 26
End	Oct. 25 (12)	Oct. 12 - Nov. 4
Total Days (Begin-End)	41 (12)	28 - 53
Harvester Operation:		
Days Harvesting	27 (13)	4 - 40
Days Harvesting, as Percent of Total Days	64 (12)	14 - 83
Operating Time, Hours	174 (13)	23 - 340
Operating Time, Hours Per Day	6.30 (13)	4.91 - 8.50
Down Time[b], Hours	22 (12)	6 - 36
Total Time, Hours (Operating and Down)	182 (12)	29 - 271
Operating Time, as Percent of Total Time	87 (12)	79 - 96
Acres Harvested:		
Total Acres	50.7 (10)	10.1 - 120.6
Average Trees Per Acre	30.9 (10)	14.7 - 42.6
Fruit Harvested in Bushels:		
Own	23,663 (13)	1,958 - 63,280
Custom	0	0 - 0
Total	23,663 (13)	1,958 - 63,280
Harvest Rate:		
Trees Per Operating Hour	10.6 (11)	4.0 - 21.1
Bushels Per Operating Hour	127 (13)	38 - 188
Operating Hours Per Acre	3.60 (10)	1.58 - 6.33
Labor:		
Operators	2	1.5 - 2
Supporting Men	1	0 - 2

a/ The number in parenthesis is the number of farms (harvesters) which recorded data useful for the given factor of harvester performance.

b/ Breakdown and regular maintenance.

Table 2.
Mechanical Harvester Performance on Cherries
Survey Farms, Wayne County, New York, 1975

Characteristic	Average	Range
Harvest Period:		
Begin	July 11 (10)[a/]	July 8 - July 16
End	July 26 (10)	July 21 - Aug. 1
Total Days (Begin-End)	16 (11)	6 - 24
Harvester Operation:		
Days Harvesting	12 (11)	6 - 22
Days Harvesting, as Percent of Total Days	77 (11)	33 - 100
Operating Time, Hours	83 (12)	28 - 147
Operating Time, Hours Per Day	6.23 (11)	4.67 - 9.50
Down Time[b/], Hours	14 (11)	1 - 34
Total Time, Hours (Operating and Down)	93 (11)	29 - 161
Operating Time, as Percent of Total Time	86 (11)	70 - 97
Acres Harvested:		
Total Acres	18.3 (6)	4.7 - 31.6
Average Trees Per Acre	100 (6)	
Fruit Harvested in Pounds:		
Own	163,194 (12)	22,000 - 381,233
Custom	36,728 (12)	0 - 162,792
Total	199,899 (12)	22,000 - 381,233
Harvest Rate:		
Trees Per Operating Hour	25.7 (6)	12.2 - 38.5
Pounds Per Operating Hour	2,273 (12)	1,118 - 4,574
Operating Hours Per Acre	4.70 (6)	2.60 - 8.30
Labor:		
Operators	2	1 - 2
Supporting Men	1	0 - 3

a/ The number in parenthesis is the number of farms (harvesters) which recorded data useful for the given factor of harvester performance.

b/ Breakdown and regular maintenance.

The amount to be recovered (A) is the purchase price minus investment tax credit minus salvage value. It was assumed that all growers who purchased harvesters were paying sufficient tax to claim 7 percent Federal Investment Tax Credit and 4 percent State Investment Tax Credit in the first year. The useful life of the investment (n) was assumed to be 10 years for a new harvester and the salvage value (SV) 10 percent of purchase price. For the two machines purchased second hand, useful life was assumed to be 7 years. An insurance and housing allowance was set at $10 per $1,000 of average investment and $500 was allowed annually for major overhaul or rennovation.

Variable costs of operating included operator's labor ($3.50/hour), supporting labor ($3.00/hour), fuel, repair and maintenance. Total cost per bushel of apples ranged from $0.212 to $1.678 and averaged $0.469. For cherries, mechanical harvesting costs averaged $0.026 per pound and ranged from $0.013 to $0.057 (Table 3). Overhead costs represented about two-thirds of the total harvesting costs.

Table 3.
Machine Harvesting Costs for Apples and Cherries
15 Survey Farms, Wayne County, New York, 1975

Farm Number	Apples (¢/bushel)	Cherries (¢/pound)
1	26.0	3.2
2	47.8	1.9
3	33.9	5.7
4	23.7	2.5
5	37.9	1.5
6	38.1	3.8
7	23.9	1.4
8	23.1	1.8
9	65.3	---
10	41.6	2.4
11	21.2	---
12	167.8	---
13	59.7	3.9
14	---	1.3
15	---	1.8
Average	46.9 (13)	2.6 (12)

For the 1975 season, the basic hand harvest cost for processing apples (direct labor, Social Security, Workmen's Compensation, housing and transportation) was about $0.31 per bushel. Only 5 of the 13 harvesters recorded costs less than the hand harvest cost. For cherries, a comparable alternative harvesting cost is the custom harvesting charge, which for the 1975 season varied from $0.03 to $0.05 per pound. Eight of the twelve growers recorded costs lower than $0.03 per pound and only one recorded a cost greater than $0.04 per pound.

The calculated mechanical harvesting cost for either apples or cherries is influenced by the amount of time spent harvesting the other fruit since overhead costs are allocated on the basis of time spent harvesting. It is possible that savings on mechanically harvesting cherries may overcome a deficit on harvesting apples or vice versa. Although only 5 of the 13 machines which harvested apples had savings over hand harvest costs, 7 registered net savings when cherries were taken into account (Table 4).

Table 4.
Overall Savings (Losses) from Mechanical Harvesting
Survey Farms, Wayne County, New York, 1975

Farm Number	Savings on Apples[a]	Savings on Cherries[b]	Combined Savings
	$	$	$
1	+ 1,361	- 416	+ 945
2	- 2,202	+ 2,628	+ 426
3	- 764	- 1,034	- 1,798
4	+ 2,542	+ 495	+ 3,037
5	- 1,613	+ 3,387	+ 1,774
6	- 1,490	- 273	- 1,763
7	+ 2,220	+ 6,107	+ 8,327
8	+ 5,019	+ 4,086	+ 9,105
9	- 5,140	0	- 5,140
10	- 1,905	+ 318	- 1,587
11	+ 2,791	0	+ 2,791
12	- 5,580	0	- 5,580
13	- 562	- 843	- 1,405
14	0	+ 6,031	+ 6,031
15	0	+ 4,208	+ 4,208

a/ Compared to hand harvest cost of 31¢ per bushel.

b/ Compared to custom harvest cost of 3¢ per pound.

Factors Affecting Apple Harvest Rate

Rate of machine harvest, as measured by hours per acre, is important in determining total acreage of apples which can be mechanically harvested during the season. Rate of machine harvest, as measured by bushels per hour, is important in determining the total quantity of apples which can be harvested and, therefore, the total operating savings (compared to hand harvest) which can be achieved. For a grower considering the purchase of a mechanical apple harvester, an estimate of harvest rate is an essential prerequisite in determining economic feasibility.

Harvest Rate -- Hours Per Acre

Harvest rate (hours per acre) is likely to be affected by a number of factors, including the following: (1) trees per acre, (2) yield per tree, (3) tree size, (4) apple variety, (5) harvester type, (6) operator experience, (7) managerial ability, and (8) orchard preparation. Eleven of the fifteen farms surveyed provided detail of the orchard conditions under which the harvesters were operated. Using these details, as well as the harvester type, a management rating and the number of years for which the harvester had been owned as explanatory variables, the following relationship was postulated:

$$\text{Rate} = \alpha + \beta_1 \text{ trees} + \beta_2 \text{ yield} + \beta_3 \text{ Mac} + \beta_4 \text{ Cort} + \beta_5 \text{ Green} +$$

$$\beta_6 \text{ Rome} + \beta_7 \text{ Small} + \beta_8 \text{ Large} + \beta_9 \text{ Harv C} + \beta_{10} \text{ Mgt. P} +$$

$$\beta_{11} \text{ Mgt. G} + \beta_{12} \text{ Yrs.} + \text{E.}$$

where:
- Rate = harvest rate in hours per acre
- α = a constant
- trees = number of trees per acre
- yield = bushels of apples per tree
- Mac = McIntosh variety
- Cort = Cortland variety
- Green = R. I. Greening variety
- Rome = Rome variety
- Small = Small tree size
- Large = Large tree size
- Harv C = Perry C harvester
- Mgt. P = Management rating poor
- Mgt. G = Management rating good
- Yrs. = Number of years harvester owned
- E = Residual.

Variables 3 through 11 are dummy variables. If a variety being harvested was not one of the four identified, it was included in an "all other" category and a zero was entered for all variety variables. Harvester type was classified as either Perry Model C (the most common in use on the survey farms), which is included in the equation, or "other" for which no entry is made. Each farm was given a subjective management rating (good, medium or poor) intended to reflect management practices likely to affect harvest rate. To be classified as "good" a grower would need:

(1) to have an adequate crew for machine operation,
(2) to have the orchard prepared for rapid shaking, and
(3) not spend an "undue" amount of time hand picking apples from the tree or from the ground.

Based on previous research [1, 3, 5, 6, 7] and field observation, it was hypothesized that more trees per acre, higher yield per tree, larger tree size, poor management and Cortland variety would be associated with a slow harvest rate. Since high hours per acre represents a slow rate of harvest, we would expect these variables to have coefficients with positive sign. Conversely, we would expect negative signs for McIntosh and R. I. Greening varieties, small tree size, good management, and years of experience.

Detailed data were provided for 109 blocks of apples on the eleven farms. The equation listed above was estimated from these data by ordinary least squares techniques. In general, the signs of the estimated coefficients (Table 5) are as might be expected from intuition and from published research [3, 5]. A positive regression coefficient indicates that the variable is associated with greater hours per acre and, therefore, a slower harvest rate.

As expected, greater tree numbers per acre significantly[1/] slows the harvest rate. It should be noted, however, that the highest tree density recorded in this study was 109 trees per acre and only 6 of the 109 blocks for which data were available had tree densities of 80 trees or more per acre.

High yield per acre also significantly reduced harvest rate. Contrary to other findings [3, 6, 7], tree size did not significantly affect rate of harvest. Again, few observations were available on small trees (15 of the 109 blocks were classified "small", 58 "medium", and 36 "large"). Since the operators allowed most of the small trees to be picked by hand, those small blocks that were machine harvested may have had inferior topography or other limiting characteristics.

1/ A statistical significance level of 99 percent was used throughout this study.

Table 5.
Apple Harvest Rate in Hours Per Acre

Independent Variables	Regression Coefficient	T-Value
Trees (Trees/Acre)	0.05	6.91
Yield (Yield/Tree)	0.16	6.93
Mac.	-0.56	-1.40
Cort.	0.83	1.65
Green.	-0.38	-1.19
Rome	-0.21	-0.55
Small	0.00	0.00
Large	0.19	0.60
Harv. C	-0.10	-0.30
Mgt. P	1.66	4.65
Mgt. G	-0.94	-2.49
Yrs.	-0.27	-1.94
Constant ($\propto$)	0.55	0.76

R^2 unadjusted = 0.70

R^2 adjusted = 0.66

LaMont, Markwardt and Longhouse [3, 6], found the Cortland and Twenty Ounce varieties the most difficult to machine harvest and the McIntosh and R. I. Greening varieties easiest to machine harvest. Of the varieties included in the equation, only Cortland and McIntosh approached statistical significance in their difference from the omitted "all other" category. The overall rating of ease of harvest, as determined by subsequent reestimation of the equation omitting one variable at a time, is (from most difficult to easiest): (1) Cortland, (2) All Other, (3) Rome, (4) R. I. Greening, and (5) McIntosh.

The subjective management rating proved to be quite significant in explaining harvest rate as did experience as measured by the number of years of machine ownership. Harvester type was not statistically significant in explaining harvest rate.

In summary, a faster harvest rate (as measured by hours per acre) is associated with lower orchard density, R. I. Greening and McIntosh varieties and low yield per tree. In addition, harvest rate improves with experience and is better when practices defining "good" management are followed.

Obviously, a rapid harvest rate per acre is not the only or most important objective of the apple producer and may be detrimental to other objectives such as high yield per acre and selection of preferred varieties. In determining the feasibility of a harvester, a grower must evaluate harvest rate within the framework of existing or planned orchards.

Harvest Rate -- Bushels Per Hour

The above analysis was repeated, using bushels per hour as the dependent variable rather than hours per acre. A grower contemplating the purchase of a mechanical apple harvester needs to estimate the rate of harvest to determine if a sufficient quantity of apples can be harvested from his orchards to be competitive with hand harvest. Using bushels per hour as the measure of harvest rate, the analysis indicates: (1) a faster harvest rate is associated with higher yields per tree, more trees per acre, good management, more years of experience, and the R.I. Greening variety, (2) a slower harvest rate is associated with McIntosh, Cortland and Rome varieties and with poor management, and (3) tree size does not significantly affect harvest rate. The regression equation explained only about 50 percent of the variation in harvest rate, as measured in bushels per hour.

Investment Analysis

The purchase price of a large mechanical harvester, capable of harvesting both apples and cherries, is about $90,000. This is considerably more than paid for the harvesters included in the 1975 survey. Whether investment in such a machine is likely to be economically feasible will depend on the orchard and farm business situation being considered. It is not possible to make a general recommendation, but the following analysis is presented as a guide in judging investment feasibility.

The analysis involves calculation of the net present value of (1) the cash flow generated from investment in a $90,000 harvester, (2) the salvage value of the harvester at the end of the period, (3) the investment tax credit taken in each year, and comparison of the net present value to investment cost.

The calculations used in determining net present value (NPV) were made using a capital investment computer program developed at Cornell University [2]. The assumptions used in calculating NPV include:

(a) purchase price = $90,000.
(b) life = ten years.
(c) salvage value = $9,000.
(d) before-tax cost of capital = 11 percent.
(e) an after-tax cost of capital is calculated by the computer program. An average marginal tax rate (t) is computed for the ten years using the change in tax and the change in taxable income generated by the investment in each year. The after-tax

cost of capital (ATCC) is then calculated using t and the before-tax cost of capital (ATCC = 11 (1-t)% = 7.4% in this example).

(f) machine housing and insurance cost = $500 annually.

(g) major overhaul and reconditioning cost = $2,000 in year 4 and $3,000 in year 8.

(h) annual cost saving over hand and custom harvesting is:

$$A_a\ [Y_a \cdot H_a - (Op_a + Sm_a + F + M)\ T_a] +$$

$$A_c\ [Y_c \cdot C_c - (Op_c + Sm_c + F + M)\ T_c]$$

where: subscript "a" refers to apples
subscript "c" refers to cherries
A = acres
Y = yield per acre (bushels of apples and pounds of cherries)
H = hand harvest cost in $/bu.
C = custom harvest cost in ¢/lb.
Op = cost of machine operators per hour (number x $/hour)
Sm = cost of supporting people per hour (number x $/hour)
F = fuel cost per hour
M = maintenance costs per hour
T = harvest rate in hours per acre.

An annual cost saving of $13,000 is used in this example.

(i) marginal Federal tax rate (without the investment) = 22 percent. For a given marginal Federal tax rate, the program assumes a pre-investment Federal Taxable Income in the center of the given bracket (in this case $10,000). The State Taxable Income is assumed to be higher than this ($10,514) so that when State taxes are subtracted the Federal Taxable Income before investment is, in fact, $10,000. The program used in this analysis calculated State Unincorporated Business Tax by subtracting $10,000 in deductions from State Taxable Income and taxing the remainder at 5.5 percent.

(j) depreciation method = double declining balance with additional 20 percent first year depreciation on $20,000.

(k) Investment Tax Credit was taken where possible. Ten percent Federal Tax Credit can be claimed and may be carried back to the 3 preceding tax years and the balance still unused may be carried forward to the 7 succeeding years. There is a New York State tax credit allowance of 2 percent on Personal Tax and 2 percent on any Unincorporated Business Tax. This may not be carried back but may be carried forward indefinitely.

Under the assumptions specified above, the net present value of the investment is $185 (Table 6). This calculation indicates that a grower with a taxable income of $10,000 and a cost of capital of 11 percent would require a savings of $13,000 per year over hand and custom harvesting to break even on a $90,000 harvester.

Table 6.
Net Present Value of Mechanical Harvester Investment

Year	Cash Flow Before Tax	Depreciation	Taxable Income	Investment Tax Credit	Tax	After Tax Cash Flow	Present Value
				- - -Dollars- - -			
0	-90,000	---	---	---	---	---	-90,000
1	12,500	21,200	-8,700	5,760	-7,794	20,294	18,916
2	12,500	13,760	-1,260	1,966	-2,334	14,834	12,873
3	12,500	11,008	1,492	2,426	-1,944	14,444	11,681
4	10,500	8,806	1,694	738	- 191	10,691	8,044
5	12,500	7,045	5,455	469	1,413	11,087	7,765
6	12,500	5,636	6,864	406	1,995	11,505	6,852
7	12,500	4,509	7,991	468	2,378	10,122	6,148
8	9,500	3,607	5,893	352	1,690	7,810	4,418
9	12,500	2,909	9,591	15	3,477	9,023	4,746
10	12,500	2,520	9,980	---	3,651	8,849	4,334
10	9,000	---	---	---	---	---	4,408
Total							185

The calculations outlined above were repeated for initial Federal Taxable Income of $2,500, $10,000 and $18,000 and annual cost savings over hand and custom harvesting of $12,000, $13,000, $14,000 and $15,000 (Table 7). The results indicate that a grower with a low taxable income operation would need to achieve annual cost savings over hand and custom harvesting of slightly over $14,000 to break even. On the other hand, a relatively high taxable income business could break even by annually saving slightly over $12,000.

Conclusions

Slightly over half of the mechanical tree fruit harvesters analyzed resulted in lower harvest costs than the growers would have had to pay had they hand harvested their apples and custom harvested their cherries. A large portion of the difference in physical efficiency of mechanical harvesters can be explained by trees per acre, yield per tree, variety, harvester operation experience and harvester management practices. At 1975 price levels, annual cost savings of $12,000 to $14,000 would be

Table 7.
Net Present Value of Harvester Investment Under
Selected Initial Taxable Incomes and
Selected Annual Operating Margins

Annual Operating Margin	Initial Federal Taxable Income		
	$2,500	$10,000	$13,000
	- - - - - - - -Net Present Value- - - - - - - -		
$12,000	-11,104	- 4,590	- 970
13,000	- 5,728	185	3,557
14,000	- 65	5,213	7,677
15,000	5,745	10,185	12,110

required to make a mechanical harvester a break even investment. Given the normal variation in orchard characteristics, operator management capabilities and farm business income, each grower will need to evaluate the profitability of harvester investment for his situation.

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