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An Economic Analysis of Mechanical Harvesting of Sweet Potatoes

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PREFACE

This is a report of an economic analysis of hand versus mechanical harvesting of sweet potatoes. The study was carried out by members of the Agricultural Economics department at Virginia Polytechnic Institute and State University using, in part, data developed by members of the Agricultural Engineering and Horticulture departments.

The cost and performance data are, in most part, based on a simulation of operations of a machine which is still in the developmental stage. These analyses provide a basis for evaluating the commercial application of the experimental mechanical harvester when its costs and operating coefficients are known.

TABLE OF CONTENTS

LIST OF TABLES AND FIGURE

AN ECONOMIC ANALYSIS OF MECHANICAL HARVESTING OF SWEET POTATOES

by

Joseph M. Johnson and Richard Hinman[1/]

INTRODUCTION

Virginia producers grow in excess of 15,000 acres of sweet potatoes annually. Hand harvest labor of 60 to 70 hours per acre is required. The supply of qualified labor willing to do this type of work is becoming increasingly limited and piece-work rates are trending rapidly upward. In 1969, Virginia growers paid $0.22 per bushel for picking up sweet potatoes and many were unsatisfied with the manner in which the workers performed.

Producers need an alternative means of harvesting sweet potatoes that will reduce labor requirements, improve working conditions, and reduce costs of harvesting.

Over the past decade, several mechanical aids were developed for harvesting sweet potatoes. These aids have generally fallen short of hoped for economic advantage over conventional hand harvest methods either because they have not reduced labor requirements sufficiently or their physical capacity has been too low. In some cases. they have improved working conditions materially, and some have resulted in improved quality of product.

Members of the Agricultural Engineering and Horticulture departments at Virginia Polytechnic Institute and State University are experimenting

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1/ Professor and Graduate Research Assistant, respectively, in Agricultural Economics at Virginia Polytechnic Institute and State University, Blacksburg, Virginia 24061.

with a late model John Bean 1-row sweet potato harvester furnished by F.M.C. Corporation, which they have modified and equipped with an experimental sizing unit and a commercial bulk loading attachment.

The unit has not had extensive field testing and is scheduled for further modification. However, results of limited tests, in 1969, indicate that it has a greater physical capacity than many of the other harvesters currently being tested, it requires far less labor, and should result in an improved quality of potatoes, more accurately graded than is now being obtained by hand methods. The purchase price of the unit is not known for sure, and its operating coefficients and costs are still uncertain. Many estimates must be used in attempting an economic analysis comparing costs of harvesting using the experimental harvester with costs using conventional hand methods.

This study has drawn upon reports of research in Virginia and North Carolina and on progress reports and field notes from the researchers working with the experimental harvester.

The results of this study should allow growers to better evaluate the feasibility of using a harvester in their situation once its purchase price, operating costs, and operating coefficients are established.

To aid in clarity of presentation, the estimated hand and mechanical harvester costs will first be developed under a "core" set of assumptions of operating coefficients, machine ownership and operating costs, and other attendant conditions. These costs will be compared. The effect of changing the assumptions will then be discussed and further cost comparisons will be made.

HAND HARVEST OPERATIONS AND COSTS

Typically, hand harvest of sweet potatoes involves several consecutive operations.1/ The vines are cut with a rotary mower or rotobeaten, following which the potatoes are plowed from the beds. Labor crews then shake the soil from the potatoes, simultaneously placing the potatoes from 4 or 5 rows together in a furrow. The No. 1 size potatoes are then hand selected from the furrow and placed in either bushel baskets or field crates. In 2 following operations the No. 2 size potatoes and the culls are collected in a similar way. This crew operation is estimated to take from 60 to 70 man-hours per acre. However, the grower typically pays for this labor on a piece-work basis, with cost per acre directly related to yield of potatoes per acre.

The core assumptions used in estimating conventional hand harvest costs are shown in Table 1.

Using these assumptions, the costs of harvesting sweet potatoes by conventional hand methods are developed in Table 2 for 3 levels of yield per acre.

Preparation costs are a negligible part of total hand harvest costs and per acre costs almost directly reflect the piece-work rate.

1/ See: Bell, James B. and Austin, Max E., Evaluation of Hand and Mechanical Harvest of Sweet Potatoes, Mimeo. Rpt.,Virginia Polytechnic Institute, Blacksburg, Virginia 24061, January 1967.
Harwood, D. G. Jr., Covington, H. M., and Westerbeek, Pieter, Will Sweet Potato Harvesting Machines Pay, Mimeo. Rpt., Dept. of Economics, North Carolina State University, Raleigh, North Carolina, August, 1968.

Table 1. Core assumptions made in development of hand harvest costs

Item	Assumptions
Machine operator wage	$1.65 per hour
Piece-work rate	$0.22 per bushel
Tractor operating cost1/	$1.17 per hour
Mower operating cost1/	$0.51 per hour
Plow operating cost1/	$0.58 per hour
Mowing time2/	.52 hours per acre
Plowing time2/	.43 hours per acre
Product recovery	Same as for harvester
Product quality	Same as for harvester
Container handling	Same as for harvester

1/ Machine costs were adapted from: Smith, Easley S. and Oliver, James D., Estimating Farm Machine Costs, Cooperative Agricultural Extension Service Bulletin 290, V.P.I., Blacksburg, Virginia 24061, June, 1965. Include overhead as well as variable operating costs.

2/ Operation rates from: Bell, James B. and Austin, Max. E., Evaluation of Hand and Mechanical Harvest of Sweet Potatoes, Mimeo. Rpt., V.P.I., Blacksburg, Virginia 24061, January, 1967.

Table 2. Estimated costs of harvesting sweet potatoes by conventional hand methods with 3 levels of yield of sweet potatoes per acre

Item	Bushels per acre 250	350	450
Preparation costs	- - - - - Dollars per acre - - - - -		
Mowing	1.74	1.74	1.74
Plowing	1.46	1.46	1.46
Total preparation	3.20	3.20	3.20
Picking-up costs	55.00	77.00	99.00
Total all costs	58.20	80.20	102.20
Cost per bushel	0.233	0.229	0.227

MACHINE HARVEST OPERATIONS AND COSTS

The experimental harvester lifts the potatoes from the beds, elevates them as the soil is separated from the potatoes and the potatoes are separated from the vines, conveys the potatoes to the mechanical sizer, and conveys the sized potatoes to the appropriate bulk containers. The combined operations accomplish the same jobs that are necessary in hand harvest; at the same time, it does a more complete job of harvesting the crop and sizes the potatoes with greater accuracy. Observers judged that the potatoes in the bins were less bruised and skinned than at the end of hand harvest operations. Limited tests showed about 3 percent of total production lost in machine harvest compared with estimates of from 10 to 20 percent unharvested by typical harvest crews. The operation requires two tractor operators and two harvester operators. Annual costs of owning and operating the harvester fall into two categories: (1) fixed regardless of amount of use and (2) variable with hours of annual use.

The "core" assumptions used in the development of machine harvesting costs are shown in Table 3. These assumptions are used in developing the estimates of fixed and variable harvester costs in Table 4. Machine operating costs are approximately 1/3 of the variable operating costs, which amount to $22.17 per acre. These operating costs are assumed not to be affected by yield of potatoes, as the sizing unit is judged to be capable of handling yields typical of the area at the harvesting rate shown if two additional sizing V's are added to the existing sizing chassis. At present, sizing is limited to 160 bushels per hour with four sizing V's but the expanded unit would take care of 240 bushels per hour.

Table 3. Assumptions used in developing the costs of harvesting sweet potatoes with the harvester

Item	Assumptions
Fixed costs	
Purchase price of harvester (dollars)	12,500
Depreciation schedule	Straight line 5 years
Salvage value	5% of purchase price
Interest allowance	10%
Taxes, insurance, and housing1/	2% of average investment
Variable costs	
Machine operator's wage	$1.65 per hour
Tractor costs2/	1.17 per hour
Bulk loader	.20 per hour
Wagon costs2/	.05 per hour
Harvester operating costs	.80 per hour
Harvest rate3/	2.22 hours per acre
Product recovery	Same as for hand harvest
Product quality	Same as for hand harvest
Container handling	Same as for hand harvest

1/ Rate from: Doane's Agricultural Report, Doane's Agricultural Service Inc., Vol. 23, No. 11-7-8.

2/ Adapted from: Smith, Easley S. and Oliver, James D., Estimating Farm Machine Costs, Cooperative Agricultural Extension Service Bulletin 290, V.P.I., Blacksburg, Virginia 24061, June, 1965. Includes both operating and fixed costs.

3/ From limited trials of the harvester in 1969 on the P.W. and W.C. Davis farm.

Table 4. Estimated fixed and variable costs of owning and using a sweet potato harvester for harvesting sweet potatoes

Item	Annual and per acre costs (dollars)	
Fixed costs annually		
Capital recovery and interest1/	3195.12	
Taxes, insurance, and storage	131.25	
Total annual costs		3326.37
Variable costs per acre		
Tractors	5.19	
Bulk loader	.44	
Farm wagon	.11	
Harvester	1.78	
Machinery operators	14.65	
Total variable costs per acre		21.17

1/ Computational procedures shown in: Walrath, A.J., Economic Tools for Analysis of Investment Opportunities, Unpublished Manuscript, E.R.S., U.S.D.A., c/o V.P.I., Blacksburg, Virginia 24061.

HAND AND MACHINE HARVESTING COSTS COMPARED

In Table 5, the estimated total costs of harvesting by the 2 methods are compared under varying conditions of yield per acre and number of acres harvested annually.

The costs of harvesting with the machine are extremely high at small acreages but decline rapidly with increased acres harvested. The decrease in costs occurs more rapidly with high yields. The acreage required to equate machine and hand harvest costs can be approximated by either interpolating between the per bushel values for the different acreages shown or by plotting either total or per bushel values on a graph, as in the figure on page 10. A more accurate determination can be made by solving for acres in the following equation:

(Equation 1) $VC_{H/acres} \times acres = FC_M + (VC_{M/acre} \times acres)$ in which:

$VC_{H/acre}$ = Variable hand harvest costs per acre (Table 2)

FC_M = Fixed annual costs (Table 4)

$VC_{M/acre}$ = Variable machine harvest costs per acre (Table 4)

For example, the breakeven acreage at a yield of 250 bushels per acre would be solved for as follows:

$VC_{H/acre}$ = \$ 58.20

FC_M = \$3,326.37

$VC_{M/acre}$ = \$ 22.17

Substituting into equation 1:

58.20 x acres = \$3,326.37 + (\$22.17 x acres), and collecting terms:

36.03 acres = \$3,326.37

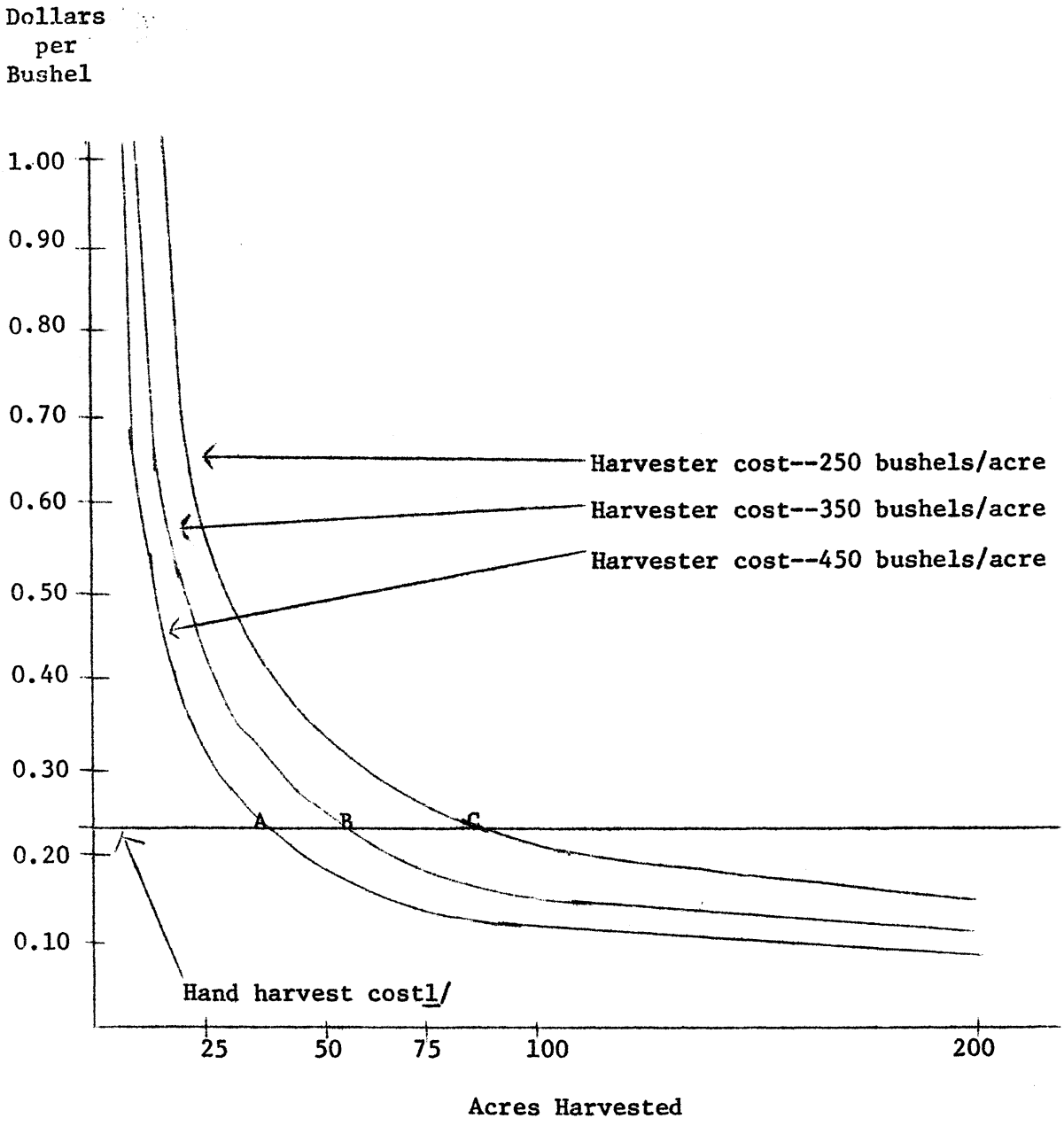
Acres = 92.32

Breakeven acreages for 350 bushel and 450 bushel yields would be 57.32 and 41.56 acres, respectively. Any acreage harvested above these shown at a given yield will result in lower per bushel costs for machine harvest.

Table 5. Projections of Tables 2 and 4, estimated costs of hand and machine harvesting of sweet potatoes under varying conditions of yields and number of acres harvested annually

Acres harvested annually	Bushels per acre					
	250		350		450	
	Hand	Harvester	Hand	Harvester	Hand	Harvester
	Dollars total cost					
1 acre	58	3,349	80	3,349	102	3,349
25 acres	1,455	3,881	2,005	3,881	2,555	3,881
50 acres	2,910	4,435	4,010	4,435	5,110	4,435
75 acres	4,365	4,989	5,015	4,989	7,665	4,989
100 acres	5,820	5,543	8,020	5,543	10,220	5,543
200 acres	11,640	7,760	16,040	7,760	20,440	7,760
	Dollars per bushel 1/					
1 acre	0.233	13.394	0.229	9.567	0.227	7.441
25 acres	0.233	0.621	0.229	0.443	0.227	0.345
50 acres	0.233	0.355	0.229	0.253	0.227	0.197
75 acres	0.233	0.266	0.229	0.190	0.227	0.148
100 acres	0.233	0.222	0.229	0.158	0.227	0.123
200 acres	0.233	0.155	0.229	0.111	0.227	0.086

1/ Dollars total cost are divided by number of acres harvested multiplied by yield.



1/ The slight difference in hand harvest cost for different yields could not be shown on this graph.

Figure. Comparative costs per bushel for harvesting sweet potatoes by hand and by harvester with different yields and number of acres harvested annually. A, B, and C indicate acreages where hand and harvester costs of harvesting are equal.

Even with these rather conservative assumptions, substantial savings could be made by using the harvester on relatively large acreages and with good yields.

INFLUENCE OF ASSUMPTIONS ON HARVESTING COST

All of the assumptions used in deriving harvesting costs in the preceding sections are estimates and may change with time or with improved machines or work methods. Which of these assumptions are most likely to cause major changes in costs of harvesting?

First, let us look at the three assumptions that there was no difference in harvesting efficiency, quality of product or cost of container handling by the two methods. All of these tend to discriminate against the mechanical harvester. For instance, if even 7 percent higher yields are obtained from machine harvesting due to increased recovery of total production, the breakeven acreage drops to 62.14, 40.30, and 29.82, respectively, for yields of 250, 350, and 450 bushels per acre. At 350 bushels per acre with 100 acres harvested annually, the per bushel cost is reduced to $0.082 as compared with $0.158 when no difference is assumed. Table 6 shows the per bushel costs of harvesting at varying acreages and yield rates under the still conservative assumption of difference in harvesting efficiency.

Harwood et al[1/] indicates that mechanically harvested sweet potatoes may have improved quality that results in as much as $0.25 per bushel increased value of No. 1 size potatoes. If this improvement in value of the No. 1 size potatoes could be realized with the harvester, the cost of harvesting 100 acres at 350 bushels per acre with 50 percent No. 1

1/ Harwood, D.G. Jr., Covington, H.M., and Westerbeek, Pieter, Will Sweet Potato Harvesting Machines Pay, Mimeo. Rpt. Dept. of Economics, North Carolina State University, Raleigh, North Carolina, August, 1968.

Table 6. Estimated machine harvest costs per bushel at varying yields and number of acres harvested with increased yields due to machine harvest taken into account1/

Acres harvested	Bushels per acre		
	250	350	450
	- - - - - - - - Dollars per bushel - - - - - - -		
1	12.452	8.876	6.889
25	0.515	0.349	0.257
50	0.266	0.171	0.119
75	0.183	0.112	0.073
100	0.142	0.083	0.050
200	0.080	0.038	0.015

1/ It is assumed that they will be 7 percent more bushels harvested with the machine than would be by hand methods and that a bushel is worth $1.00.

size would be reduced from $0.158 in Table 5 to $0.033. Breakeven acreages would reduce to 49.4, 41.69, and 36.05, respectively, for yields of 250, 350, and 450 bushels per acre.

If both of these assumptions were changed as indicated, that is, yields were increased 7 percent and the value of No. 1 size potatoes were increased $0.25 per bushel, the breakeven acreages would become 36.54, 24.65, and 19.70, respectively, for yields of 250, 350, and 450 bushels per acre. With 350 bushels per acre and 100 acres harvested annually, the increase in value of the additional potatoes plus the improved price on the No. 1 size potatoes would exceed the costs of harvest by $1,587.88 or by $0.042 per bushel. This would mean a $0.271 per bushel greater return for machine harvested potatoes than from hand harvested ones.

There is no evidence to indicate whether costs of handling sweet potatoes in bulk containers are higher or lower than in 1 bushel containers, but experience with other products would suggest that bulk handling would be less expensive. However, the difference in costs would be a very minor factor affecting harvesting costs in any case.

There were 4 assumptions made in deriving hand harvesting costs: (1) wage rates for machine operators, (2) machine costs per hour, (3) preparation time requirements, and (4) piece-work rates for grading and picking-up. The only one of these assumptions that seriously affects hand harvest costs is the piece-work rate. The per acre preparation costs would double and only raise the harvest cost from $0.233 to $0.246 at a yield of 250 bushels per acre. The increase would be still smaller at higher yields. The increase in harvest costs is almost proportional to the piece-work rate increase.

There are many more assumptions that must be considered with machine harvest. Five of these are connected with establishing the annual cost

of owning the machine: (1) purchase price, (2) depreciation schedule, (3) salvage value, (4) interest rate, and (5) cost of taxes, insurance, and housing. Three assumptions influenced the variable costs of machine harvesting: (1) operating coefficients, (2) machine operating costs, and (3) wage rate for machine operators.

A 20 percent change in each of these assumptions, each of which would result in increased costs, would in combination result in a 46 percent increase in harvesting cost per bushel, from $0.158 to $0.232 with a yield of 350 bushels per acre and 100 acres harvested. Breakeven acreages would change to 188.14, 102.37, and 70.32, respectively, for yields of 250, 350, and 450 bushels per acre.

Purchase price and the depreciation schedule are the primary factors affecting the costs of owning the machinery. Interest rates are also quite important. Operator wage rates and machine operating costs are the most important of the 3 assumptions affecting variable costs. However, the operating coefficients may become important if they are such that they do not allow you to harvest enough acreage annually to reach the breakeven acreage. In the example above with a 20% higher time requirement to harvest an acre, or 2.664 hours per acre, it would not be possible to harvest the breakeven acreage at 250 bushels per acre yields (188.14) if there were only 300 hours available for harvesting.

SUMMARY AND CONCLUSIONS

This is an economic analysis of the feasibility of adopting a mechanical harvester for sweet potatoes equipped with mechanical sizing and bulk loading attachments.

The harvester, developed by research workers from the Agricultural Engineering and Horticulture departments at Virginia Polytechnic Institute

and State University, is still in the modification process, and has had only limited field trials. Its purchase price, operating costs, and operating coefficients are not definitely known.

This analysis, therefore, is based upon earlier Virginia Polytechnic Institute studies of costs, the data from limited field trials, and multi-level estimates of purchase price, operating costs, and operating coefficients for the development of harvester costs.

Sweet potato producers were paying $0.22 per bushel for labor to field grade and pick up sweet potatoes in 1969. In addition, it was estimated, using core assumptions of labor rates and operating costs, that it cost $3.20 per acre to prepare the fields for the labor crew.

With core assumptions of purchase price, operating costs, and operating coefficients for the harvester, the acreage required to be harvested annually to result in an equal cost with the harvester was 91 acres with a yield of 250 bushels per acre, 57 acres with a yield of 350 bushels per acre, and 42 acres with a yield of 450 bushels per acre.

If the harvester is used on more than the number of acres indicated at each yield level, even lower costs would be realized.

Modification of the core assumptions would alter breakeven acreages and per bushel costs. With the hand harvest operation, the only important assumption was the piece-work rate of pay which is negotiated each season. A change in this rate results in almost proportional change in the cost of harvest because costs of preparing the potato fields for the labor crew are a very small proportion of the total cost of hand harvesting.

With the mechanical harvester, the assumptions of purchase price, depreciation schedule, rate of pay of machine operators, and machine operating costs were most important in influencing cost. However, even with 20 per-

cent increases in each of the 8 assumptions influencing mechanical harvester costs, the per bushel costs with high yields and large acreages harvested annually compared very favorable with hand harvest costs.

It is likely that a consideration of the relative harvesting efficiency by the 2 methods, the relative quality of the harvested product, and the relative cost of container handling would improve the comparative position of the mechanical harvester.

If a harvester is developed that is reliable in operation and comes close to the operating coefficients that are indicated, it should be profitable to adopt it for harvesting 50 or more acres of potatoes annually if yields of 350 bushels or more can be expected. If the machine can be used without the sizing attachment to harvest Irish potatoes also, many sweet potato producers with even smaller acreages would find it profitable to use the harvester.