Costs And Productivity In Harvesting Of Aquatic Plants[1]

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ABSTRACT

Productivity and costs of two aquatic plant harvesting systems operated by Dane County, Wisconsin were studied during 1972 and 1973 to obtain seasonal totals and hourly averages of various production parameters and of costs. For 1973 the seasonal average harvesting rate for the two machines was found to be approximately 0.73 acres per hr at a cost of $60.00 per hr. Data on the percentages of machine time occupied by actual operation, down time, moving from site to site, preventative maintenance, and bad weather are given. Percentages of total annual costs spent on operation, repair, investment, supervision, and shop facilities are also presented.

INTRODUCTION

For many years harvesting has been an important method for managing nuisance aquatic plants. Although this method is generally believed to be environmentally sound, its reputed high cost and alleged short-term effectiveness have been a deterrent to wider adoption. Harvesters, which incorporate both cutting and collection of plants, have not yet reached the high state of refinement and reliability common to modern agricultural machinery. Commercially available units do not normally incorporate any on-board processing, and disposal frequently consists of trucking as-received plants to a sanitary landfill area, usually an expensive procedure.

In harvesting programs that have been undertaken machinery is utilized for a variety of operations including shallow-water clean-up, lagoon clearing, and work in relatively open areas where shallow depths or submerged obstacles are not a problem. In many instances harvesting has been conducted on a small scale and only for a few seasons, so that very limited data are available on the productivity, costs, and effectiveness of a sustained harvesting effort. Since 1965, the City of Madison, Wisconsin and more recently Dane County have been utilizing harvesting as the principal method of nuisance aquatic plant management in the Madison Lakes. Research was undertaken endeavoring to improve methods for harvesting, processing, and disposal or utilization of nuisance submersed aquatic plants, and some of the results of this research are being incorporated into the County's harvesting components. Since estimates of the performance (operating costs, productivity, effectiveness, etc.) of current harvesters are highly variable, an important aspect of this research has been to obtain reasonably accurate data on machines used in the Dane County Program. Such data are essential in making realistic before and after evaluations of improvements made in the harvesting machines or systems, and can also serve to identify improvements which might be made either in the machines or in their application.

Consequently, the efforts reported in this paper sought data on the productivity of harvesting machines in acres per hr and tons of vegetation harvested per hr, and on the costs in dollars per acre and per ton harvested. Since the figures were found to be widely variable and to depend on many factors, maxima and minima are given as well as average figures. The breakdown of these cost figures into various categories provides some insight into where economies of operation might best be achieved. It is hoped that such productivity and cost information can be useful to groups presently engaged in aquatic plant harvesting, groups contemplating aquatic plant harvesting, manufacturers of harvesting equipment, and to others interested in increasing the viability of aquatic plant harvesting relative to other methods of coping with the problems of excess aquatic vegetation.

Dane County's program included the operation of three

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harvesters during 1972 and 1973, with overall budgets for the aquatic plant management program of $89,300 in 1972, $125,500 in 1973, and in 1974 a total of $223,000, which included the purchase of additional harvesters. Thus it is believed to be a substantial program which is reasonably representative of present practice.

METHODS

In order to acquire meaningful data, it was necessary to develop measuring methods which would not significantly impede the on-going harvesting operations. Of prime importance was the ability to delineate and measure surface areas on bodies of water. Also essential was measurement of biomass harvested from given areas. Records of fuel, lubricants, and other supplies consumed as well as hours of operation, number of loads harvested, breakdown time, and hours lost to bad weather were kept by Dane County operating personnel. Also, information on capital costs, equipment and supplies, buildings and facilities, salaries, etc., was supplied by Dane County.

Five different methods for measuring surface were tried and evaluated. These procedures and techniques have been described in a technical report.[2]

Measurements of the quantity (weight) of harvested material were accomplished in two different ways. The first method utilized portable highway scales to weigh trucks before and after loading them with harvested vegetation. The second method utilized gages mounted on the corners of the harvester transport barges to determine displacements before and after loading with harvested plants. Harvested aquatic vegetation contains varying quantities of both cellular and entrained surface moisture, depending on the plant species and maturity and on such factors as the methods used in handling, temporary storage, processing, etc. It is therefore necessary to take representative samples at the time of weighing and to determine the moisture content if the weight of dry matter is desired.

Measurements of elapsed times were made either with a stop watch or with an ordinary watch as was appropriate to the particular operation.

HARVESTER PRODUCTIVITY

Variables which affect the productivity of aquatic plant harvesters include: (1) width of cut, (2) forward velocity, (3) maneuverability, (4) plant density, (5) species of plants, (6) wind velocity and wave action, (7) water depth and bottom obstructions, (8) skill and incentive of operator, (9) matching of accessory equipment (transport barges, conveyors, trucks) to the harvester and to overall conditions, (10) mechanical design and condition of harvester as related to breakdown time, and (11) percentage of time spent on non-harvesting operations, such as moving from location to location. Since such a large number of variables affect harvester productivity, comparisons between harvesting machines and programs are difficult to make. In this study, maxima and minima were recorded for two different harvesting systems as well as recording their total hours and production for the 1973 season to arrive at seasonal average figures.

The two systems on which data were kept during the 1973 season were:

(1) Modified Grinwald-Thomas Harvester.[3] As originally built, the harvester had a storage hopper at its stern where approximately 1.0 ton of harvested vegetation was collected. When the hopper was filled, harvesting was momentarily halted while the contents of the hopper were pushed, by means of hydraulic cylinders, onto a transport barge temporarily coupled to the harvester. The unit was modified to incorporate a forage chopper on the harvester deck through which all harvested vegetation is passed. Rubber covered feed rolls for the chopper, which it was hoped would be helpful in removing entrained surface moisture prior to chopping, proved to be unworkable. From the chopper the material is conveyed directly to a transport barge coupled in tandem to the harvester whenever it is operating. When one transport barge is filled it is uncoupled and an empty transport barge coupled to the harvester while the loaded transport proceeds to the shoreline unloading area. Chopping the harvested material substantially reduces its volume and puts it into a free-flowing form which can be handled by conventional conveyors. The storage areas on the two transport barges which work with this harvester are equipped with self-unloading forage boxes modified from those used conventionally in agriculture.

(2) Aquamarine Trio.[4] This set of equipment consists of a harvester, a transport barge which receives cut vegetation from the harvester at intervals and transports it to shore, and a shoreline conveyor to transfer the cut vegetation from the transport barge to a waiting truck. Conveyor mesh covering the decks of both the harvester and the transport barge make it possible to mechanically load and unload the harvested vegetation.

For cutting and collection of vegetation both machines utilize reciprocating cutter bars ahead of inclined, porous elevating conveyors. Both harvester units are paddle-wheel driven and utilize hydraulic power transmission and controls. Some of the differences between the systems are listed in Table 1. While data were kept on both harvesters, valid comparisons of their optimum productivities are difficult to make because of differences in their characteristics and of the ways in which they are utilized.

The original version of Machine 1 was approximately as maneuverable as Machine 2, which can turn within its own length by running the two paddle wheels in opposite directions. However, with the transport barge attached to

[2]Koegel, R. G., Livermore, D. F., and Bruhn, H. D. 1974. Evaluation of Large-Scale Mechanical Management of Aquatic Plants in Waters of Dane County. Technical Report WIS WRC 74-08, 36 pp. Water Resources Center, 1975 Willow Drive, Madison, Wisconsin 53706.

[3]Manufactured by the Grinwald-Thomas Company of Hartland, Wisconsin. (Company no longer in business.)

[4]Manufactured by the Aquamarine Corporation, 1116 Adams St. Waukesha, Wisconsin 53186.

Table 1. Comparison of Harvester System Characteristics.

Harvester	Machine 1	Machine 2
	(Modified Grinwald-Thomas System)	(Aquamarine System)
1. Maneuverability:	Somewhat limited because of tandem-attached transport barge	good
2. Width of Cut:	10 ft	8 ft
3. Number of Transport Barges Used in 1973:	2	1
4. Transport Barge Propulsion:	Outboard motor	paddle wheel

the harvester, maneuverability is substantially reduced. This did not prove to be a serious handicap because Machine 1 is generally used for cutting long narrow weed beds parallel to shore where turning occupies an extremely small percentage of the total time. It was initially thought that the large side area presented by the tandem-coupled harvester and transport barge might make operation in a cross wind difficult. Experience showed, however, that the outboard motor at the stern of the transport barge could be used to compensate for the wind and also to give the harvester a greater forward velocity during cutting.

In order to obtain estimates of the relationships between plant density and the harvesting rates in acres per hr and lb per hr, a number of timid trials were conducted with each harvester in areas of various plant densities measuring times, areas covered, and weight of plants harvested. The results of 15 timed trials during 1973 and 1974 are shown in Figures 1 and 2. The areas harvested in these trials ranged from approximately one fourth acre to one and one fourth acres. In Figure 1, the pounds of wet vegetation harvested per hour, (M), is plotted versus the density of plant growth in pounds of wet vegetation harvested per acre, (D). Figure 2 is a plot of acres harvested per hr, (A), against density of plant growth, (D). The relationship between the variables in these two figures is.

$$M(\text{lb/hr}) = A(\text{acres/hr}) \times D(\text{lb/acre}).$$

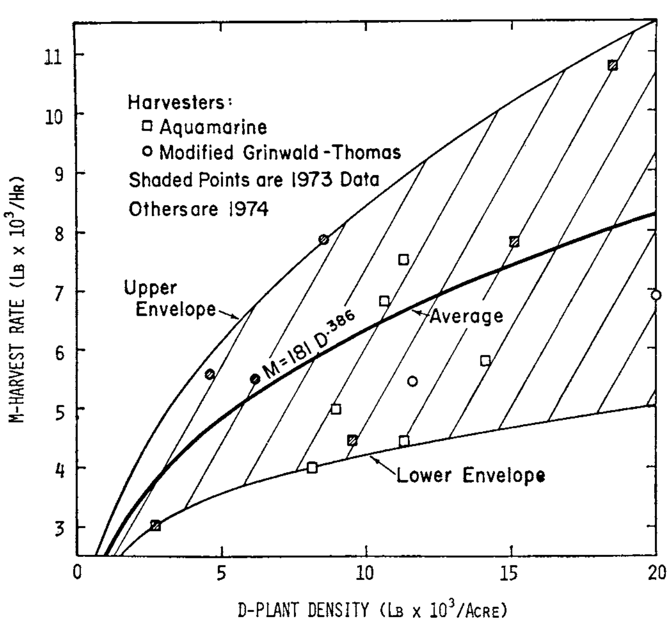

Figure 1. Harvesting rate (lb/hr) versus plant density (lb/acre).

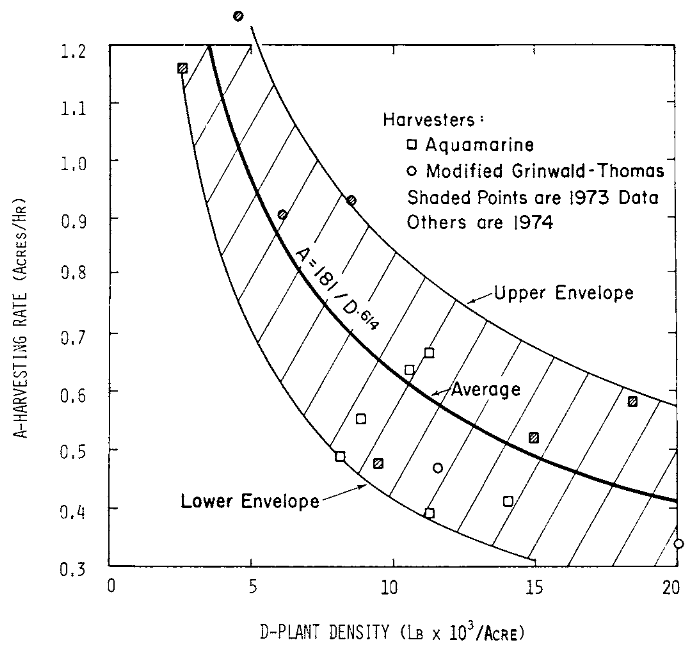

Figure 2. Harvesting rate (acres/hr) versus plant density (lb/acre).

By plotting the data on log-log paper and drawing straight lines representing the envelopes of the data points, the curves and approximate equations for M versus D and A versus D shown in Figures 1 and 2 were obtained. The "average" curve lines shown represent the numerical means of the two "envelope" lines for any given values of plant density. The equations for the "average" curves are given in the figures.

These figures provide some indication of how harvesting rates vary with plant density. The scatter of points within the envelopes is quite substantial, but this is to be expected since there are so many variables which influence harvesting rates (see earlier discussion).

During 1973, a seasonal average plant density in areas harvested was estimated to be 6,450 lb(as received) per acre, less than one-third of the maximum density observed. For this "seasonal average" plant density, Figures 1 and 2 give "seasonal average" harvesting rates of 5350 lb/hr and 0.83 acre/hr as the composite of rates for the two harvesters observed. Most of the data points in Figures 1 and 2 are seen to have been obtained in areas of greater plant density than the "seasonal average." However, the "seasonal average" was based on the total harvest for the season, and thus includes considerable operation in relatively low density areas, in trimming operations, and waiting for the return of transport barges. The timed runs involved continuous operation and, in all but three instances, were conducted in areas where plant densities were higher than the "seasonal average."

For 1973, total seasonal production by each of the two harvesters observed was obtained by multiplying the number of transport barge loads (as tallied by the operators) by an average load weight. A number of loads were weighed to arrive at average load weights for each transport barge. The total seasonal production for each harvester was then divided by the total number of operating hours logged to give "seasonal average" harvesting rates in lb/hr. These averages were 5930 and 3525 lb/hr for machine numbers 1 and 2 respectively.

Combining these seasonal average results with data from the 1973 tests of weight and area coverage rates for the two harvesters gave the "seasonal average" plant density of 6450 lb/acre and gave "seasonal average" area coverage rates of 0.94 and 0.63 acres/hr of machines 1 and 2 respectively. If it is assumed that 5% of the operating time was spent for turning and unloading and that the effective width of cut was 1.0 ft less than the width of the cutter bar, the above area coverage rates correspond to working speeds of 0.91 and 0.78 mph respectively. Records were kept for slightly different periods of time for the two harvesters, but at the rates calculated, the areas covered in a 2.5 month harvesting season would have been 380 and 236 acres respectively. Table 2 shows important 1973 seasonal production totals, and Table 3 gives observed maxima, minima, and seasonal averages for a number of performance variables.

The data for 1973 indicated somewhat better productivity for machine number 1. However, as seen from the data points in Figures 1 and 2, the 1974 performance test results showed little difference between the productivities of the two machines. Among the factors which probably account for these variations are the following:

TABLE 2. 1973 SEASON PRODUCTION FROM TWO HARVESTERS.[a]

	MACHINE 1 (Modified Grinwald-Thomas)	MACHINE 2 (Aquamarine Trio)	TOTAL FOR TWO HARVESTERS
Acres Harvested[b]	380	236	616
Tons Harvested[c]	1226	760	1986
Tons Dry Matter Harvested[d]	147.0	91.2	238.2
Lb of Nutrients in Vegetation[e]	N 8820 P 735 K 4115	N 5470 P 455 K 2550	N 14,290 P 1,190 K 6,665
Hr Operated[a]	415	430	845
Hr Operated per Month[a]	165.6	172.5	338.1

[a]Values shown in this table are corrected to an operating season of 2.5 months, considered to be the approximate productive period of each summer. Actual record periods were 4 June thru 27 July 1973 for Machine 1 and 18 May thru 31 July 1973 for Machine 2.
[b]Actual operating hours were logged. These were multiplied by 0.94 acres/hr for Machine 1 and 0.63 acres/hr for Machine 2 to obtain acreage cut.
[c]The number of loads were logged. Seasonal averages of 7500 lb/load and 3371 lb/load were used for Machines 1 and 2 respectively.
[d]A seasonal average of 88% moisture was used. This is probably high for early in the season and low for late in the season.
[e]Nutrient contents of 3% nitrogen, 0.25% phosphorus, and 1.4% potassium (dry basis) were used.

TABLE 3. MAXIMA MINIMA AND SEASONAL AVERAGES FOR 1973.

	MACHINE 1 (Modified Grinwald-Thomas)			MACHINE 2 (Aquamarine Trio)		
	Maximum observed	Minimum observed	Average	Maximum observed	Minimum observed	Average
Lb harvested per acre	22,500	2600	6450	22,500	2600	6450
Acres Harvested per hr	1.23	0.91	0.94	1.16	0.47	0.625
Lb (wet wt) harvested per hour	7850	5530	5930	12,680	3060	3525
Loads harvested per hr	1.14	0.81	0.79	1.15	0.67	1.045
Lbs per load	10,000 by displacement	2700 (partial load)	7500	3975	2970	3371
Velocity for harvester (mph)	2.37 (shuttle pushing)	0.42	0.91[a]	1.49	1.05	0.78[a]
Velocity for empty shuttle barge (mph)	3.76	3.75	3.75	2.62	2.49	2.56
Velocity for full shuttle barge (mph)	2.14	2.14	2.14	2.94	2.37	2.41

[a]Based on effective cut 1.0 ft less than cutter bar width, and 5% of time used for turning and unloading.

1. During 1973, the forward speed of machine no. 1 was being augmented by using thrust from the outboard engine on the tandem coupled transport barge. Use of this engine also improved directional control and ability to operate in cross winds. During 1974, only the side paddle wheels of the harvester were used to propel both the harvester and the tandem coupled transport barge.
2. The total output for machine no. 2 during 1973 was somewhat reduced because it was serviced by only one transport barge, resulting in occasional waits by the harvester for the return of the transport barge.
3. During the 1973 period for which records were kept on machine no. 1, the crew chief was the engineering student who had done much of the design work on the modifications incorporated into the machine for the 1973 season. Hence he was strongly motivated to operate the machine effectively.

ANALYSIS OF HARVESTER TIME UTILIZATION AND COSTS

The distribution of harvester times between various activities for the 1972 and 1973 seasons are shown for both harvesters in Figure 3. The percentage of time spent in actual harvesting increased significantly for both units between 1972 and 1973. In the case of machine 1, which was left in Lake Monona during the entire 1973 season, the reduction in time spent moving from site to site was very substantial. Another significant reduction from 1972 to 1973 was that of the down time of machine 2. This is attributed to a pre-season overhaul involving replacement of engine, cutter bar, and certain hydraulic components, and indicates the importance of off-season maintenance work to put the machines in the best possible condition before the start of a new season.

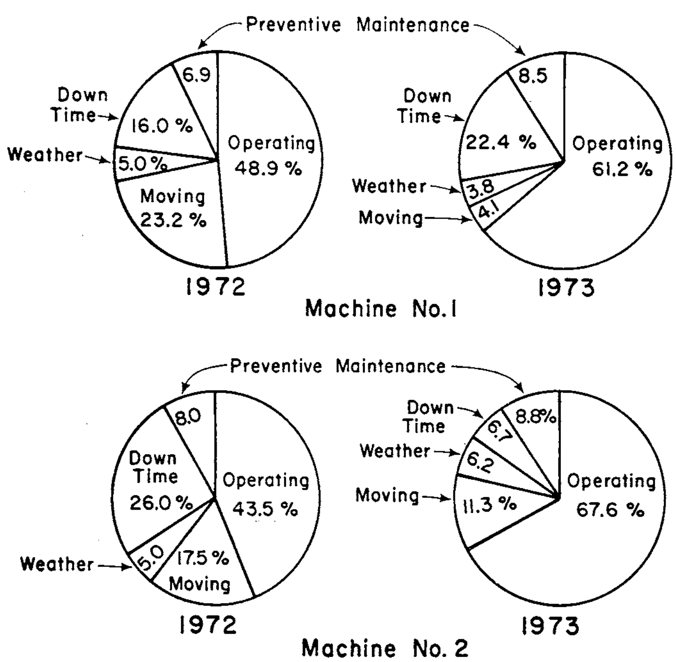

Figure 3. Distribution of machine hours in aquatic plant harvesting operations.

The percentage of down time for machine 1 increased from 1972 to 1973, but this category included time spent "debugging" the modifications which were incorporated into the unit just prior to summer 1973. The distribution of "down time" for the harvesters is shown in Figure 4

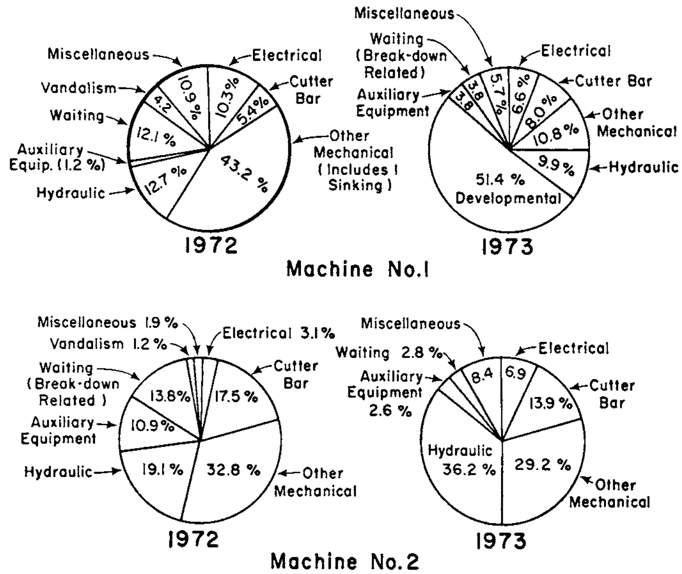

Figure 4. Distribution of down time in aquatic plant harvesting operations.

for both 1972 and 1973. This distribution shows that approximately half of the machine 1 down time for 1973 was developmental in nature rather than resulting from actual breakdowns. Cutter bar problems and hydraulic problems form two major categories of breakdown. Cutter bar problems are frequently caused by hitting some unseen obstruction, and are difficult to prevent. However, the severity of these problems can be minimized by careful operation in areas where obstructions are expected, by rugged construction, by the use of components which can be easily and quickly replaced, or by the use of appropriately flexible suspension systems.

The cost data presented in Table 4 is based on Dane County's 1973 operating records and on the average productivities listed in the preceding section. The figures used do not include any costs for transportation or disposal of harvested vegetation, since this was the responsibility of the municipality in which the harvesting occurred rather than of Dane County. These costs vary considerably from location to location. Of the total vegetation harvested in 1973 and 1974, it is estimated that approximately 40% was hauled away and utilized by private citizens for soil conditioning purposes. Improved processing and better publicity could result in a significantly greater percentage of the harvested vegetation being thus utilized.

Assumptions on which the results of Table 4 are based are:

1. Operating costs assume actual Dane County procurement costs for 1973 of gasoline at $0.20/gal, lubricating oil at $0.35/qt, hydraulic oil at $0.27/qt, and wages computed as follows:

Table 4. Harvesting Costs for 1973.

TYPE OF COST	MACHINE NO. 1			MACHINE NO. 2		
	Dollars per hr	Dollars per Acre	Percent of total cost	Dollars per hr	Dollars per acre	Percent of total cost
Operating	16.37	17.40	25.4	15.93	25.50	27.2
Repair, overhaul, modification, parts and mechanics salary	20.42	21.75	31.8	19.70	31.55	33.6
Supervision	6.93	7.38	10.8	6.70	10.70	11.7
Investment costs	17.86	19.00	27.8	13.65	21.85	23.3
Shop and storage facilities	2.71	2.88	4.2	2.62	4.20	4.5
Totals	64.29	68.41	100.00	58.60	93.80	100.00

Crew of three with an average wage of \$3.00/hr = \$9.00/hr. This figure was multiplied by a ratio of

$$\frac{13 \text{ paid hr}}{8 \text{ operating hr}}$$

to yield \$14.65 per operating hr (see distribution of machine hours) including one paid hr per day spent traveling between headquarters and harvesting site.

2. Total costs for parts, repair, and overhaul (\$23,631) plus mechanics annual salary (\$10,243) were divided equally among the four large harvesters operated during 1973. This figure (\$8468) was divided by the number of operating hours in 2.5 months during 1973 (machine 1: 415 hours) to obtain an hourly rate. Since the two remaining harvesters worked relatively few hours, the actual repair and overhaul costs for the machine systems 1 and 2 were undoubtedly higher than shown. However, both of these machines underwent extensive overhaul and/or modification in 1973. Hence, the costs shown might be indicative of an average year. While some of the operating crew's time is spent on minor repairs, the mechanic occasionally operates the harvesters. Thus there is some exchange between operation and repair.
3. Supervision represents the annual salary of one foreman divided equally among four large harvesters. Other salaried Dane County Personnel who make contributions to aquatic plant harvesting are not included. It should be noted that on an annual basis a large part of the foreman's time (probably over half) is spent on repair and/or modification of the harvesting equipment.
4. Annual investment costs were based on 15 years (due to the relatively small number of operating hours per year) straight line depreciation plus 8% interest on an average of one-half of the initial cost. For example, assuming the initial cost of the machine 2 system was \$55,000, the annual investment cost would be

$$\$55{,}000\left(\frac{1}{15} + \frac{.08}{2}\right) = \$5{,}860$$

The initial price of machine 1 and associated equipment is more difficult to assess, because of the modifications. However, an equivalent initial price of \$60,000 was used giving an annual investment cost of \$6,400. To this an annual cost of \$1,000 was added for the lease of two outboard engines to propel the two transport barges.

5. The \$4,500 annual cost of garage and shop facilities was divided equally among four harvesters.

Figure 5 is a graphical presentation of the cost of harvesting divided into five categories based on averages for the two harvesters for a 2.5-month working season.

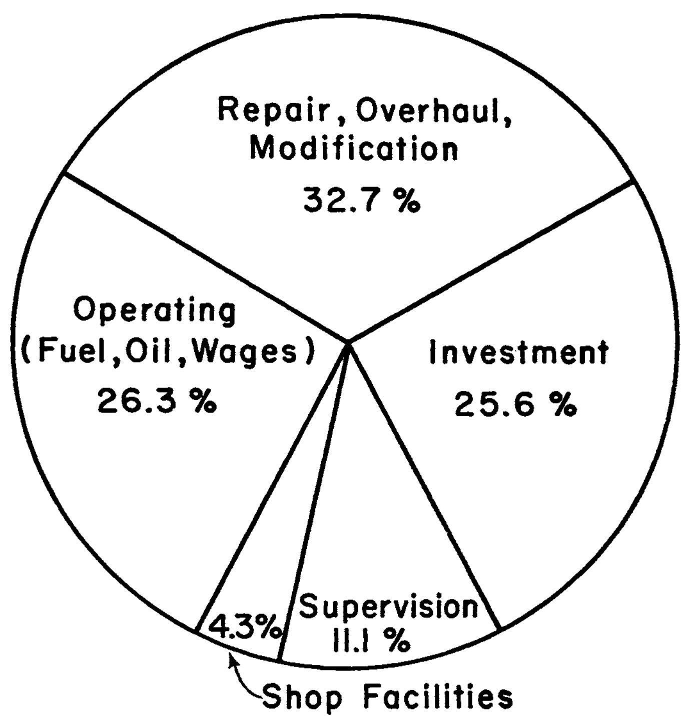

Figure 5. Distribution of expenses for harvesting in the year 1973.