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ABSTRACT

The purpose of the strip selection thinning was to determine the economic and silvicultural implications of a mechanized harvesting system. The selectively cut strips were thinned from an original basal area of 26.6 square meters per hectare (116 square feet per acre) to a residual of 15.6 square meters per hectare (68 square feet per acre). The 4.57 meter (15 feet) wide clearcut strips reduced the over-all residual stocking to 12.6 square meters per hectare (55 square feet per acre). An average of 193 tons of whole tree chips per hectare (78.1 tons per acre) were removed at a harvesting cost of $8.64 per ton. Thirty-two percent of the residual trees sustained harvesting damage. Of the 32 percent damaged, 13 percent were "minor" injuries [less than 323 square centimeters (50 square inches) of sapwood exposed] and 19 percent "major" injuries [more than 323 square centimeters (50 square inches) of sapwood exposed].

INTRODUCTION

There are approximately 12.9 million hectares (32 million acres) of the northern hardwood forest type in the eastern United States (5). A large portion of this acreage is in unmanaged pole and sapling size stands. If thinned, these stands should be capable of increased production of high quality forest products. Historically land owners have been discouraged from undertaking a thinning program because of high initial costs and lack of any immediate monetary benefit. With the increasing demand for timber and wood fiber and more efficient harvesting systems, commercial thinnings should become more attractive.

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This study has two objectives: to test and evaluate a mechanical harvesting system for thinning a hardwood stand; and to provide whole tree chips for an experimental trial burn as an auxiliary source of energy in a coal fired electric generation power plant. The study was co-sponsored by Michigan Technological University, North Central Forest Experiment Station of the U.S. Forest Service, Michigan Department of Natural Resources, Marquette Board of Light and Power, and the Michigan Department of Commerce--Energy Administration.

SCOPE AND OBJECTIVES

In 1974, the North Central Forest Experiment Station tested four mechanical harvesting schemes to determine the feasibility of thinning fully stocked pole-sized northern hardwood stands (2). Of the four mechanized methods tested, strip thinning with removal of pre-selected trees between strips proved to be the preferred method, as it was reasonably productive and silviculturally acceptable. This study incorporates a similar harvesting scheme using a different array of equipment components. Instead of using a rubber tired feller-buncher which maneuvered through the stand during selection thinning, a tracked long-reach Drott 40LC Feller-Buncher was employed which made it unnecessary to enter the selectively cut strips with harvesting equipment[1].

Specific objectives were: (1) to test strip-with-selection thinning by means of a tracked, long-reach feller-buncher; (2) to determine production rates and costs for harvesting and transporting; (3) to evaluate residual damage and effects of compaction caused by harvesting equipment; (4) to measure tree response and reproduction establishment as a result of mechanized thinning; and, (5) to determine logistics and economics of utilizing whole tree chips as an auxiliary fuel for generating electricity in a conventional coal burning boiler.

Only the immediate harvesting results are reported here. At least ten years will be required before the long term results of the study can be evaluated. Moreover, our production and cost data, as well as damage and soil compaction, apply specifically to this study and cannot be assumed to apply equally well to all other thinning operations.

STUDY AREA AND HARVESTING METHOD

The study area is located in Sections 1 and 2, T45N-R22W in Alger County, Michigan, approximately 41.8 kilometers (26 miles) southeast of Marquette, Michigan. The predominantly pole-sized stand was composed of 73 percent sugar maple, 22 percent American elm and the remaining 5 percent is basswood, quaking aspen and black cherry. The stocking level before cutting was 628 trees per hectare (254 trees per acre) and 26.6 square meters (116 square feet per acre) of basal area. Because of severe incidence of Dutch elm disease, it was necessary to harvest all of the elm. This precluded the possibility of maintaining a uniform stocking level of 16.1 square meters per hectare (70 square

[1]Mention of trade names does not constitute endorsement of the products by the University or U. S. Forest Service.

feet per acre) in those areas where elm predominated. The leave-tree marking system was implemented by the Michigan Department of Natural Resources "Forest Cultivation" team. All leave-trees were marked with a painted ring around the tree, to facilitate identification by the feller-buncher operator from whatever angle of approach. Post harvest measurements indicated a residual basal area of 15.6 square meters per hectare (68 square feet per acre) in the 12.2 meter (40 feet) wide selection thinned strips and 12.6 square meters per hectare (55 square feet per acre) in the combined selection and clearcut strips.

Following marking, feller-buncher routes were established by locating compass lines east and west 16.76 meters (55 feet) apart and perpendicular to the access road. These lines served as a guide to the feller-buncher operator for clearing a 4.57 meter (15 feet) wide clear-cut strip and to provide operating space for the feller-buncher and a skidding path for the grapple skidder. The 6 meter (20 feet) reach capability of the machine also enabled the operator to selectively thin a 6 meter strip on both sides of the strip line. This harvesting pattern resulted in alternate 12.2 meter (40 feet) wide selection thinned strips with 4.57 meter (15 feet) wide clearcut strips for the bunching and skidding of whole trees (Figure 1).

RESULTS

Thirteen major pieces of equipment were used in the operation. The type, model and estimated purchase cost (f.o.b. delivered) of each piece of equipment, is listed in Table I. The crew consisted of: one feller-buncher operator, one skidder operator, one chipper operator and five truck drivers. There was no designated foreman or supervisor.

Table I. *Itemized Cost in 1978 Dollars*

Type and Model	Estimated Purchase Cost (f.o.b. delivered) (in dollars)
1 Drott 40 LC Feller-Buncher	$112,604
1 John Deere 740 Grapple Skidder	84,700
1 Morbark (22" Chiparvestor)	150,000
5 truck/tractors @ $40,000	200,000
5 chip vans @ $12,000	60,000
TOTAL	$607,304

Feller-Buncher

The feller-buncher operator formed tree bunches either to the left or right of the clearcut strip while proceeding away from the chipper. When leaving the stand it was necessary for the operator to swing the cut trees 180 degrees and lay them behind with butts facing toward the chipper, to facilitate skidding. Table II summarizes the production rates of the Drott 40 LC Feller-Buncher. The felling productivity of 94 stems per hour is considered satisfactory, but would have been higher had the accumulator arm been functioning properly. Attempts

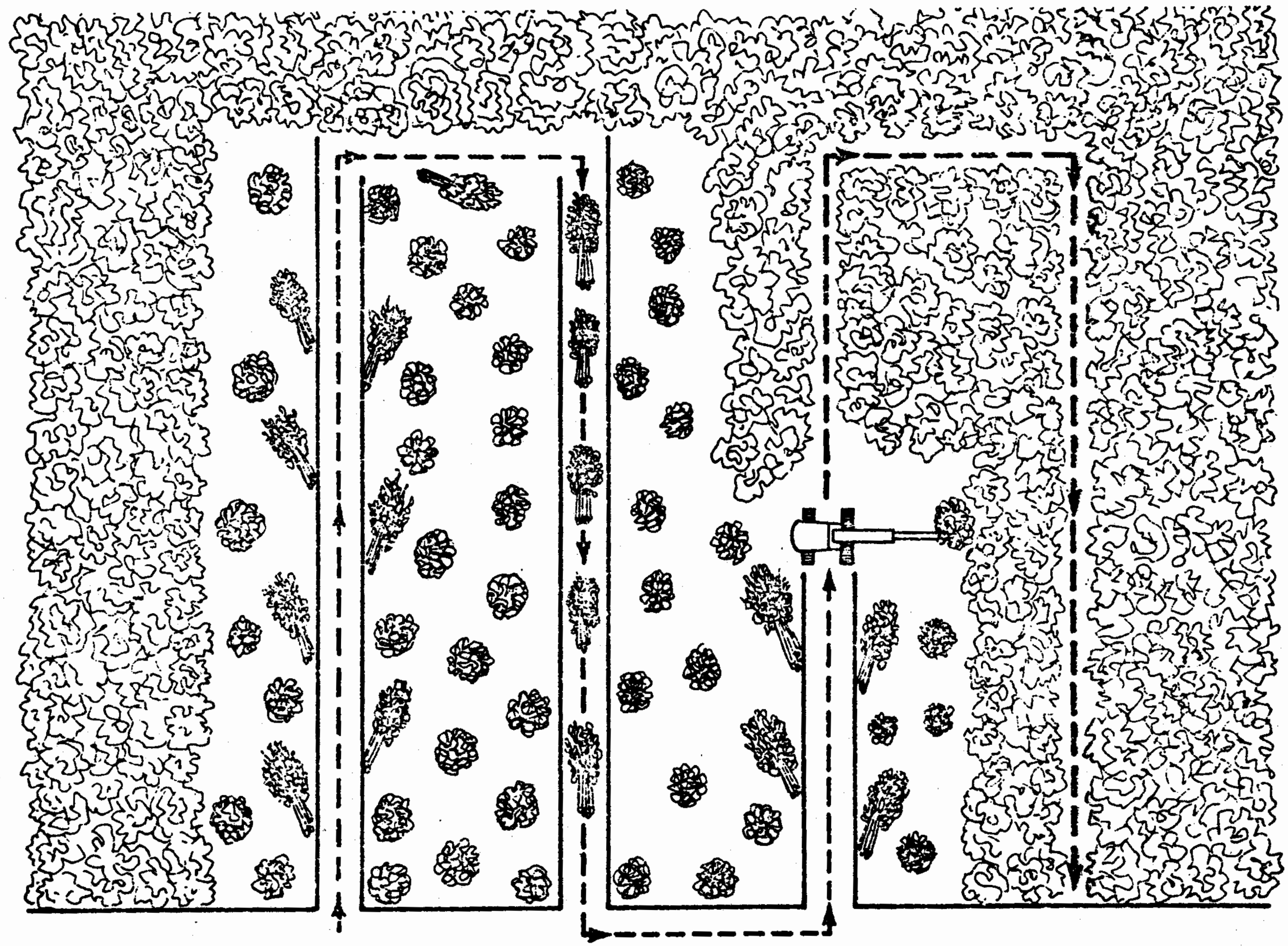

Figure 1. Strip with selection thinning employing 15 foot wide strips and 40 foot wide bands of thinned leave area.

were made to correct the malfunctioning accumulator arm, but it remained inoperable during most of the harvesting. This necessitated the feller-buncher working 30 percent longer each day to maintain a production equivalent to the skidder and chipper.

Table II. *Drott 40 LC Feller-Buncher Production Rates in Strip-with-Selection Thinning*[1]

Stems/cycle[2]	Stems/skidder bunch	Stems/hr. w/o delays	Stems/hr. w/delays
1.3	11.0	94.05	71.7

[1]Based on 744 felling cycles
[2]Accumulator not functioning for a portion of the study.

Skidding

Skidding distances were reduced by moving the chipper to positions 91.4 meters (300 feet) apart along the access road. Average skidding distance was only 97.8 meters (321 feet) [75.9 meters (249 feet) in the woods and 21.9 meters (72) feet) on skidding road] which permitted a single skidder to supply the chipper. Table III presents the productivity of the grapple skidder. The skidder also functioned as a dozer, clearing slash at the landing, pushing trucks and grading the main haul road when necessary.

Table III. *John Deere 740 Grapple Skidder Production Rates in Strip-with-Selection Thinning*

Average Distance	Average Stems/skid	Average wt/skid	Cycle Time
97.8 meters (321 ft.)	11.4	4.2 tons	5.1 min.

Chipping

Bunches were skidded to either side of the chipper equipped with a self-feeding hydraulic knuckle boom grapple. The chips were blown directly into waiting vans. The chipping rate was 41.5 green tons per production hour. Table IV summarizes the chipping production rate.

Table IV. *Morbark 22XL Chiparvestor Production Rates*

Stems/chipper cycle	Stems/van load	Skid loads/van	Green tons/hour
1.6	68.6	6.0	41.5

The equipment was scheduled to do 33 hours of productive work (6). Twenty-five percent of this time was recorded as delay. The major cause was waiting for chip vans. The single lane access road and rainy weather interferred with truck efficiency.

Production versus Cost

A 1,000 green ton chip contract with the Marquette Board of Light and Power limited the scope of the study to this predetermined weight. Average yield was 193 green tons per hectare (78.1 green tons per acre) which was considerably higher than the average yield of 116 green tons per hectare (46.8 green tons per acre) produced on the 1974 thinning study (2). The higher per acre volumes in this case study can be attributed to the large elm harvest. The tabulation below summarizes the production of this logging system.

Total tons delivered to Marquette Board of Light and Power	1,000 tons
Number of van loads	40
Average tons per van	25
Total harvested area (5.3 hectares)	13 acres
Tons per acre yield (193 tons per hectare)	78.1 tons
Total harvest (estimated)	2,738 trees
Average green weight per tree (331 kilograms)	730 pounds

Because it is extremely difficult to obtain detailed cost data from the contractor for cost analysis, the following assumptions were made for the equipment: stumpage, overhead (assumed 15 percent), and labor costs (Table V).

Table V. *Assumptions for Equipment Used*

Equipment	Estimated Economic Life (yr.)	Working Days per year	Scheduled Hours or Miles/yr.	Machine Utilization
Feller-Buncher	5	250	2,250 hr.	65%
Skidder	3	250	2,000 hr.	67%
Chipper	5	250	2,000 hr.	75%
Truck-Tractor	5	250	40,000 mi.	-
Chip Vans	8	250	20,000 mi.	-

Stumpage: The stumpage prices vary from one place to another. $.60 per green ton was used in this estimation, based on "Forest Residues Energy Program" (3).

Labor Cost: $9.00 per hour, including fringe benefits.

The total purchase cost of the equipment, using 1978 dollar prices amounted to $607,304. Based on our data and our assumptions, the estimated cost with labor for the logging (felling, skidding, and chipping) and transportation equipment were calculated to be $4,150 and $2,840, respectively. Dividing these figures by a total system production of 1,000 green tons, we obtained $4.15 per green ton for the logging equipment and $2.84 per green ton for transportation equipment (Table VI). Adding $.60 per green ton for stumpage and conservative allowance of 15 percent for overhead, the total estimated costs would average $8.64 per green ton.

Table VI. *Summary of Mechanized Thinning Case Study Cost, 1978 (estimated values)*

	dollars/green ton
Felling, skidding, and chipping	$4.15
Transportation (26 miles)	2.84
Sub Total	$6.99
Stumpage	.60
Sub Total	$7.59
Overhead (assumed 15 percent)	1.05
TOTAL	$8.64

Stand Damage

Damage to residual trees in partially cut stands as a result of mechanical harvesting is a major concern of the timber manager. Damage, especially in hardwood trees where quality is a major consideration, can cause important reductions in the future value of a tree.

The damage results reported here combine both skidding and felling damage since no attempt was made to segregate one from the other. Observation clearly indicated skidding damage to be the major source of injury. Table VIIa shows 32 percent of the trees sustained harvesting damage. Table VIIb shows the location of tree injury.

Table VIIa. *Frequency of Skidding and Felling Damage*

	Number of Trees		Percentage
Total Trees	269/ha	109/a	
Trees with one or more injuries			
Minor injury[1]	34/ha	14/a	13
Major injury[2]	52/ha	21/a	19
Total Injuries	86/ha	35/a	32

[1]Injury has less than 323 square centimeters (50 square inches) of sapwood exposed (4).
[2]Injury has more than 323 square centimeters (50 square inches) of sapwood exposed.

Table VIIb. *Location of Tree Injury*

Location	Number of Trees		Percentage
Stem damage only	40.0/ha	16.2/a	45
Root damage only	15.3/ha	6.2/a	17
Stem and root damage	34.1/ha	13.8/a	38

Comparing these results with other mechanical harvesting studies (Table VIII), indicates that injuries were about 6 percent higher than average and 12 percent higher than the selection with strips conducted by the U.S.D.A. Forest Service 1974 study. Much of this difference can be attributed to the intensity of cut. The number of tree injuries differed only by 10 trees per hectare (4 trees per acre), but the number of residual trees differed by 116 trees per hectare (47 trees per acre), thus making a significant percentage difference between the two thinnings.

Table VIII. *Tree Damage Survey Summary (frequency of tree injuries by harvesting method)*

Harvesting Method	Number of Residual Trees		Number of trees with one or more injuries		Percentage
1974 Study (2)					
Shelterwood	269/ha	109/a	57/ha	23/a	21
Selection	338/ha	137/a	114/ha	46/a	34
Strips	865/ha	350/a	212/ha	86/a	25
Selection with strips	385/ha	156/a	77/ha	31/a	20
Present Study					
Selection with strips	269/ha	109/a	86/ha	35/a	32
Average	425/ha	172/a	109/a	44/a	26

The necessity of bunching the trees between the standing trees as the feller-buncher proceeded away from the access road, was a significant factor in increasing damage. Removing these bunches from among the standing trees resulted in unavoidable damage during the skidding process. Another factor contributing to damage was the spreading nature of the elm tops, which caused the loads to be wider than they would normally be with other species. The John Deere 740 Grapple Skidder had the capacity to double up on bunches, which made some of the loads excessivly wide, causing additional damage.

It may be possible to modify the harvesting system to reduce residual damage by at least 10 percent. The installation of access roads one-quarter mile apart would allow for the bunching of all trees behind the feller-buncher as was done when the feller-buncher proceeded toward the chipper. This system confines all bunching and skidding activity within the clearcut strip, and avoids bunching trees among the standing trees.

Soil Compaction

Soil compaction by harvesting equipment has been a subject of concern to the soil scientist (1). As a part of the study, we investigated some effects of tree harvesting equipment on the soil.

Seventeen skidder strips were sampled. Each strip was subdivided equally into thirds; and within each third, 1/3 square meter micro-plots were randomly located. One of the micro-plots in each 1/3 of a strip was to have a clear impression of the skidder tire. At each micro-plot, ten penetrometer observations were made at the bottom of treads (lugs) and in the space between treads (Figure 2) using a pocket penetrometer (Soiltest Model CL-700) which measured the unconfined strength of the soil mass in kilograms/cm^2.

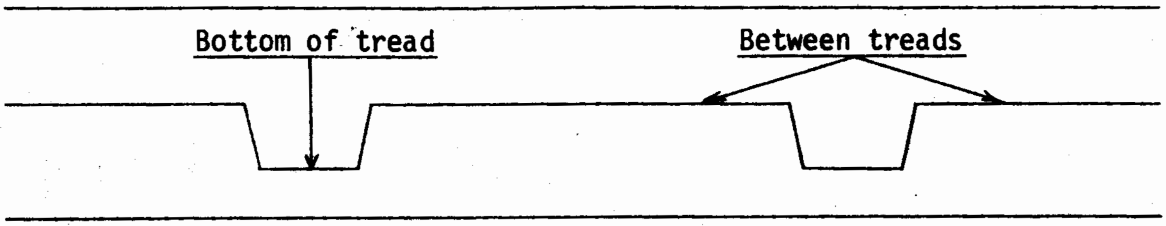

Figure 2. *Pocket Penetrometer Reading Locations*

Data were also collected at the time of penetrometer observations with regard to moisture condition (*e.g.*, dry, moist, water standing, etc.), number of skidder passes, type of surface soil, whether or not tops had been dragged over the track, field determined soil texture, and percent coarse fragments larger than 7.5 cm on the surface. Three surface soil categories were developed as a result of these field observations.

Mineral - sandy loam texture, less than one percent coarse fragments, moist, with no standing water, all leaf litter and organic matter removed.

Leaf litter - track made on moist intact forest floor, no coarse fragments.

Organic - mixture of litter and mineral soil, no coarse fragments.

In addition to the condition of the surface of each strip, three strata were used for the penetrometer observations. They were: undisturbed site, where tops had been dragged over the skidder path between treads, and at the bottom of treads.

Penetrometer Reading Results

Soil density increases exponentially with compressive forces applied at a given soil moisture content (1). These forces also destroy large pores or reduce their size, interfering with both internal and external air and water movements. Changes in air and water movements could occur next to plant roots at the location of the wheel track, influencing growth.

Table IX summarizes the results of penetrometer observations collected from the 1/3 square meter micro-plots on the 17 skidding strips. The data compare penetration resistance by type of soil surface and number of skidding passes. Figure 3 presents a graphic display of the data from Table IX.

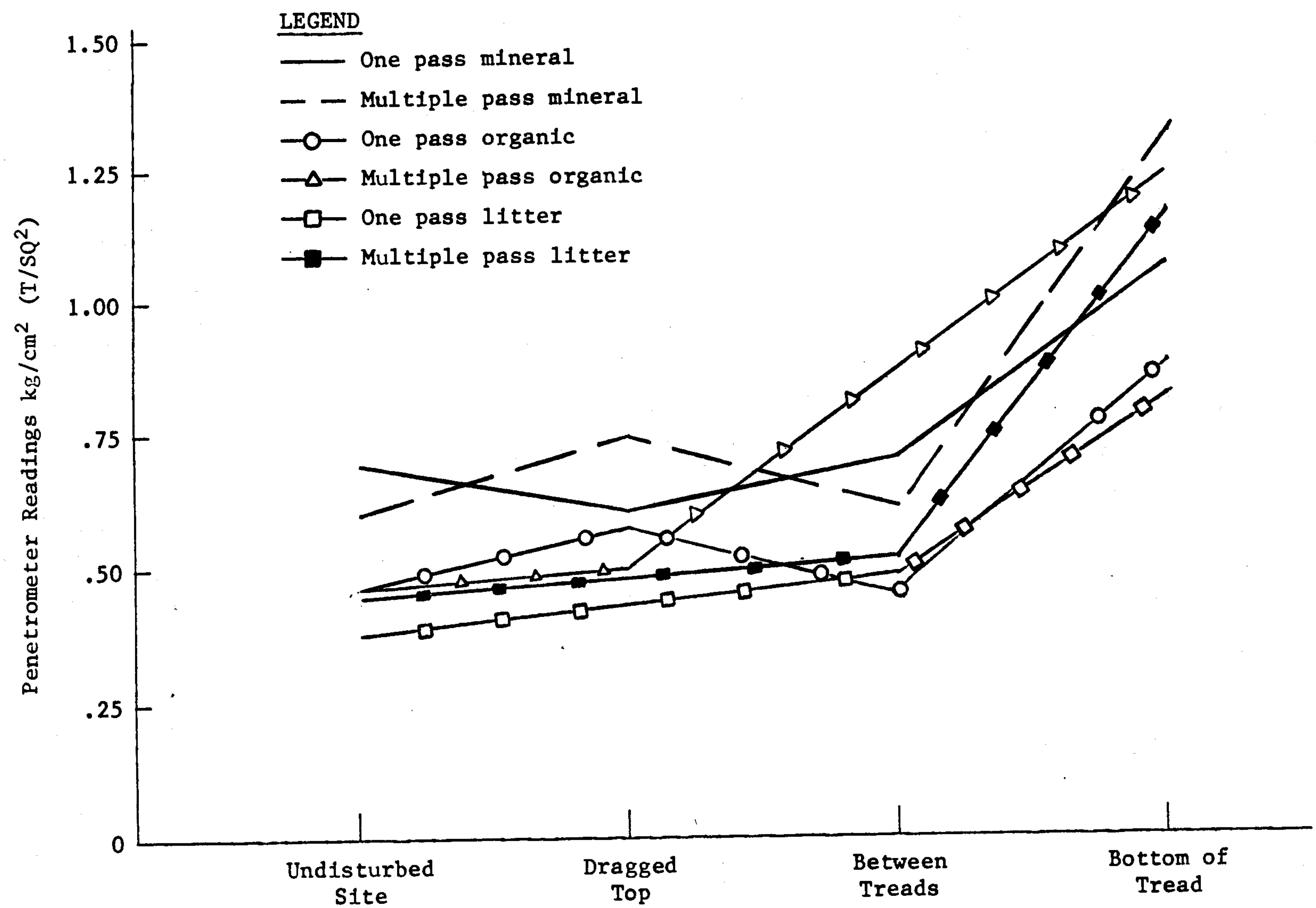

Figure 2. *Penetrometer readings in kg/cm² for several surface soil conditions impacted by a wheeled tree harvest skidder.*

Table IX. *Summary of Penetrometer Values for FFC-DNR Tree Harvest Study*

Number of Skidder Passes	Type of Surface Soil	Penetrometer Readings							
		Undisturbed Surface Soil		Dragged Top		Between Treads		Bottom of Tread	
		kg/cm^2		kg/cm^2		kg/cm^2		kg/cm^2	
		$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
One pass	mineral	.70	.34	.61	.35	.71	.19	1.06	.26
Multiple	mineral	.58	.22	.75	.41	.59	.30	1.31	.33
One pass	organic	.46	.26	.56	.37	.46	.18	.88	.46
Multiple	organic	.47	.20	.50	.10	.87	.13	1.25	.38
One pass	litter	.38	.29			.40	.27	.81	.29
Multiple	litter	.47	.21			.50	.26	1.15	.37

Regardless of surface soil, the undisturbed sites have low penetrometer readings compared to the disturbed track areas. As expected, leaf litter in either case has the lowest readings and mineral soil the highest. Leaf litter is essential in reducing apparent compaction, since it acts as a blanket to distribute the forces of compaction over a larger area than where the force is applied.

Exposed mineral soil shows the highest penetrometer values, but what effect this may have on tree growth requires continued monitoring. Skidder strips over which tops were dragged do not appear to be substantially affected. Dragged tops may act as a cultivator and loosen the soil.

The areas between lug impressions have lower penetrometer readings than the bottom of the lug impressions. Only a slight increase in penetrometer readings were noted on litter and organic micro plots where the skidder made only a single pass. However, as the number of passes increased, penetrometer readings increased proportionally for all three types of wheel track surface conditions. The greatest resistance to the penetrometer was at the bottom of the tread. Mineral surface conditions show a higher resistance to penetration than litter or organic surfaces. This suggests that utmost care be exercised by woods harvesting crews to maintain sufficient litter cover to lessen the impact of heavy skidder equipment.

CONCLUSIONS

The strip-with-selection thinning method compared favorably with one conducted in 1974, proving to be both efficient and productive. Not only was the felling productive (94 stems per hour), but stand damage as result of felling was minimal. On the other hand, skidding damage exceeded expectations, but could probably be reduced by altering the harvesting pattern and reducing skidder load through the use of a smaller skidder.

The cost of $8.64 per green ton compared favorably with the 1974 thinning of $8.48 per green ton. Cost will vary according to terrain, stand stocking, weather conditions, stumpage values, operator efficiency, road building costs, and other constraints imposed upon the system which may have been absent from this particular study.

The average productivity of 41.5 tons per productive hour is a realistic rate for this combination of equipment and would probably increase as more experience is acquired with this technology.

The primary purpose of the strip-with-selection thinning is to conduct the felling and skidding procedures so as to do the least amount of damage to the residual stand while still performing an acceptable silvicultural function. Even though the cost figures appear attractive, the harvesting system is a departure from conventional silviculture; so, it will be important to monitor the long term effects on the permanent growth plots established for this purpose.

It seems reasonable to expect that damage should be confined to 25 percent or less of the residual trees; but how much damage is really acceptable is not known at this time. As with the 1974 study, continued monitoring of the damaged trees and the long term effects of the operation will allow us to better evaluate the silvicultural and economical ramifications of the harvesting system.

Certain soils and surface conditions undergo adverse physical changes from harvesting machinery, especially when mineral soil is exposed. Higher penetrometer readings were found at the bottom of the tread than between treads. Multiple passes along the same skidder strips increased apparent compaction, and dragging tops over skidder strips may have loosened the surface soil.

The tree response and reproduction establishment results of the harvesting system will have to await further measurements. It is expected that investigation of long term effects will be continued for at least ten years.

ACKNOWLEDGEMENTS

Michigan Technological University - Served as project coordinator. Installed permanent study plots for the purpose of inventorying existing stand conditions and for monitoring results. Evaluated residual tree damage, silvicultural effects and compaction effects.

Forestry Sciences Laboratory, North Central Forest Experiment Station, U.S.D.A. Forest Service - Provided additional personnel to augment University staff. Conducted time and motion study of harvesting equipment and determined production rates and harvesting costs.

Michigan Department of Natural Resources (Forest Cultivation Program) - Provided the thinning site and marked the stand for harvest. Also, contributed $4,000 to partially defray project costs.

Marquette Board of Light and Power - Purchased chips ($10,000) developed from thinning for an experimental burn in a coal fired generating plant.

Michigan Department of Commerce, Energy Administration - Provided advice and assurance of assistance authorized by the creation of the Administration.

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