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Over the next decade or two, most of the 15 to 20 million acres of pine plantations in the South will become ready for a first commercial thinning. The magnitude and nature of the job is illustrated by the situation in slash pine—the most extensively planted of the southern pines.

Slash pine plantations are heavily concentrated in a belt extending on either side of the Georgia-Florida State line. During the peak planting years of 1957 through 1960, 200,000 to 300,000 acres were planted each year on private nonindustrial ownerships under the impetus of the Conservation Reserve of the Soil Bank program. In addition, the forest industry planted about 100,000 acres of its lands annually during this period. Although planting on nonindustrial properties has declined sharply since the Soil Bank program expired, it has increased substantially on forest industry lands.

Each year plantations on 200,000 or more acres are reaching the preferred age for a first commercial thinning. The task is enormous and sufficient labor is not available to do the job by current labor-intensive thinning methods. Also, thinning is becoming more expensive because of the constantly rising wage rates.

Foresters, therefore, are looking for faster ways of accomplishing the job with limited, increasingly costly manpower. Mechanized systems for row thinning might be the answer. Switching from labor-intensive to capital-intensive technology would reduce labor requirements per acre. Because of the greater productivity of mechanized crews, workers could be paid higher wages. In addition, loggers would acquire higher status as machine operators, and the otherwise onerous job of thinning young stands would become less difficult and more attractive. Row thinning is specifically designed for patterned forests. Since entire rows are removed, there are no costs for marking trees to be cut, and the cleared rows serve as convenient roads for skidding.

This study measured the productivity of the principal types of mechanized logging systems that could be used in row thinning slash pine plantations, identified the factors that affected their performance, and evaluated their effect on output in various plantation environments. Information of this kind is needed to estimate thinning costs, determine economical thinning opportunities, and obtain an optimum balance among the machines combined into a system.

The study was limited to mechanical row thinning of slash pine plantations growing in sandy soils on flat terrain. Results are applicable to like operations in plantations on similar sites throughout the slash pine belt. However, they cannot be applied directly to stands of other species on different topographies.

The efficiencies of alternative systems were not compared since the operations observed were at different levels of development. One was a fully balanced, commercial operation; another was a pilot test of a prototype machine; and a third was an experimental run conducted solely for this study. Neither did the various systems carry processing to the same level of end product. For two systems, further processing took place at the mill. Comparisons were also inappropriate because with a single example of each system, operator performance could strongly affect results. In addition, the manager selecting a thinning system must consider more than machine efficiency. Railroad transportation, for example, may necessitate selection of a shortwood system. Availability of parts and service can also be a determining factor in the choice of a particular machine.

MACHINES

Three types of harvesting systems were appraised in the production of pulpwood from thinnings. These were the shortwood, long-log, and whole-tree systems, as classified by the output from the harvester. Individual machines were selected on the basis of their availability for study. However, the cycle times for the harvesters might be considered representative of other harvesters in similar systems. The other principal machine in each system was a skidder.

Shortwood System

The shortwood system included a Timberline TH-100[1] thinner-harvester—a machine designed for thinning southern pine plantations (fig. 1). It can cut trees with stump diameters of up to 12 inches. Mechanical arms hold the tree while the shear closes to fell it. The bole is then fed butt first into the processing mechanism, delimbed by a set of fixed knives, and cut by a buckshear into bolts of a predetermined length (from 5 to 7 feet) down to a 2-inch top. Each bolt drops into a cradle as it is bucked. When a third of a cord has accumulated in the cradle, the bundle of bolts is deposited on the ground alongside the row being cut. The harvester proceeds down one row and returns up the next one to be removed.

A Franklin 133 prehauler gathered the bolts left by the TH-100 and removed them from the plantation. The grapple mounted on the machine loads the woodrack, which has a capacity of approximately 2 cords. The load is transported to the landing, where the grapple unloads the bolts onto a set-out trailer.

[1] Mention of trade names is solely to identify equipment used and does not imply endorsement by the U.S. Department of Agriculture.

Long-Log System

The long-log system featured a Caterpillar 950 tree harvester, which felled, limbed, and bunched (fig. 2). It can sever trees with a stump diameter of up to 18 inches and can delimb a bole down to a top diameter of 2½ inches. The tree is gripped by two grapple arms and sheared. The bole is then tilted forward so that it is fed horizontally through the delimbing knives while the machine backs up to the selected piling area. There the butt is placed even with those of the other piled stems. The machine then moves forward as the delimbing process continues. The stem is dropped as the shear tops the tree, completing the cycle. The harvester operates only when traveling away from the landing so that all stems will be piled with their butts toward the landing. When a row is completed, it returns to the landing area to begin removal of the next row.

The bunched stems left by the harvester were skidded to the landing by a Caterpillar 518 skidder equipped with a 94-inch Fleco grapple. Because of the large capacity of this machine, the operator would proceed to the most distant bunch of logs in a row and then pick up successive bunches to complete a load as he headed back toward the landing.

FIGURE 1.—*Timberline TH-100 shortwood harvester.*

Whole-Tree System

A Soderhamn Go-Go harvester did the felling and bunching in a whole-tree system (fig. 3). This machine was developed for thinning southern pine plantations by modifying a Go-Go skidder. The shear can sever a tree with a stump diameter of up to 12-inches. The severed tree falls into an accumulator mounted on the left side of the machine. As many as seven trees may be collected in the accumulator before the dumping arm drops the bundle off to the side. To bunch stems with their butts toward the landing, the Soderhamn harvester fells trees only as it proceeds toward the landing. A workman with a chainsaw limbs and tops the trees in each pile before they are skidded from the plantation.

A Dunham Log Hog skidder, which is essentially a modified farm tractor equipped with 40-inch grapple, did the skidding for the whole-tree system. It can pick up one full-size pile of logs dropped by the harvester or two small piles of only two or three stems each. The operator would begin skidding logs from a row by picking up the bunch nearest the landing and then proceed to pick up successive bunches down the row.

FIGURE 2.—*Caterpillar 950 long-log harvester.*

FIGURE 3.—*Soderhamn whole-tree harvester.*

STUDY AREA

All field data were collected in north Florida, where mechanized row thinning operations were being carried on in the area's extensive plantations. One reason for this activity is that there are large pulpwood markets nearby for the small diameter trees removed in thinnings. Also, logging conditions here are favorable for machines. The plantations in which mechanized thinning was studied are fairly typical. They are on dry, sandy sites that will support heavy machinery. The terrain is level to slightly sloping. Ground cover consists largely of gallberry, palmetto, and blackberry bushes.

The three plantations were on land with a site index of 70 at age 25 and in all three survival was generally good. The shortwood and long-log operations were in 17-year-old stands; the whole-tree operation was in a 14-year-old stand. Initial spacing in the plantation thinned by the shortwood harvesting system was 6 feet between rows and 8 feet within rows. In the plantation thinned by the long-log method, trees had been planted at 10 feet between and 6 feet within rows. In that thinned by the whole-tree method spacing was at 8 and 6 feet, respectively. In all thinning operations, every third row was taken out.

DATA COLLECTION

Time and production data were collected on the tree harvester and the prehauler or skidder in each operation. The harvester was the key piece of equipment; skidding data were needed only for the purpose of balancing the system. In each operation, data on harvesting and skidding were taken on the same machine and same operator. All operators were experienced men whose performance was considered above average.

Felling and Processing

Sample plots were line segments in rows being cut. Segments were selected to cover a range of tree diameters and spacing intervals. Segment length was limited by the extent of uniformity of the tree diameters and intervals between trees. Consequently, segment length ranged from 12 to 60 feet, and number of trees varied from two to six.

On each operation, a total of 30 sample plots were installed in rows to be cut. For each sample plot the following information was recorded before cutting:

(1) Length of segment from the first tree to the first tree beyond the segment, measured to the nearest tenth of a foot;

(2) D.b.h. of each tree, measured to the nearest tenth of an inch;

(3) Total height of each tree, measured to the nearest foot.

Time required to cut and process the trees on a plot was recorded to the nearest tenth of a second. Timing began when the first tree in the segment was sheared and ended when the first tree beyond the segment was sheared.

While the TH-100 was working within a sample plot, the number of bolts processed from each tree was counted, and the number of times the cradle was dumped was also recorded. After the Cat 950 had completed processing trees in a sample plot, log lengths and top diameters were measured. The same measurements were taken on the plot after the trees cut in a sample by the Soderhamn had been limbed and topped.

Skidding

For the Franklin 133 prehauler, data were collected on 13 roundtrips. Time spent in travel empty, loading, travel loaded, and unloading was recorded for each trip. Measurements for each trip were distance travelled empty, distance traveled loaded, distance traveled while loading, number of stops to pick up piles of bolts, and cords carried per load.

Total time was kept for each roundtrip by the Cat 518 and the Dunham Log Hog skidders. Timing began the moment the previous load of logs was dropped and continued until the load being timed was dropped. Before skidding began, the distance from the landing to each bunch of logs was measured, and log measurements were taken. During each skidder trip, the following were recorded:

(1) Distance from the landing to the first bunch of logs picked up,

(2) Number of bunches picked up for the load,

(3) Number of logs in the load.

Volumes per trip were calculated from the log measurements. Time and measurement data were obtained for 14 Cat 518 skidder trips and for 36 Dunham Log Hog skidder trips.

In all operations, times were taken to the nearest tenth of a second, distances were measured to the nearest foot, and volumes were calculated to the nearest tenth of a cord.

ANALYSIS OF HARVESTING TIMES

Data collected for each harvester were subjected to regression analysis. A stepwise regression procedure was used to select the best prediction equation.

The dependent variable was time, expressed in minutes per hundred feet of plantation row. All data were converted to a hundred-foot basis. The factors tested for their statistical significance were:

(1) Number of trees

(2) Total length of stems cut

(3) Average d.b.h., i.e., sum of d.b.h. ÷ number of trees

(4) Average d.b.h. squared, i.e., sum of d.b.h.^{2} ÷ number of trees

(5) Total length of stems cut ÷ average d.b.h. squared

(6) Sum of d.b.h. squared ÷ sum of d.b.h.

Number of 7-foot bolts and sum of log lengths in feet were used as two alternative measures of total length of stems cut, depending on the form of output by the harvesting system.

Variables 5 and 6 were found to be significant at the 5 percent level. The first is a measure of total log lengths per unit of basal area. The second is a measure of the dispersion of tree size around the mean. Together these two measures combine all the variables tested.

Regression coefficients, multiple correlation coefficients, and standard errors of estimate for the estimating equations for the three harvesters are shown in table 1.

Another equation can be substituted for the standard form in the case of the whole-tree harvester, which unlike the other two machines fells but does not further process trees. This equation is simpler since it has only one variable—total length of stems cut. The constant and regression coefficient are:

$$Y = -1.013 + 0.012X$$

where:

Y=Time per 100 feet of row, in minutes

X=Sum of log lengths, in feet.

The alternative equation for the whole-tree harvester gives a better fit than the standard form, especially for estimates at points distant from the mean. The proportion of variance explained is improved from 77.7 to 84.5 percent; and the standard error of estimate is lowered from 0.87 to 0.71 minute.

The equations apply to productive time only. Therefore, allowance must be made for machine downtime, idle time, and turn-around time depending on the method of operation.

HARVESTER PRODUCTIVITY AND COST

To determine how rates and costs of production will vary in different plantation situations, use of each of the three types of harvesters was simulated.

The Plantations

Detailed descriptions of stand structures were obtained from Bennett and Clutter's *Multiple Product Estimates of Unthinned Slash Pine Plantations*,[2] which gives stand and height tables by age, site index, and density. Tables were chosen for plantation ages 15 and 20 years, a range which covers the preferred age for thinning.

[2] Bennett, F. A., and Clutter, J. L. **Multiple-product yield estimates of unthinned slash pine plantations—pulpwood, sawtimber, gum.** USDA For. Serv. Res. Pap. SE-35, table 1, page 9, and table 3, p. 12. Southeast. For. Exp. Stn., Asheville, N.C. 1968.

TABLE 1.—*Estimating equations for time to harvest 100 feet of plantation row*

Harvesters	Equations	R^2	SE
Shortwood	$Y = -13.142 + 4.462(\Sigma B \div \frac{\Sigma D^2}{N}) + 2.377(\Sigma D^2 \div \Sigma D)$	79.6	1.47
Long-log	$Y = -6.390 + 0.743(\Sigma L \div \frac{\Sigma D^2}{N}) + 0.949(\Sigma D^2 \div \Sigma D)$	83.7	0.57
Whole-tree	$Y = -8.551 + 0.395(\Sigma L \div \frac{\Sigma D^2}{N}) + 1.264(\Sigma D^2 \div \Sigma D)$	77.7	0.87

Y=Time per 100 feet in minutes; D=D.b.h. in inches; L=Log length in feet; B=Bolts; N=Number of trees.

Also, site indices of 60 and 70 feet at 25 years were selected because they represent the preponderance of sites where slash pine is planted. Merchantable trees were limited to those in the 4-inch diameter class and larger. These sizes were typically utilized in the thinning operations observed; smaller trees were simply pushed down.

For each density class, intervals between trees within rows were calculated for plantations spaced 5, 6, 8, and 10 feet between rows. Tree lengths were computed to a 2-inch top diameter for bolts and a 3-inch one for logs with formulas developed by Bennett et al.[3] Tree volumes were figured to the same top diameters. Stand characteristics were then used with the estimating equations to obtain time per hundred feet of row.

Estimating Productivity

In simulating hourly production for each harvester, we assumed that a 40-acre tract—20 chains on a side—was being thinned and that each row would be 1,320 feet long.

The shortwood harvester could travel up one row, turn, and return down the next row to be felled since the prehauler used with this system could enter a row from either end. Grapple skidders, however, travel with a load of logs in the direction the butts are pointing. Therefore, to limit skidding distance, the long-log and whole-tree harvesters would cut half of the row with butts facing one way and half facing the other. They would do this by entering a row from one end, cutting 660 feet, returning to the end of the row, and then entering the next row to be removed. Because of these differences in cutting patterns, nonproductive operating time for the long-log and whole-tree harvesters is considerably greater than that for the shortwood harvester, which loses time only while turning at the end of a row. Return time for the tree-length harvester is about 2 minutes. The whole-tree harvester takes twice as long because it is driven over the bunched trees on the return trip to breakdown tops to ease the job of limbing and topping.

Hourly output in cords for the TH-100, Cat 950, and Soderhamn is shown in figures 4, 5, and 6. For the shortwood harvester, productivity is positively correlated with spacing between rows. This pattern persists throughout the four combinations of age and site index assessed. The difference between the curves is least where the trees are smallest (site index 60, age 15 years) and greatest where the trees are largest (site index 70, age 20 years). Each curve peaks, indicating the density for which the production rate is maximum for that particular spacing between rows.

For the long-log harvester, only 8- and 10-foot spacing between rows was considered because the width of the harvester make it infeasible to operate where rows are closer. The curves for the two spacings are nearly identical over the range of densities. The production function approximates a negative sloping curve extending from about 7 cords per hour at 300 trees per acre to 4¼ cords at 800 trees, for site index 70 and age 15. Other combinations of site index and age show similar patterns, with the height of the curve rising with each increase in site index and age.

The sheafs of curves for the full-tree harvester, which were computed with the alternative equation, display negative slopes for all combinations of plantation ages and site indices. Thus, productivity is higher in stands with fewer trees per acre. The spread of curves was about the same for all combinations of site index and age except site index 60 at age 15. For all stands considered, curves increase in height with each reduction in spacing between rows.

Harvester Costs

Cost per cord of mechanical thinning in a particular plantation depends on the rate of production and on the cost of owning and operating the machines, including wages.

The hourly cost of the harvesters (table 2) is the sum of the fixed and variable machine costs plus the cost of the operator. In calculating these costs, we assumed a machine life of 5 years and a salvage value of 20 percent of the delivered price. Operating time, figured on the basis of one 8-hour shift per day for 250 days per year, was 2,000 hours per year, or 10,000 hours for the life of the machine.

The fixed costs of ownership include depreciation, interest charges, and insurance payments.

[3] Bennett, F. A., Swindel, B. F., and Schroeder, J. G. **Estimating veneer and residual pulpwood volumes for planted slash pine trees.** USDA For. Serv. Res. Pap. SE-112, p. 2. Southeast. For. Exp. Stn., Asheville, N.C. 1974.

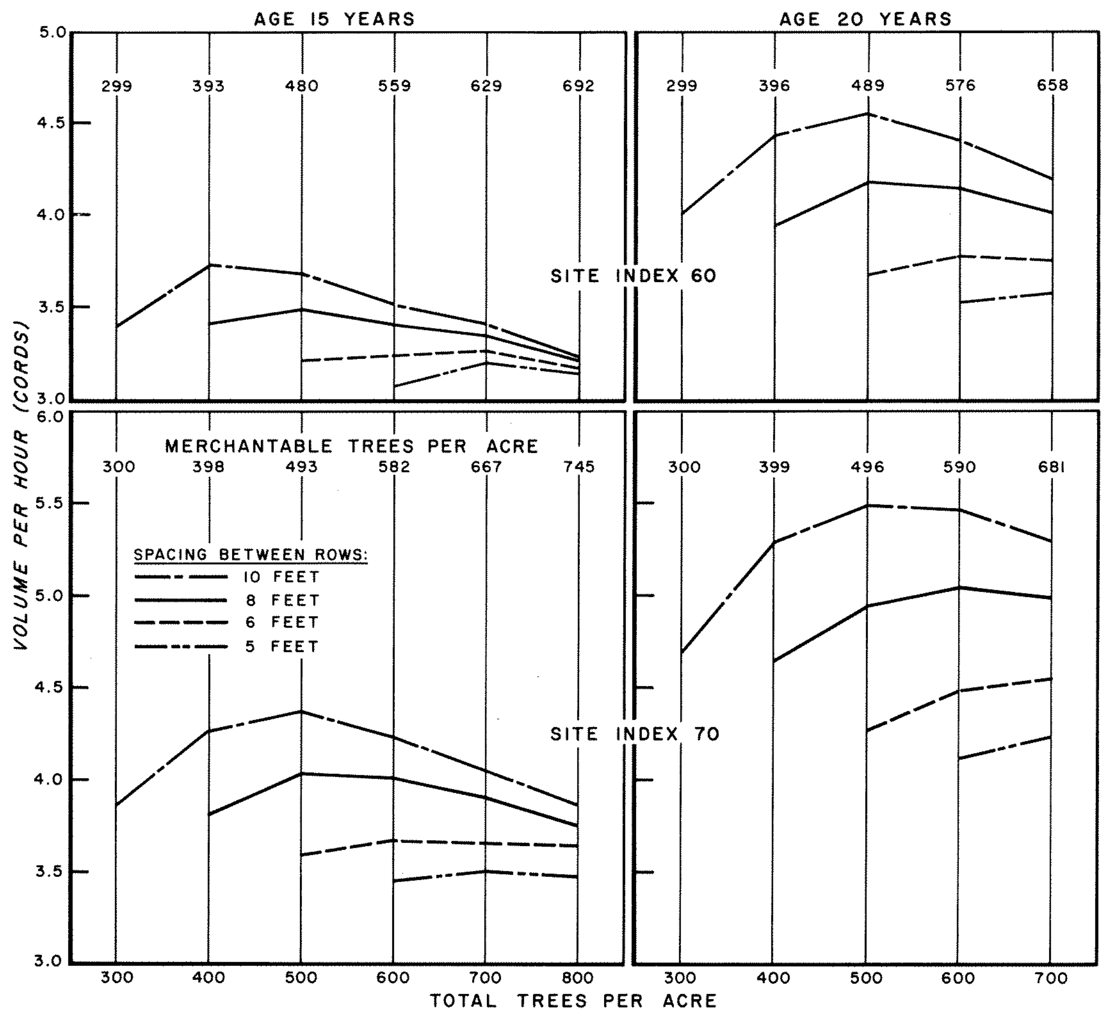

FIGURE 4.—*Potential hourly output of the shortwood harvester.*

TABLE 2.—*Hourly cost of owning and operating three harvesters*

Expenditure	TH-100	Cat 950	Soderhamn
		Dollars	
Fixed costs:			
Depreciation[1]	2.80	5.20	1.84
Interest and insurance	1.19	2.21	.78
TOTAL FIXED COSTS	3.99	7.41	2.62
Variable costs:			
Repair and maintenance	3.50	6.50	2.30
Fuel	.50	.93	.29
Lubrication and engine oil	.05	.09	.03
TOTAL VARIABLE COSTS	4.05	7.52	2.62
Operator	3.50	3.50	3.50
TOTAL MACHINE COSTS	11.54	18.43	8.74

Approximate delivered price is $35,000 for the TH-100, $65,000 for the Cat 950, and $23,000 for the Soderhamn.

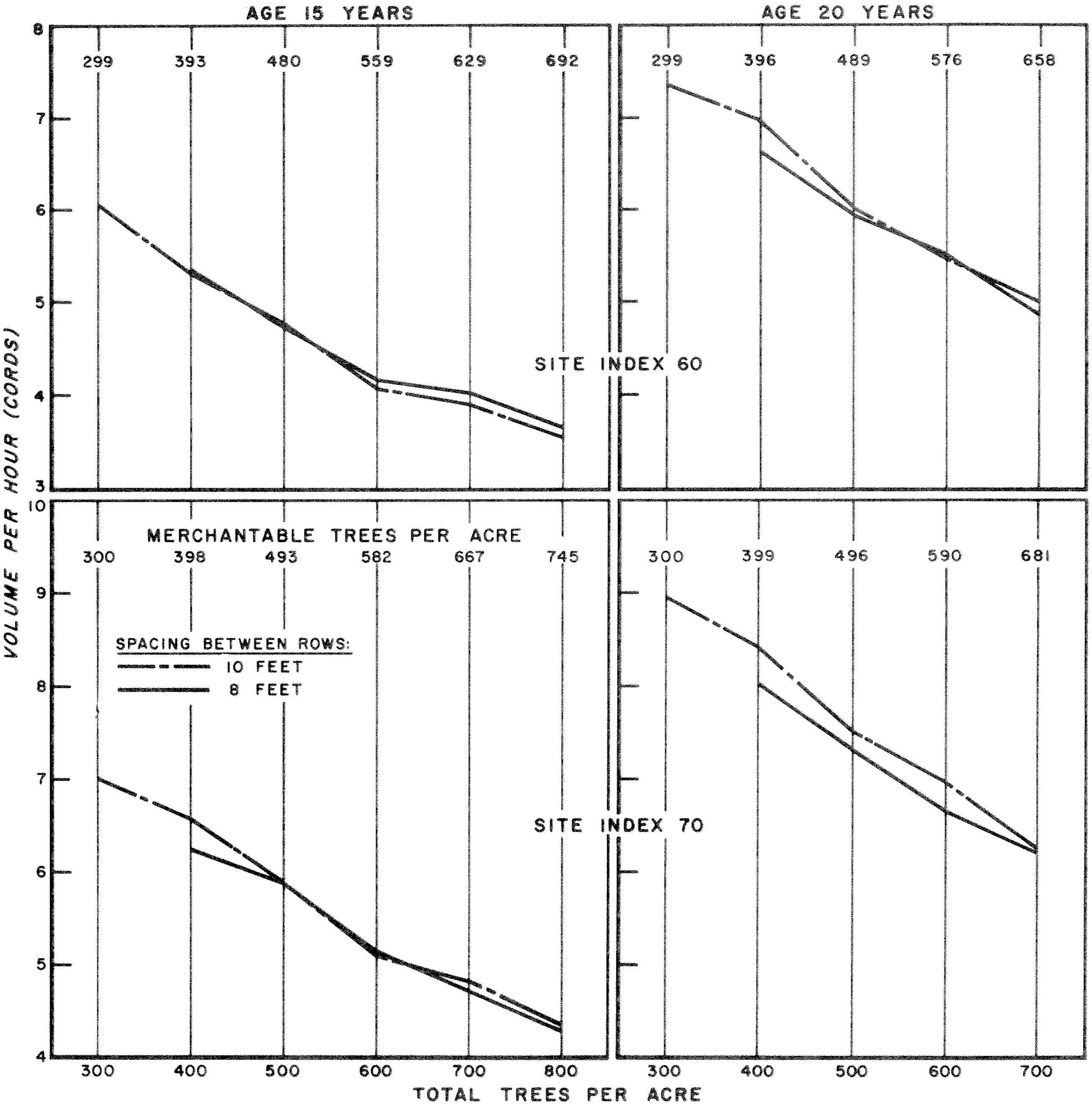

FIGURE 5.—*Potential hourly output of the long-log harvester.*

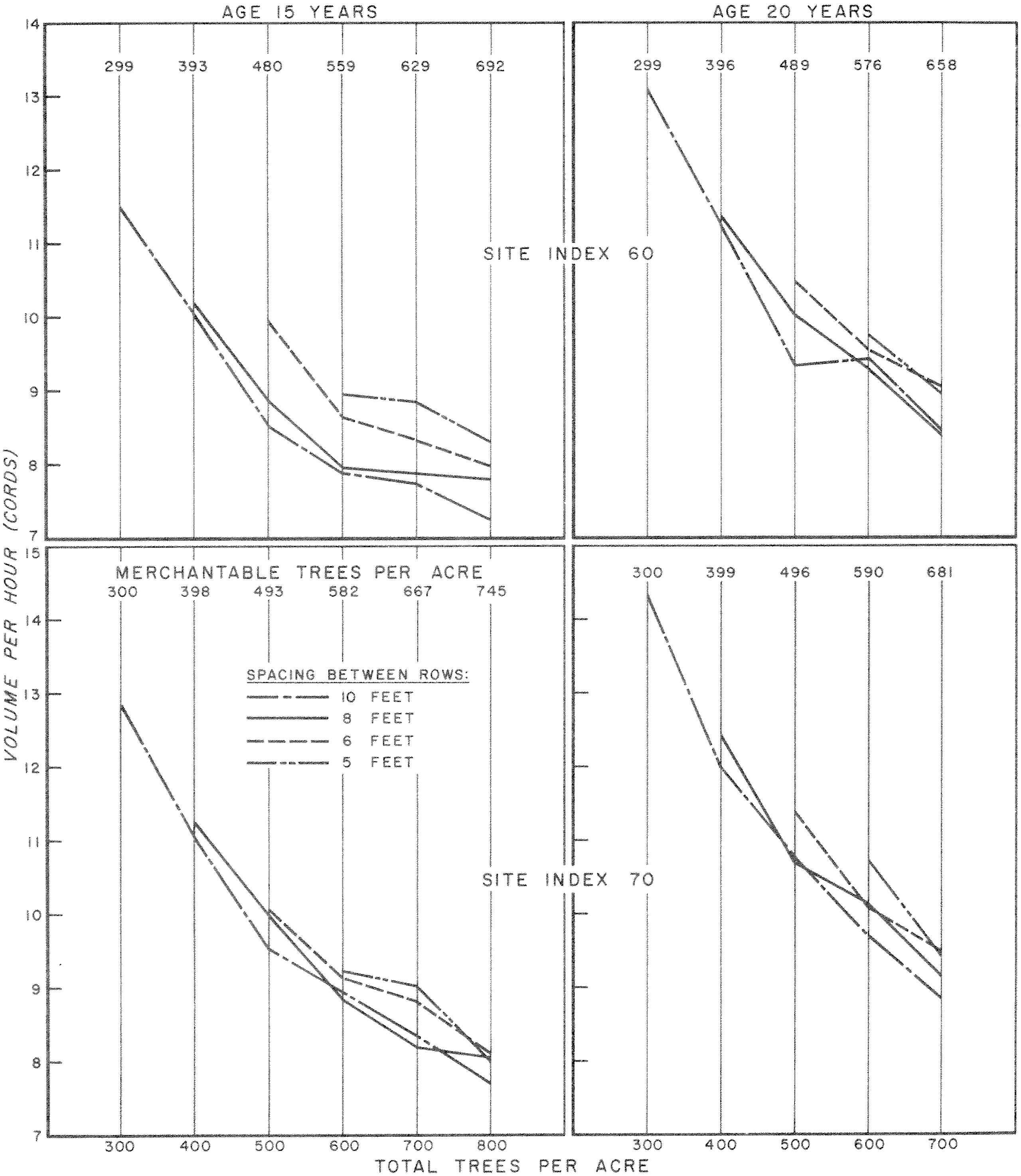

FIGURE 6.—*Potential hourly output of the whole-tree harvester.*

Straight line depreciation was calculated as follows:

$$\text{Depreciation per hour} = \frac{\text{delivered price—salvage value}}{\text{hours of machine life}}$$

Interest and insurance were figured as 10 percent of the average investment. The standard formula for average investment is:

$$AI = \frac{(I-R)\ (N+1)}{2N} + R$$

where:

AI = Average investment in dollars

I = Delivered price in dollars

R = Salvage value in dollars

N = Life in years.

The variable costs, which are associated with the time the machine operates, include repairs and maintenance, fuel, and lubrication and oil. The charge for repair and maintenance over the life of the harvester was assumed to be equal to its delivered price. Fuel costs were figured on the basis of 1 gallon per hour per 70 bhp at a price of $0.50 per gallon. Lubrication and oil changes were priced at 10 percent of the cost of fuel. These components of variable costs were also put on an hourly basis.

The cost of the machine operator was set at $3.50 per hour, which included wages plus Social Security taxes, State unemployment compensation, and workmen's insurance paid by the employer. No allowance was made for supervision.

To estimate harvester costs per cord, the hourly machine cost may be divided by the hourly output of the machine for the selected stand situation. For example, cost per cord for a Cat 950 was figured for a 15-year-old stand planted in rows 8 feet apart on site index 70 land. There were 500 trees per acre of which 480 met utilization standards. In such a plantation, this particular harvester would turn out 5.9 cords per operating hour at a cost of slightly more than $3 per cord. At a density of 300 trees per acre, cost per cord would be more than 15 percent less; and at a density of 800 trees, more than 35 percent greater. In younger stands growing on poorer sites cost per cord would be higher; in older stands on better sites, it would be lower.

The preceding example illustrates the procedure for estimating costs per cord of a machine for various stand conditions. Those making their own analyses, however, should use these data with care. Hourly production data for each harvester represent potential hourly output (i.e., at 100 percent machine availability). It would be unrealistic to expand hourly production to a daily basis by simply multiplying by the number of hours per shift. Likewise, in estimating costs per cord, the hourly production rates can be reduced by whatever figure one wants to assume for machine availability. In the example, if 80 percent availability were assumed, output would be 20 percent less and the cost per cord raised from $3 to $4. Still lower availability would reduce output and raise the cost per cord proportionately. Also, costs per cord for each harvester are not directly comparable since the output from each is in a different stage of production.

BALANCING THE SYSTEM

The three tree harvesters, of course, are only a part of the respective logging systems, although the most important part. To complete each system, supporting equipment and men must be added. The major piece of supporting equipment is the skidder. The number of skidders and harvesters needed to make a balanced system depends on the relative capacities of the two machines.

Skidder Production

For the shortwood system, the total time involved per trip in running bolts from the woods with the prehauler is the sum of the travel times empty and loaded plus the times spent loading and unloading the prehauler. The equation for travel time empty is:

$$Y = 0.2605 + 0.0012X$$

and that for travel time loaded is:

$$Y = 0.1004 + 0.00188X$$

where:

Y = Time (in minutes)

X = Distance (in feet).

The proportion of variation in travel time explained by distance was 74.2 percent for the first equation and 80.4 percent for the second. The standard error of estimate was 0.15 and 0.20 minute, respectively, for the two equations. The average time required to load the prehauler was 8.25 ± 0.90 minute, and to unload it was 3.85 ± 0.90 minute at the 67-percent confidence level. Average volume per load was 2.28 cords.

In the long-log and whole-tree operations, total times were determined for the entire skidding cycle. The equation for predicting skidding time in the long-log system was:

$$Y = 0.960 + 0.250X_1 + 1.107X_2.$$

The equation for the whole-tree system was:

$$Y = 0.804 + 0.003X_1 + 0.586X_2.$$

For both equations:

Y = Time per round trip (in minutes)

X_1 = One-way skidding distance (in feet)

X_2 = Bunches of logs per load (number).

The two variables explained 95.6 percent of the variation in skidding time in the long-log system; the standard error of estimate was 0.41 minute. The equation for the skidder in the whole-tree system explained 58 percent of the variation in skidding time and had a standard error of estimate of 0.55 minute. Average volume skidded per trip in the long-log system was 1.14 cords, typically made up of three bunches of logs. For the whole-tree system, the average volume per trip was 0.23 cord, normally comprising one bunch.

An Example

Balancing a system can be illustrated with the shortwood operation employing Timberline TH-100 thinner-harvesters and Franklin 133 prehaulers. A first approximation was made by comparing the cords handled per hour by each machine in the 40-acre plantation hypothesized. For the prehauler, the time required per trip for an average skidding distance of 660 feet was:

Travel empty	1.1 minutes
Loading	8.3
Travel loaded	1.3
Unloading	3.9
Total	14.6 minutes.

Hauling an average volume of 2¼ cords per trip, the prehauler could remove 9 cords of bolts per hour from the woods.

Where stand age was 15 years, site index was 70, and stand density was 500 trees per acre, the TH-100 would produce less than 4½ cords per hour. Under these circumstances, one prehauler could handle the output of two harvesters. The ratio will change according to different stand conditions.

Of course, other factors must also be taken into account in balancing a particular system. For example, a 2:3 ratio on the shortwood operation where timing was done reflects the usage of the prehauler for other purposes such as straightening the loads on the set-out trailers and the machine availability that had been experienced. Machine availability can vary widely depending on operators and maintenance practices. Thus, the formulas for the various skidders should be used only as a rough guide to balance the number of machines needed with the harvesters.

DISCUSSION

This study has related stand characteristics of slash pine plantations to the performance of selected tree harvesters used for row thinning. Additional factors must be considered, however, in relation to mechanized thinning and the selection of machines.

Tract size and volume to be removed are important factors in the success of any mechanized system. Small tracts could not be profitably thinned by this method unless several could be combined to provide a sufficient volume to be harvested from a given area.

Productivity of the harvesters will vary for other species. Those with larger crowns and heavier limbs than slash pine will require longer processing times.

Limitations in machine design will affect performance and selection of harvesters. Nonmerchantable trees can be a problem if the machine is not designed so small trees can merely be ridden down. If they must be removed with the shear, productivity is lowered. Of course, shear size will preclude the use of some machines in older plantations.

The operator too plays a large role in controlling productivity. The marginal worker cannot be entrusted with the operation and care of the complex and expensive equipment. Skilled labor is needed. Ideally, individuals possessing the dexterity, judgment, and disposition to qualify as operators would be selected by screening tests and then given formalized training and supervised experience on the job.

This investigation of mechanized row thinning in slash pine plantations can serve as a guide for other studies of this type. Those studying a particular machine can follow the steps specified in this report. It illustrates the data collection procedure, analytical method, and application of results. With the movement toward capital-intensive thinning systems, the need for such studies increases because the consequences of poor planning and administration becomes more and more costly.

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From machine times and tree measurements taken on row-thinning operations in slash pine plantations, equations were developed to estimate productivity of harvesters in shortwood, long-log, and whole-tree systems. Output and costs were calculated for specific stand conditions.

Additional keywords: Harvesters, mechanization, productivity, and logging costs.