Harvesting Costs and Utilization of Hardwood Plantations[1]

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INTRODUCTION

The use of short rotation, intensive culture (SRIC) practices in hardwoods to meet fiber supply needs is becoming increasingly widespread. Total plated area of short rotation hardwood fiber plantations is currently about 22,000 ha (McDonald and Stokes 1993). That figure should certainly to grow in response to public concerns over loss of natural hardwood stands. With many of the plantations currently approaching first harvest, questions have been posed about the adaptability of conventional harvest systems to SRIC stands. Past efforts in development of specialized SRIC equipment have achieved some success (Stuart and others 1983), but markets sufficient to justify commercialization of the concepts are not likely in the near future. Without SRIC-optimized equipment available, conventional harvesting machinery will have to be used. This study was initiated to test the use of harvest equipment common in the Southern United States in SRIC stands. Objectives were to determine productivity, costs, and recovery of felling, skidding, and processing short rotation sycamore (*Platanus occidentalis L.*) stands.

METHODS

The study was established on property owned by Scott Paper Company located in Escambia County, AL, approximately 80 km northeast of Mobile. The stand was planted in l-year-old sycamore seedlings at a 1.5- x 3.0-m spacing (2,153 stems/ha) in March 1988. Average diameter at breast height (dbh) in winter 1993 (after five growing seasons) was 7.5 cm, and the yield from the plantation was 143 green t/ha/year. Understory vegetation was controlled as part of the silvicultural regime, thus it was not a hindrance during harvesting. The site was generally flat and poorly drained. A period of rainfall forced operations to halt during the study, but conditions at the time of testing were generally good.

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In February, 1993, 10 trees from each dbh class in the 2.5 cm to 15.0 cm (2.5 cm increment) range were felled and weighed. A regression equation relating dbh class (cm) with weight (kg) was developed ($P < 0.001$, $R^2 = 0.9$) in the form $w = \alpha d^2$, where w = weight, d = dbh, and α = 054 was a regression coefficient.

Time Study

A Scott Paper Company crew that ordinarily produced whole-tree chips for fuel performed the harvesting. The harvest system consisted of three HydroAx 411B[2] feller-bunchers with 40 cm shears, two TimberJack 450B grapple skidders, and a Morbark mode1 30 (76 cm diameter disk, 600 kW) chipper. Felling productivity was determined for one operator and skidding productivity was determined for two operators.

Fellers ordinarily cut two rows per pass through the stand. Bunches of approximately 40 to 60 stems were built, usually from four felling head accumulations. This bunch size represented a full load for the skidders. Building bunches that large required additional maneuvering for the feller-bunchers, perhaps resulting in Iower overall felling productivity. In addition to testing these normal operating procedures, a special time study was also carried out on the system when the feller-buncher operator built bunches of two accumulations, forcing the skidder to assume some of the burden in making a full turn.

Individual machine productivities could not be established in 1993 because the harvest was halted by wet weather. Harvesting was resumed in late February, 1994, and all skidding, felling, and chipping productivity data were collected in March, 1994.

For time study purposes, felling cycles were broken down into the following elements: (1) move to first tree, (2) cut and accumulate a full felling head, (3) move to dump, and (4) dump.

Move-to-first-tree and move-to-dump distances were also measured and recorded. Before the tests, the trees in the rows to be cut were numbered and measured for dbh. The identification numbers of the stems accumulated during each cycle were noted.

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[2]The use of trade, firm, or corporation names in this paper is for the information and convenience of the reader. Such use does not constitute official endorsement or 'approval by the U.S. Department of Agriculture of any product or service to the exclusion of any other that may be available.

Skidding cycles were broken down into: (1) travel empty, (2) position, (3) grapple, (4) intermediate travel, (5) travel loaded, and (6) ungrapple.

Intermediate travel was time spent moving between bunches. Travel empty, intermediate travel, and travel loaded distances were also measured.

When operating normally, there was no intermediate skidder travel because each bunch represented a full turn. In the test where bunches consisted of two accumulations, they were doubled up by the skidder operator, requiring both intermediate travel and a second grappling task. For analysis purposes, grapple times in this case were combined.

Chipping productivity was based on observations of time required to fill a trailer. Product weights were obtained from load tickets. Recovery was estimated by weighing chipper rejects by chip van load.

In earlier tests of this harvest system in short rotation sycamore, the chipper produced a high percentage of long, thin material that caused handling problems at the mill. It was assumed that the unsuitable material resulted from the chipper grabbing and pulling through whole branches and tops. As a possible means of reducing the amount of material unsuitable for pulp, a Peterson chain flail was briefly tested in March 1993 with the harvest system To estimate flail losses, 10 groups of approximately 8 trees each were weighed, then fed through the chain flail and the residues collected. Chips from flailed and unflailed trees were tested at the mill for percentages of accepts, fines, and overs.

RESULTS

Felling Productivity

Time study data were obtained from a total of 11 and 9 bunches for the 2 and 4 accumulations per bunch (apb) tests, respectively. Felling time per tree (t_t, total cycle time divided by number of sterns accumulated) was modeled using the following equation:

$$t_t = a\mu + b\,\alpha + g_j, \qquad [1]$$

where μ was move-to-first-tree distance (m), α was the average dbh of trees accumulated in a bunch, and g_j was a fixed value for j = 2 or 4 apb. Each parameter was significant at the P < 0.005 level, and overall model R^2 was 0.25. Parameter coefficient values (standard errors in parentheses) were a = 0.00084 min/m (0.00031), b = 0.010 min/cm (0.0032), and g_j was 0.0116 (0.027) min for j = 2 and

(0.00031), b = 0.010 min/cm (0.0032), and g_j was 0.0116 (0.027) min for j = 2 and 0.0278(0.025) for j = 4. Including other sampled elements in the equation (move-to-dump distance, dump time, and accumulation time) did not significantly improve the model.

Least square mean time per tree was 0.119 mm for apb = 4, and 0.103 min for apb = 2. These values were significantly different (P = 0.01). Using the estimated mean times, and assuming an average tree weight of 31.8 kg (7.6 cm dbh), felling productivity was 582 stems, or 18.5 green t, per PMH for apb = 2, and SO4 stems, or 16.0 green t, per PMH for apb = 4.

Table 1. Parameter estimates for the coefficients of equation 1.

Parameter	Estimate	Standard Error
P	0.139	0.032
α_t	0.00054	0.000038
α_i	0.0010	0.000089
g_j, 1 bunch per turn	0 2 2	0.06
g_j, 2 bunches per turn	0.55	0.06
U	0.05	0.02

Skidding Productivity

Skidding data was obtained for a total of 12 cycles, 6 each with either 1 bunch per turn (4 felling accumulations) or 2 bunches per turn (2 accumulations). Grapple times were summed when skidding two bunches. Travel times were linearly related to travel distances ($P < 0.002$, $R^2 > = 0.9$), and regression coefficients for the travel empty and loaded functions were not significantly different. The regression coefficient for intermediate travel, however, was about twice that for travel empty or loaded and was significantly different from both ($P < 0.01$).

From these results, skidder cycle time was modeled as

$$t = p + a_t d_t + a_i d_i + g_j + u, \qquad [1]$$

where, p was average position time in minutes, a_t was the regression coefficient relating travel empty/loaded round trip time with distance, d_t in m, a_i was the regression coefficient relating intermediate travel time with distance, d_i also in m, g_j was grapple time in minutes for picking j = 1 or 2 bunches, and u was average ungrapple time in minutes. Because of the relatively low number of observations, cycle elements were modeled individually and total cycle time was assumed to be their sum. The overall prediction error rate, therefore, is not known. This implies that the model is more descriptive in nature and should be used with caution in other applications. Table 1 shows estimated values for the parameters of equation 1. Measured average round trip skid distance was 399 m, and average intermediate travel distance was 20 m. Average number of stems skidded per turn was 42.8. Using these values, skidder productivity was 35.8 green t/PMH with bunches of 4 feller-buncher accumulations, and 24.6 green t/PMH for bunches of 2 accumulations. Stokes and Hartsough (1993) reported productivity of a smaller grapple skidder (60 kW) to be much lower in similar stands--9.4 green t/PMH.

Table 2. Assumptions used in calculating machine rate for all equipment tested.

Cost	Basis	Value
Machine	Years	5
Salvage value	% Purchase Price	20
Interest rate	%	12
Fuel cost	$ per Liter	0.26
Lube and oil cost	% Fuel Cost	37
Operator wage and benefit	$ per SMH	10
Scheduled machine hours	year	2,000

Chipper Productivity

Four observations were made of time to chip a van load, reject weight (on two loads), and product weight. An average of 97.1 percent of total material was recovered as chips. Average chipping time per load was 18.8 min, not including move and position time for the van. Position times were not measured and a value of 7 min was assumed. Based on this assumption and an average load size of 25.3 t, chipping productivity was 57 green delivered t/PMH.

System Costs

Machine rates for the equipment used in the study were calculated from the methods presented in Brinker and others (1989). Assumptions used in calculating machine rate are shown in table 2. Machine-specific values needed for the calculations, as well as the machine rates themselves, are shown in table 3.

Table 3. Machine-specific costs and machine rate for studied equipment.

Cost	Units	Timberjack 450B Grapple Skidder	HydroAx411 Feller Buncher	Morbark Model 30 Chipper
		Machine		
Purchase Price 1993		$121000	$125500	$289000
utilization	% SMH	60	65	75
Repair & Maintenance	% Annual Depreciation	90	100	100
Fuel Use	$\frac{l}{kW-hr}$	0.14	0.13	0.12
Engine Power	kW	132	94	600
Insurance & Taxes	% Purchase Price	5	45	2
Machine Rate	$ per PMH	65.75	61.65	118.41

From the productivity results, a balanced system for the study conditions would consist of four feller-bunchers, two skidders, and the chipper-slightly different from the system tested that had only three feller-bunchers. When piling 2 apb, the feller-buncher had higher productivity, but this gain was more than offset in loss of productivity for skiddii. Harvest costs per green t, based on 4 apb and excluding transport, totaled $8.71 per green t and are shown in table 4. Adler (1985) reported $0.06/t-km as an average haul cost in the New England area. Assuming a value of $0.07 per t-km at current prices, and a haul distance of 80 km, transport costs would raise the total to $14.3/green t. This cost excludes overhead, i.e. crew transport, service vehicles and equipment, and profit.

Chip Quality and Flail Recovery

Problems with clogs in the material handling system from long, thin chips were encountered at the mill with material received from the short rotation sycamore plantations. The probable source of the troublesome material was identified as smalldiameter limbs and tops yanked by the chipper disc through the chipper feed rolls This problem was largely overcome by modifying the chrpper feedmg methods, i.e. overlapping grapple loads as they were fed in, which left enough material between the feed rolls at any particular time to prevent the chipper disk from snatching smaller material through. Before this method was perfected, however,. a flail was tested as an alternative for reducing the amount of small-diameter material entering the chipper.

Table 4. Productivity and costs for a balanced system operating in short-rotation Sycamore.

Machine	Number	Productivity *green delivered t per PMH*	Costs *$ per PMH*
Feller-Buncher	4	62	246.6
Skidder	2	75	131.5
Chipper	1	579	118.4
System			f8.71 per green t

Recovery was measured by weighing bundles of 6 to 8 *stems* before and after flailing. Results for 10 such bundles indicated that on average, 32 percent of the whole tree, by weight, was lost in flailing. Flailing also resulted in lower fines and bark contents after screening (table 5), but an increase in the percentage of overs. This was unexpected and could have indicated that the flail was not effective in reducing the potential for dogs in the material handling system at the mill.

Table 5. Results of after-screen chip quality analysis for flailed and unflailed short-rotation sycamore.

Material	No Flail (%)	with Flail (%)
Overs (>10 an)	3 5	4.4
Fines	1.4	0.6
Bark	4.9	3.9

Including the flail as a component in the system was evaluated using production data from a previously unpublished study conducted in 1989 with Scott Paper Company. The study was done to determine recovery of various hardwood species, including short-rotation sycamore. Productivity of flailing (Peterson Pacific, Model 4800) was also measured, although observations were limited and the operator was inexperienced. Results indicated that, for 5.3 cm dbh green sycamore trees, 2,039 stems/PMH could be processed. Assuming the same number of stems per hour, a 30 percent loss in product from flailing, and a 7.6 cm average dbh, flail productivity would be 45 green t/PMH. System costs for the flail are summarized in table 6. Hourly cost for the flail is based on the value reported in Hartsough and others

(1992) of $78/SMH and an assumed utilization of 60 percent. Final system cost, excluding transport, was $13.9/green t. This cost, however, would likely change and is only approximate.

Table 6. Productivity and costs for a balanced system, including a chain flail, operating in short-rotation sycamore.

Machine	Number	Productivity green delivered t per PMH	Costs $ per PMH
Feller Buncher	4	62	246.6
Skidder	2	75	131.5
Flail	1	45	130
Chipper	1	57	118.4
System			$13.9 per green delivered t

SUMMARY

Productivity of conventional harvesting equipment operating in 6-year-old, short-rotation sycamore plantations was determined. Results indicated that a four-wheel feller-buncher produced 165 green m t/PMH in 7.6 cm *diameter trees* planted on a 1.5 x 3.0 m spacing. No statistically significant felling production improvement was found when bunching 2 versus 4 accumulations per bunch (apb). Productivity of felling 4 apb was 15.5 green t/PMH. Skidding productivity, however, was affected significantly by the number of felling apb-35.8 versus 24.6 green t/PMH for 4 and 2 apb, respectively. Chipper productivity was estimated to be 59 green t/PMH. Based on the measured results, a balanced system consisted of 4 feller-bunchers, 2 skidders, and the chipper, with estimated harvest costs of $8.42/green t. Including a flail in the system raised the cost per green t to $13.9.

LITERATURE CITED

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