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**Cut-To-Length Harvesting of Short Rotation Eucalyptus  
at Simpson Tehama Fiber Farm**

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**Abstract**

A system consisting of a cut-to-length harvester, forwarder, mobile chipper and chip screen was tested in a 7-year-old plantation. Three levels of debarking effort by the harvester (minimal, partial and full), and two levels of screening (with and without) were evaluated. The harvester had the lowest production rate and highest cost of the system elements. Harvester production rate was strongly affected by tree size and somewhat by debarking level. Bark contents for full **debarking** averaged 1.5%; screening apparently did not reduce bark content any further. Estimated stump-to-truck costs (without screening) for the system in stands of good form varied from \$17/BDT for 11" DBH trees to \$65/BDT for 3" trees. The system may be cost-competitive with whole tree systems.

**Keywords:** CTL harvesting, production, cost, bark content, screening

**Introduction**

At present, most short rotation woody crop harvesting on the west coast is carried out by systems that include *feller/bunchers*, skidders, *chain* flail *delimber/debarkers*, and chip vans for hauling the clean chips to the pulp mill. Residues from the flaii are usually comminuted on site with a tub grinder or other device, and hauled in chip vans to a powerplant. This system works very well when a viable fuel market exists for the residues.

When fuel prices do not cover the costs of comminution and transport, managers must decide whether to leave the residues on site, and what system to use in this situation. **One** possibility is a cut-to-length (**CTL**) system consisting of a harvester and a forwarder. The harvester removes the branches and top at the stump, and cuts the tree to log lengths that may be selected by the operator. Residues are left distributed within the stand, **recycling nutrients** and eliminating disposal costs. In Australia and South Africa, harvesters have also *been* employed to debark eucalyptus stems. Howe (1994) studied a Bell TH 120 harvester clearcutting a eucalyptus plantation in South Africa. He reported a production rate of 11 .8 m<sup>3</sup> per scheduled hour for felling, debarking and piling of 6-m logs on flat terrain for skyline yarding, with tree volume averaging about 0.24 m<sup>3</sup>.

Although **skidders could** be used to transport delimbed and topped trees or log lengths, forwarders must be utilized to transport debarked logs, in order to **avoid contamination** by soil. Most forwarders **are limited to carrying** logs of about 20 feet or less in length. Forwarders generally travel on the mat of slash **left** by the harvester, and therefore have the potential to create less soil compaction than do skidders. Compared with skidding, very little dust is produced while forwarding.

Possible disadvantages of the CTL system include higher site preparation costs due to the on-site residues, and higher **harvesting** costs. Although rankings vary from study to study, in many cases CTL systems have cost more than whole tree skidding systems operating under similar conditions.

This study quantified the costs of a CTL system operating in eucalyptus, and the resulting bark content of chips from three levels of debarking intensity, with or without screening.

**Approach**

**Stand**

A seven-year-old stand of *Eucalyptus viminalis* was chosen for the trial. Seedlings had been planted on an 8-ft by 10-ft spacing. A sample **cruise** prior to harvest indicated that 490 stems per acre remained, including forks below breast **height** and standing dead stems. **Trees** averaged 5.6 inches DBH, 46 feet tall, and 3.3 cubic feet volume inside bark.

The trees, grown from unimproved seed, were highly variable in diameter (Figure 1), height and form. Almost a quarter of the trees were forked, and many trees had crooks. A majority of the trees were leaning due to the prevailing wind, and five to ten percent of the original trees were uprooted and leaning severely or on the ground. The uprooting was attributed to a high water table during the winter months. The terrain was flat, the soil surface was dry during the harvesting trial, and there was little or no undergrowth.

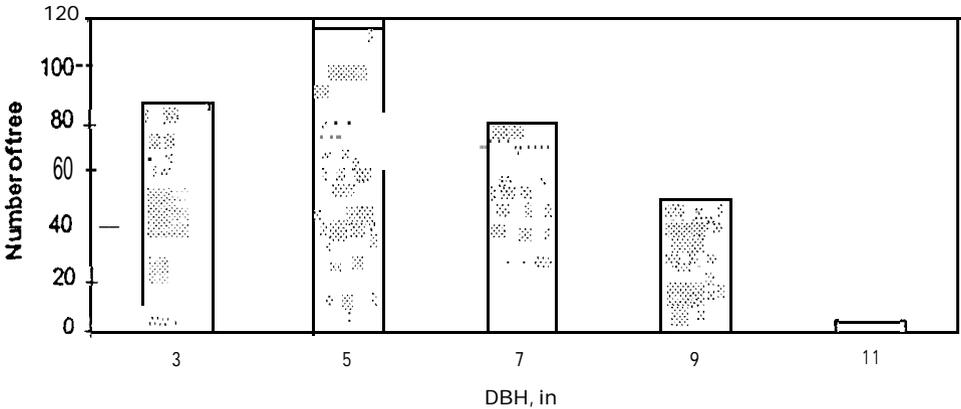


Figure 1. Distribution of diameters of the harvested stems.

**Equipment and Harvesting Operation**

Western Power and Equipment of Bend, Oregon, supplied a Bell **TH120** tracked harvester with an SP 550 single grip harvester head, and a Bell **T12B 12-ton** forwarder. The harvester head was modified to improve its debarking performance in eucalyptus by replacing the chain-equipped rubber-tired feed rollers with steel rollers equipped with spiral cutting edges,

When the harvester head is used on **eucalyptus** in South Africa, the double-bevel lower delimiting knives are replaced by single-bevel knives to improve debarking, but the head supplied for the tests had the **standard** double-bevel knives.

The equipment operator was well-skilled, with 8000 hours of experience on various harvesters. He also ran the forwarder during the single load that we observed, and was skilled with the forwarder as well.

Harvesting and forwarding were conducted on 21-23 July 1997. The operator used the first day to familiarize himself with harvesting in the test stand. Time-motion studies were carried out during the second and third days.

The harvester cut strips parallel to the 8-foot tree spacing direction. Three to four rows were cut per strip. Because of the down and leaning trees, logs were piled only on the side of the harvester opposite the uncut stand. Logs of up to 20 ft were cut if possible, although most were in the 16-ft to 18-ft range.

To investigate the debarking characteristics of the eucalyptus and resulting bark contents, three different specifications were followed by the harvester operator: “all” bark removed, “partial” debarking, and “standard” single-stroke delimiting with whatever debarking was accomplished. Removing “all” of the bark required between one and nine passes through the delimiting knives. (On forked or crooked trees, it was not possible to remove all of the bark.) For “partial” debarking, the operator used one to five strokes, with the goal of removing approximately half of the bark from each tree. On the first day of time-motion study, “all” the bark was removed. Half of the second day was devoted to the “partial” debarking specification, and half a day to “standard” processing.

The logs were forwarded to roadside and decked for chipping and screening, which were carried out on 28 July.

An experienced chipping contractor supplied a Morbark 20 chipper. Initially, the chipper’s boom and grapple pulled logs from the cold decks, but a front-end loader was added to speed the feeding rate. Some of the logs were chipped directly into chip vans. Others were chipped directly into an Oregon Mill Service (OMS) Super Beaver portable chip screening plant, and the screened chips were conveyed into vans.

## **Data Collection and Analysis**

Height and diameter **measurements** were taken on a sample of trees before harvesting, and volumes calculated from diameter-height-volume relationships developed by Simpson for their *Eucalyptus viminalis*. Average log volume was calculated from total volume harvested and the total number of logs cut. We assumed a ratio of 32 bone dry pounds per cubic foot of bole wood under bark, and 50% moisture content, wet basis. For chip vans, we assumed 25 net green tons per load.

We conducted a time-motion study of the harvester and collected observations on over 300 stems, approximately a third of them under each debarking specification. The cycle for each stem was divided into the following elements: Move, Fell, Process, and Fork&Crook Delays. The latter were any times that could be specifically attributed to the poor form characteristics. Brushing time was recorded separately. Brushing consisted of cutting nonmerchantable trees, including standing trees of less than 3” DBH, and decayed dead and down trees. Some of the latter were up to 7 inches in diameter at 4.5 feet from the stump. Any other delays were also recorded separately. Along with the times for each tree, we recorded move distance, DBH, and number of logs cut.

Only one forwarder load was observed. The forwarding cycle was separated into **TravelEmpty**, **Load**, **TravelWithin** Stand while partially loaded, **TravelLoaded** to the roadside, and **Unload** which included decking.

The time-motion data for the harvester was statistically analyzed to estimate cycle time elements as functions of the stand characteristics and operating conditions. Since only one forwarder load was timed, forwarder relationships from another study (Hartsough et al 1977) were adjusted to give element times that were close to those observed. For chipping, results from a study of chipping directly from cold decks of CTL logs was used (Drews et al 1998).

Harvesting, forwarding and chipping cycle times and production rates were then calculated over ranges of tree size and forwarding distance, for each of the three debarking specifications. Since estimates were desired for future stand conditions, i.e. for trees with better form, adjustments were made to the observed harvester productivity and forwarder load size. The adjusted production rates were combined with estimates of hourly costs for the harvester and forwarder, to give costs per BDT.

Chip samples were taken from vans using the standard sampling apparatus at the pulp mill. The samples were analyzed for bark content, overs (>2") and fines (<1/4") by Simpson's chip evaluation lab.

## **Results and Discussion**

### **Cycle Times and Productivities**

The time-motion data is summarized in Table 1. The harvester move distance was about 15% greater than calculated from theory, assuming straight, one-way travel and the observed 3.5 rows per strip. Theoretical distance is:

$$(43560 \text{ ft}^2/\text{ac} * \text{trees}/\text{move}) / (\text{trees}/\text{ac} * \text{row spacing} * \text{rows}/\text{strip})$$

In the test stand, travel was not always straight or one way because of the leaning and down trees. The harvester also moved very frequently because of the stand conditions. For estimating production in future stands, we assumed that improved tree form would allow four rows to be cut on each strip. We also assumed that the harvester would move one tree spacing distance on each move and then cut a tree in each row before moving again.

Table 1. Cycle time elements and associated variables.

	<u>Mean</u>	<u>Std. Dev.</u>	<u>Observations</u>
Harvester			
Move, <b>cmin/move</b>	12.1	9.1	198
Trees/move	1.71		
Fell, <b>cmin/tree</b>	13.6	9.6	339
Process, <b>cmin/tree</b>	38.4	24.7	339
Brush, <b>cmin/tree</b>	9.2	23.2	340
<b>Crook&amp;ForkDelay, cmin/tree</b>	3.2	11.0	340
<b>OtherHarvProductiveDelays,</b> % of cycle <i>time</i>	4.8%		
Move distance, <b>ft/move</b>	5.05	2.89	198
DBH, in	5.62	2.11	339
<b>TreeVolume, ft<sup>3</sup></b>	3.31		
Logs/tree	1.82	0.71	340
Forwarder			
Travel empty, <b>min/load</b>	1.13		1
Load, <b>min/load</b>	9.11	(14 swings)	1
Travel within stand, <b>min/load</b>	3.44		1
Travel loaded, <b>cmin/load</b>	1.44		1
Unload/deck, <b>cmin/load</b>	5.17	( 10 swings)	1
Travel empty dist, ft	130		1
Travel within stand dist, ft	140		1
Travel loaded dist, ft	200		1
Logs/load	106		1
Load size, <b>ft<sup>3</sup> (BDT)</b>	193 (3.09)		1

Harvester cycle time relationships are shown in Table 2. Processing time increased with the specified level of debarking, and this is quantified in the regression **relationship** with the coefficients of the dummy variables, Partial and Full. Partial =1 for partial debarking, = 0 otherwise. Full = 1 for full bark removal, = 0 otherwise. (For Standard processing, both dummy variables are set to zero.)

While collecting data, we were able to clearly identify some of the additional time spent dealing with forks and crooks, but these averaged only a few centiminutes per tree, as indicated in Table 1. There was considerable other time that could not be clearly separated; the forks and crooks reduced the feed rate through the head, and decreased the length of stem that could be processed before a reversal or bucking cut had to be made. **In** stands without heavy leaners and down trees, logs can be piled on both sides of the harvester. This speeds processing because trees do not have to be rotated or moved as far. The leaning and down trees also increased felling times by restricting the directions **from** which the trees could be cut, and by requiring the operator to be more cautious to avoid hitting the ground with the chainsaw. In addition, brushing would almost be eliminated in higher quality stands of more uniform trees. Considering all of these factors, we estimated that harvester productivity would be increased by 30% or so in future stands of good quality compared to the one observed, for any given average tree size. Assuming 80% utilization, the productivity reported by Howe (1994) is similar to our adjusted rate for complete debarking of trees of comparable size --just under a productive minute per tree for 9" trees -- so the adjustment seems reasonable.

Table 2. Harvester Cycle Element Relationships, **cmin**

$$\begin{aligned} \text{Move, } \mathbf{cmin/move} &= 6.09 + 1.189 * \text{Distance} \\ &\mathbf{R^2 = 0.14, F = 33., n = 198} \\ \text{Fell, } \mathbf{cmin/tree} &= 10.40 + 0.511 * \text{DBH} \\ &\mathbf{R^2 = 0.02, F = 7.6, n = 338} \\ \text{Process, } \mathbf{cmin/tree} &= 15.75 + (0.333 + 0.166 * \text{Partial} + 0.515 * \text{Full}) * \text{DBH}^2 \\ &\mathbf{R^2 = 0.57, F = 149., n = 339} \\ \text{Brush, } \mathbf{cmin/tree} &= 9.24 \\ \text{Crook\&ForkDelay, } \mathbf{cmin/tree} &= -3.12 + 1.125 * \text{DBH} \\ &\mathbf{R^2 = 0.05, F = 17., n = 340} \\ \text{Total productive time, } \mathbf{cmin/tree} &= (\text{Move/TreesPerMove} + \text{Fell} + \text{Process} + \text{Brush} \\ &+ \text{Crook\&Fork Delay}) * (1 + \text{OhterHarvProductiveDelays}) \\ \text{LogsPerTree} &= 0.7 + 0.2 * \text{DBH} \end{aligned}$$

Relationships from a study of a CTL forwarder operating on the Stanislaus National Forest were adjusted to estimate cycle times under the easier operating conditions in the eucalyptus plantation. The adjusted relationships are shown in Table 3. When the observed values for travel distances and logs per load are used, the adjusted relationships give a total time per load that is within four percent of that observed for the single load.

The observed forwarder load size was only about 3 BDT or 6 green tons, about half the nominal capacity of the forwarder. This was due to poor packing of the relatively crooked logs, and due to the short lengths of many of the logs. With better trees, a higher percentage of the logs could be cut to maximum lengths, packing should be improved, and higher stakes could be used if needed. To estimate productivity in future stands of good quality, we assumed a forwarder load size of 6 BDT (12 green tons).

Table 3. Forwarder Cycle Element Relationships, **cmin**

$$\begin{aligned} \text{LogWeight} &= \text{TreeWeight/LogsPerTree} \\ \text{LogsPerLoad} &= \text{LoadWeight/LogWeight} \\ \text{WithinStandDistance} &= (\text{LoadWeight}*43560\text{ft}^2/\text{ac}) \\ &/( \text{TreesPerAc} * \text{RowsPerCorridor} * \text{RowSpacing} * \text{TreeWeight} ) \\ \text{TravelEmpty+TravelLoaded} &= (152.95+0.488*\text{TravDist} + 0.01224*\text{TravDist}* \text{Slope}) \\ \text{Load} &= 0.5*(642.54+10.7*\text{LogsPerLoad}) \\ \text{TravelWithinStand} &= 0.67*(458.91+0.808*\text{WithinStandDistance}) \\ \text{Unload} &= (360+2.2*\text{LogsPerLoad}) \\ \text{ForwProductiveDelays, \% of cycle time} &= 5.9\% \\ \text{Total productive time, } \mathbf{cmin/load} &= (\text{TravelEmpty+TravelLoaded} + \text{Load} \\ &+ \text{TravelWithin Stand} + \text{Unload}) * (1 + \text{ForwProductiveDelays}) \end{aligned}$$

A front-end loader was used to feed the Morbark 20 chipper during the trial. A separate loader or skidder is commonly used to break down decks of whole trees, and in some cases with cut-to-length logs (e.g. Hartsough et al 1997). Using a chipper with an infeed deck, however, it is possible to chip at high rates directly from cold decks of CTL logs, thereby eliminating the cost of the loader or skidder. We used results from a CTL study where a Morbark 27 fed itself from cold decks (Drews et al 1998):

$$\begin{aligned} \text{Total productive time per load} &= (1103. + 145.06 * \text{ChipVanNetGreenWeight} \\ &+ 9.99 * \text{GreenLogWeight}) * (1 + 11.1\% \text{ChipProductiveDelays}) \end{aligned}$$

Costs were estimated at about \$95 per productive hour for the harvester, \$78/PH for the forwarder, \$95/PH for a Morbark 27 chipper and an additional \$40/PH if the screen is included in the system. The costing assumptions are listed in the appendix. A spreadsheet was developed to calculate cycle times, productivities and costs per BDT of clean chips. Harvesting, forwarding and chipping/screening costs per BDT over ranges of tree size and operating conditions are displayed in Figures 2, 3 and 4.

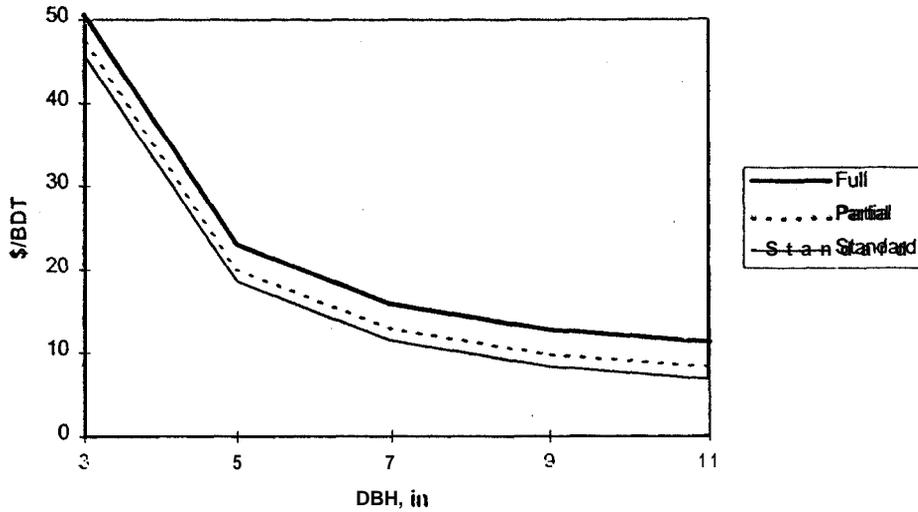


Figure 2. Estimated harvester costs in stands of good quality, for various levels of debarking effort.

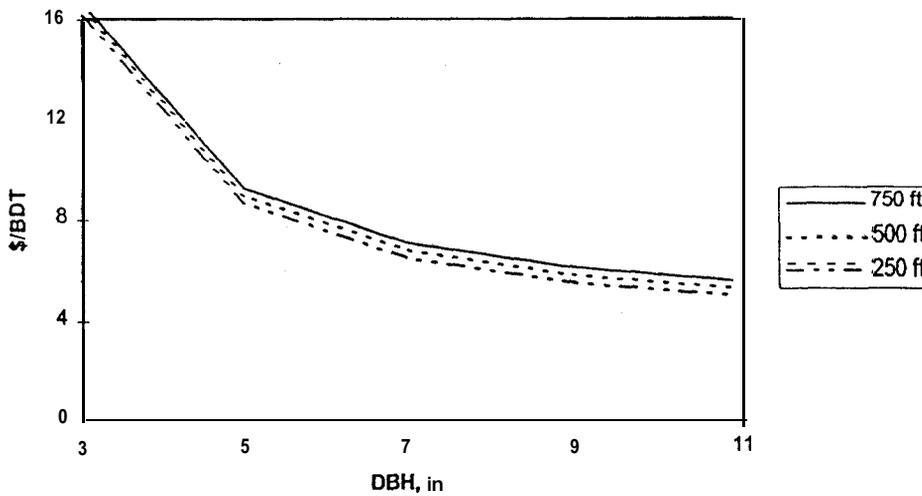


Figure 3. Estimated forwarding costs in stands of good quality, for three different forwarding distances.

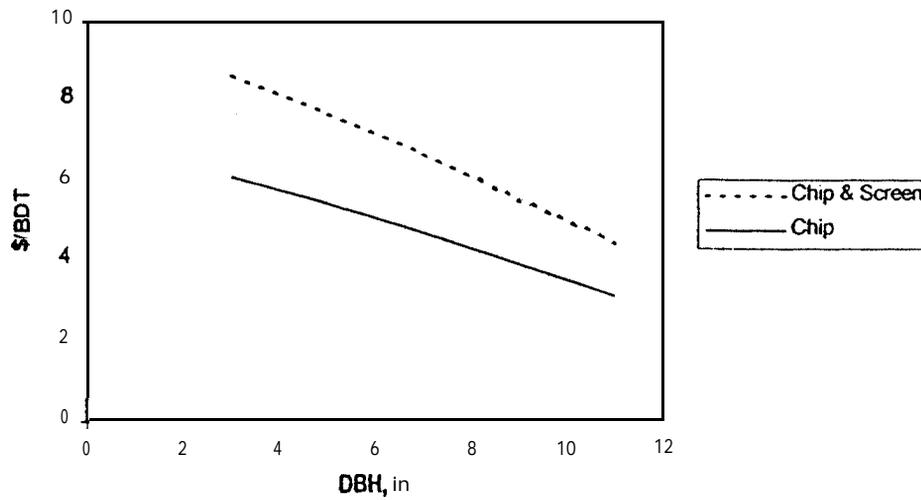


Figure 4. Estimated chipping or chipping/screening costs.

Production rates for a single harvester, forwarder and chipper are shown in Figure 5. For trees in the 5"-11" DBH range, a reasonably balanced system would include three harvesters, two forwarders and one chipper.

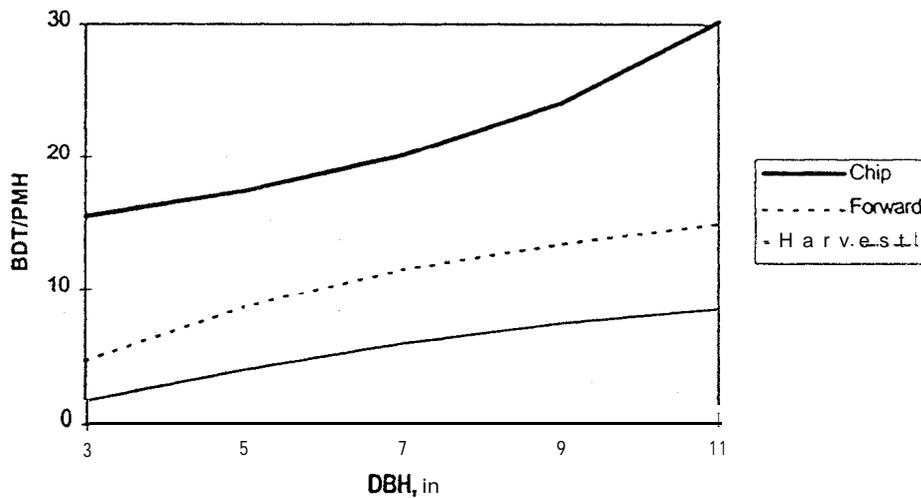


Figure 5. Production rates per productive machine hour for a harvester (full debarking), a forwarder (500 ft average distance) and a chipper.

### Stump Heights

Initially, the harvester operator tried to cut fairly low stumps, but he was dulling the chainsaw frequently because of the gravelly soil and lack of duff and litter. He then cut higher stumps, which solved the dulling problem. Stumps, however, averaged 10.3 inches tall. This compared with an average of 4.8 inches for stumps left by a shear-equipped feller/buncher in an adjacent stand on similar terrain (Figure 6).

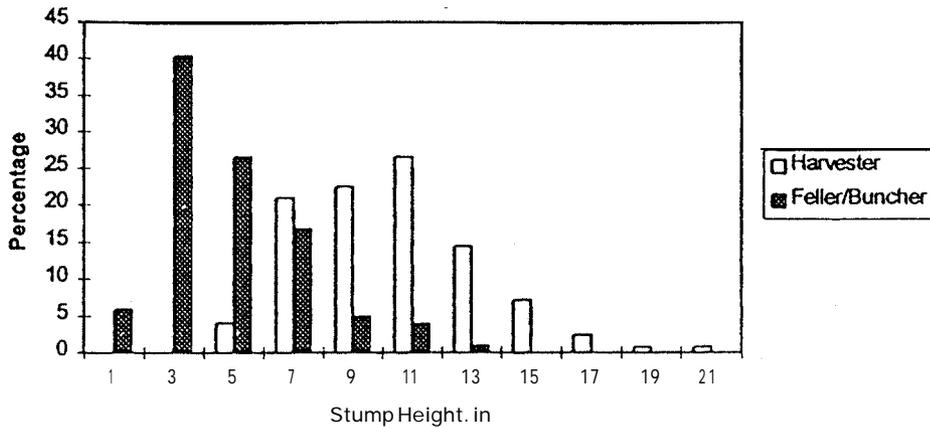


Figure 6. Distribution of stump heights, for trees cut by a shear-equipped feller buncher and by the chainsaw-equipped harvester.

Stump heights could be lowered with additional experience, and possibly by adding a spacer on the bottom of the harvester head to provide a gap between the saw and the ground. The leaning trees increased the stump heights because the head had to be raised to avoid contacting the ground with the saw chain. There also should be fewer problems with dulling the chain in soils with less rock. However, the duff and litter layer in SRIC plantations will probably remain rather thin so it is likely that shear heads will always be able to cut lower stumps than chainsaw heads.

### Bark, Overs and Fines Contents

Full debarking effort by the harvester reduced the bark content significantly (at the 5% level) in comparison to partial or standard debarking (Table 4). Screening did not further reduce bark content. It may be that the remaining bark was more tightly bonded to the stems, did not separate from the wood during chipping and therefore would not screen out. Screening did significantly reduce (at the 5% level) overs and fines percentages.

Table 4. Overs, fines and bark contents for the tested screening and debarking treatments.

	<u>Screened</u> <u>reene</u> <u>d</u>	
Overs, %	4.3	6.1
Fines, %	0.3	0.9
Bark, %		
Full	1.6	1.5
Partial	5.7	3.7
Standard	3.4	

For full debarking with or without screening, the observed average bark content of about 1.5% still exceeded the desired threshold of 1%. On trees of better form, bark content should be less. It was difficult or impossible to remove much of the bark near crooks or forks because the harvester knives and rollers could not contact the boles. Also, the trees in the test stand had not been irrigated during part of the growing season just before harvest. Continuing to irrigate until shortly before harvest might lower wood-bark adhesion and improve debarking results.

Representatives of Bell indicated that debarking might **improve as the** feed rollers were broken in, because bark might not clog the gaps between the cutting edges on the rollers. They also expected the use of the more aggressive, single-bevel **delimiting** knives to improve bark removal. They reported good results with these knives in South Africa. Other modifications that might help:

- a third feed roller to increase contact with the bark,
- hourglass-shaped rollers to increase contact with the bark,
- slightly angled roller shaft axes to impart a slicing action between the roller cutting edges and the tree, and to produce a spiral motion of the stem through the head.

### Site Preparation and Other Effects

After harvesting, the test stand was allowed to coppice regenerate, so there was no difference in site preparation or regeneration costs on this versus a **coppiced** whole tree site. Simpson replants the majority of its stands. If the stand had been planted, it was estimated that site preparation costs would have been increased by about 40% due to the higher stumps and residues. Increased fire danger is another possible negative. Expected benefits of the residues would include additional nutrients and higher soil moisture content during late spring due to the mulching effect.

### Conclusions

In clonal stands of trees with better form, and with minor changes to the harvester to improve debarking, the harvester-forwarder-chipper system may be able to produce chips with bark contents of less than one percent. Then the question comes down to harvesting economics and secondary effects. Stump-to-truck harvesting costs for the system with full debarking effort are displayed in Figure 7. Costs of **\$33/BDT** (1991 dollars) were reported for a whole tree **feller/buncher-skidder-chain flail delimitter/debarker** system (Hartsough et al 1992). The whole tree system was operating in short rotation poplar that averaged about 6" DBH. The similar costs indicate that the **CTL** system might be competitive.

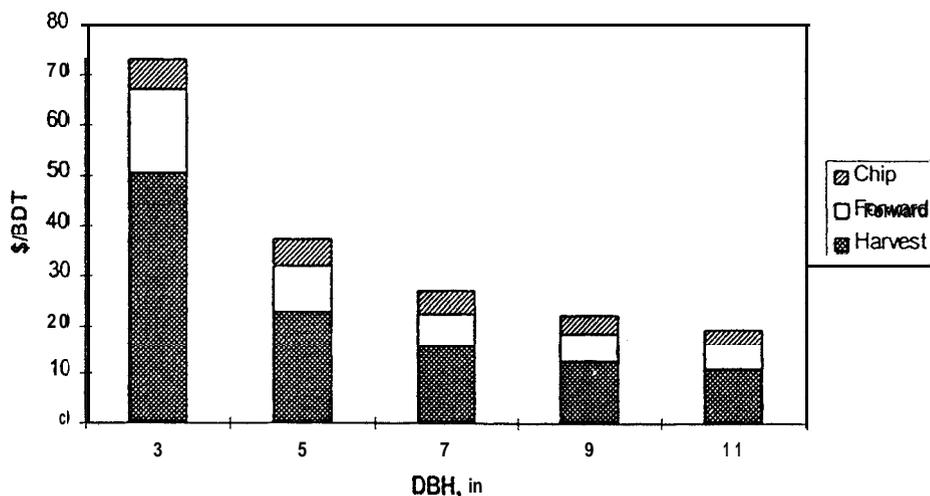


Figure 7. Stump-to-truck costs for harvesting (full debarking), forwarding (500 ft average distance) and chipping.

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