wood recovery with in-woods flailing and chipping

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Flail-and-chip harvesting produces the most clean chips, but each harvesting method has advantages that should be considered when choosing the right method for a particular mill.

In tree-length harvesting operations, the trees are usually delimbed and topped in the woods. Sawlogs are bucked, and pulpwood is loaded tree-length. The use of in-woods chipping has been limited to energywood production because high bark content limits the use of whole-tree chips as pulp furnish. Flail delimbing and debarking allows economical processing and chipping of whole trees in the woods to produce clean, acceptable chips,

In-woods processing of whole trees has several advantages over tree-length operations. Flail processing and chipping are potentially more economical for small-diameter trees than delimbing and hauling tree-length wood. Another advantage is increased biomass recovery, assuming that the limbs, top, and bark can be utilized as fuel. In-woods flailing and chipping allows the recovery of a higher-valued chip product and the use of a larger portion of the whole tree, as well as the smaller-diameter stand components. Disadvantages to the logger are the high capital investment and a system that can produce only one product-chips.

However, flail processing is a less capital-intensive alternative for a mill than whole-tree harvesting (hauling wood, bark, and foliage to the mill). A mill that receives and processes whole trees must have a specialized woodyard and specialized trailers. There may also be an economic advantage to transporting chips versus roundwood for certain tree sizes.

The recovery efficiencies of tree-length, in-woods flail delimbing and debarking with chipping, and whole tree harvesting systems, are presented in this paper. Products were determined for a typical stand as a percentage of whole-tree biomass and as weight units per area for each harvesting option.

Flail delimber and debarkers

Each geographical area of North America has its own unique history of the development of flails (1-5). A common basis for flail development was the need to have a method for economically harvesting and utilizing small-diameter trees. The use of a flail allows the recovery of pulpable chips, a higher valued commodity than energywood chips. Flailing eliminates delimbing, which has a high cost when producing tree-length wood from small stems.

Flail delimbing and debarking has recently emerged as a feasible technology for harvesting small-diameter stems. There are several flail machines on the market. These machines use chains attached to revolving drums, either horizontal or vertical, to strike the stems and remove the limbs and bark. A double set of drums is used to improve bark removal while minimizing processing time.

Methods

The in-woods flailing and chipping method was compared with tree-length and whole-tree harvesting methods to assess clean chip recovery. Recovery efficiencies were determined and compared for the three methods. The quantity of clean chips and residues were estimated for each harvesting and processing function during wood flow from stump to digester.

Percentages of recovery for the processes in the woods during the harvesting and transport phases were based on field data from a case study (6-8). All recovery efficiencies were averages for the stands harvested during the studies and were stand-specific.

The studies were conducted in slash pine (*Pinus elliottii*) plantations, clear-cut at about 21 years of age. Mill recovery efficiencies were based on averages for the southern United States for an assortment of mill facilities (9). Actual recovery levels would depend on the tree size and type of processing equipment, such as screens, at the mill.

A representative stand volume per hectare on a weight basis was estimated by diameter class using whole-tree (above-ground biomass) weight equations (*10*). An analysis was completed to calculate the resulting products as a percentage of the whole-tree biomass for the selected

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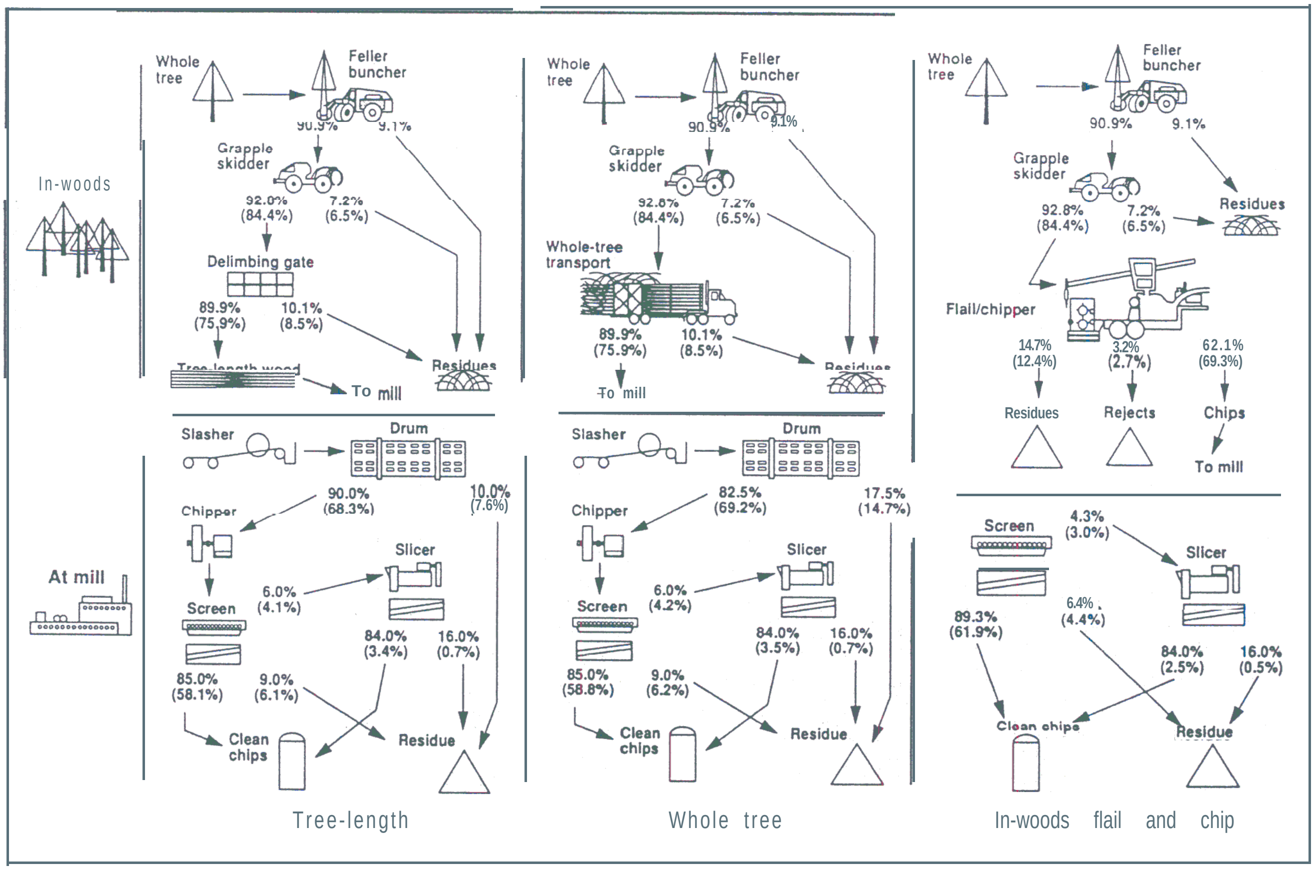
1. Wood flows and recovery efficiencies for alternative harvesting methods (values in parentheses are percentages of the whole tree)



Results

Tree-length harvesting and mill processing

For all options, the loss of limbs and tops from breakage during the felling and skidding functions accounted for 15.6% of the total tree biomass. This material was left as unrecoverable residue spread across the site.

Figure 1 shows a product flow diagram for three alternative harvesting methods. In the tree-length harvesting method, the trees were gate delimbed, leaving 8.5% of the total biomass on site as residue. The remaining 75.9%, in the form of tree-length stem wood, was hauled to the mill.

Recovery efficiencies were based on the assumption of no loss from hauling or handling at the mill where the tree-length wood was slashed and drum debarked, Ninety percent of the tree-length product was converted to debarked shortwood that was fed into the chipper at the mill (11). At this point, over 68% of the original whole tree ends up at the chipper.

Ten percent of the stem going into the drum was recovered as mill residue. This was 7.6% of the original whole tree. Drum residue was mostly bark but also contained wood fibers and tops of the stems. Such material could require additional processing before burning.

Screening removed the oversized ("overs") and undersized chips. Generally, overs are too long if they exceed 45 mm in length and are too thick if greater than 10 mm in width for softwood or 8 mm for hardwood (9). Minimal length for acceptable chips is 7 mm.

The screening process recovered 58.1% of the whole tree as acceptable chips. Nine percent of the flow that went through the screens (6.1% of the whole tree) ended up as mill residue which is usually used in the boiler. The oversized chips were sent to a slicer for further reduction. This process recovered 84% of its wood flow as acceptable chips, an additional 3.4% of the whole tree. The total proportion of acceptable chips was 61.5%.

Flail-and-chip harvesting and mill processing

Recovery efficiencies were based on studies using a Peterson Pacific* Model 4800 log debarker and Morbark Model 22 chipper to process whole trees at the deck (6-8). The process results in three products: flail residue, chipper rejects, and chips (Fig. 1). The flail residue included limbs, tops, foliage, and bark biomass. Chipper separator rejects accounted for 2.7% of the whole tree. The remaining 69.3% went into a van as chips to be transported to the mill.

The same screening processes were used as in the tree-length option. However, the recovery percentages were based on the use of a chip classifier from the case studies (6-8). The classifier rejected overs that measured greater than 32 mm in length but did not reject chips baaed on thickness. With the assumption of no loss for handling, 89.3% of the screened chips were acceptable, for a total of 61.9% of the whole-tree biomass. An additional 2.5% of the whole tree was recovered as clean chips after slicing

*The use of trade names is for the convenience of the reader and is not an endorsement by the USDA Forest Service or Mississippi State University

. Summary of products by process and harvest method

Product/process	Tree-length, % of whole tree	Flail-and-chip, % of whole tree	Whole-tree, % of whole tree
Clean chips			
First screening	58.1	61.9	58.8
Slice overs/rescreen	3.4	2.5	3.5
Total	61.5	64.4	62.3
Mill residues			
Drum debarker	7.6	...[a]	14.7
First screening	6.1	4.4	6.2
Slice overs/rescreen	0.7	0.5	0.7
Total	14.4	4.9	21.6
Forest residues			
Fell	9.1	9.1	9.1
Skid[b]	6.5	6.5	6.5
Load trim			0.5
Gate delimb	8.5		
Flail delimb/debark		12.4	
Chipper rejects	—	27	—
Total	24.1	30.7	16.1
Total	100.0	100.0	100.0

[a]"..." denotes process dii not occur for method.
[b]Skid loss includes loading loss for whole-tree harvesting method.

and rescreening; thus, a total of 64.4% of the whole tree was recovered as clean chips for the digester.

Whole-tree harvesting and mill processing

Trees were skidded directly to the loader, which loaded the "whole trees" onto trailers with screens to contain the limbs and tops. Although 15.6% (the sum of felling and skidding loss) of tree biomass was lost during the harvesting operations as in the other methods, another 0.5% was trimmed from the load to make it legal for transport on the highway (8). As a result, 83.9% of the total tree biomass arrived at the mill for processing (Fig. 1).

Assuming no handling loss at the mill, 69.2% of the total tree biomass was recovered as bole wood and 14.7% as mill residue from the drum (12). The screening, reslicing, and rescreening recovery efficiencies are based on averages as in the tree-length option (9). The mill processes resulted in 62.3% of the total tree biomass recovered as clean chips.

Discussion of results

The tree products-lean chips, mill residue, and forest residue-are summarized as whole-tree percentages in Table I. The flail-and-chip option recovered the highest percentage of clean chips, almost 3% more than the tree-length method and over 2% more than the whole-tree method.

The whole-tree method produced over 7% more mill residue than the tree-length method. The tree-length method produced almost three times more mill residue than the flail-and-chip option. Over 21%, 14%, and 4% of the tree was usable as mill residue for energywood from the whole-tree, tree-length, and flail-and-chip options, respectively.

All three harvesting options left 15.6% of the tree on the site as limbs, tops, and foliage from breakage during felling and skidding. This residue is spread out over the site and is usually considered uneconomical to recover. Another 8.5% of the tree remained in the forest as piles of slash after gate clelimbing when using the tree-length method. For the flail-and-chip option, it is often economically feasible to recover the 12.4% of the tree ejected from the flail delimberdebarker. However, this material may need further processing before it is usable. The representative stand used in our analysis had 201.2 green metric tons of standing biomass per hectare **(Table II).** Whole trees were defined as all tree components (including foliage) except the stump. Average tree diameter at breast height was 17.5 cm, and average total height was 15.9 m.

Assuming the stand was harvested using the tree-length method, almost 148 green metric tons/ha were removed as wood and bark and taken to the mill **(Table III).** Over 53 green metric tons/ha remained on site as harvesting slash. At the mill, another 28 green metric tons of slasher and drum residues were produced. The total recovery to the digester pile was 120 green metric tons of chips per hectare.

Over 139 green metric tons/ha of chips were produced in the woods when using the recovery efficiency values to determine products from the representative stand by the flail-and-chip option. This option left 30.4 green metric tons/ha in the form of flail residue and chipper rejects, and 61.9 metric tons/ha when including felling and skidding losses. At the mill, almost 130 green metric tons/ha were recovered as clean chips to the digester pile.

The whole-tree harvesting method analysis resulted in almost 169 green metric tons of wood, bark, and foliage per hectare being hauled to the mill. Total mill residues were 44 green metric tons/ha. Over 125 green metric tons/ha of screened chips were sent to the digester pile.

Direct comparison among the methods showed that the flail-and-chip option recovered an additional 4.3 and 9.6 green metric tons of acceptable chips per hectare over the whole-tree and tree-length methods, respectively. The whole-tree method produced the most mill residue. The flail-and-chip option produced the most forest residue.

Summary and conclusions

Over 64% of the whole-tree biomass was recovered as clean chips using in-woods flailing and debarking as the harvest method. Whole-tree harvesting recovered 62.3% of the total tree biomass as clean chips. The tree-length harvesting alternative recovered 61.5% of the biomass as clean chips. The tree-length harvesting alternative recovered 61.5% of the biomass as acceptable pulp chips.

More acceptable chips were recovered from the flail-and-chip option, primarily due to the increased utilization of stem wood and recovery of acceptable chips during the screening process.

A higher percentage of the total biomass was diverted to forest residue in the flail-and-chip option. If the flail rejects were recovered, then only 13.3% of the total biomass

II. Representative slash pine plantation stand

Diameter at breast height class, cm	Total height, m	Harvested trees, no./ha	Stem: Whole-tree*, green metric tons/ha	Stem: Wood only, green metric tons/ha	Stem: Bark only, green metric tons/ha	Stem: 5-cm top wood and bark., green metric tons/ha
10	10	161	6.5	4.5	1.1	5.4
13	14	230	20.6	14.8	27	17.2
15	16	299	44.8	32.5	5.6	37.8
18	18	249	54.6	39.6	6.5	46.1
20	19	143	43.7	31.8	5.2	37.0
23	20	57	23.1	16.8	2.7	19.2
25	20	12	6.3	4.5	0.7	5.2
28	21	2	1.6	1.1	0.2	1.3

'Includes foliage.

Note: Weight equations are from Reams (*10*) and others. 1982

II. Slash pine recovery efficiencies: stump to chip pile

Diameter at breast height class, cm	Whole-tree*, green metric tons/ha	Tree-length: Forest residues, green metric tons/ha	Tree-length: Mill residues, green metric tons/ha	Tree-length: Clean chips, green metric tons/ha	Flail-and-chip: Forest residues, green metric tons/ha	Flail-and-chip: Mill residues, green metric tons/ha	Flail-and-chip: Clean chips, green metric tons/ha	Whole-tree: Forest residues, green metric tons/ha	Whole-tree: Mill residues, green metric tons/ha	Whole-tree: Clean chips, green metric tons/ha
10	6.5	6.5	-		2.0	0.3	4.2	1.1 3.3	1.4	4.0
13	20.6	5.0	29	12.7	6.3	1.0	13.3		4.5	128
15	44.8	10.8	6.4	27.6	13.8	2.2	28.8	7.2	9.7	27.9
18	54.6	13.2	7.8	33.6	16.8	2.6	35.2	8.8	11.8	34.0
20	43.7	10.5	6.3	26.9	13.4	22	28.1	7.1	9.4	27.2
23	23.1	5.6	3.3	14.2	7.1	1.1	14.9	3.7	5.0	14.4
25	6.3	1.5	0.9	3.9	1.9	0.3	4.1	1.0	1.4	3.9
28	1.6	0.4	0.2	1.0	0.5	0.1	1.0	0.3	0.3	1.0
Total	201.2	53.5	27.8	119.9	61.8	9.8	129.6	325	43.5	125.2

'Includes foliage.

would be left on the site. This amount would then be only slightly more than the whole-tree system.

For the slash pine plantation, an additional 9.6 green metric tons of acceptable chips per hectare were recovered with the flail-and-chip alternative over the tree-length method and 4.3 green metric tons/ha over the whole-tree option. Of the forest residues produced with the flail-and-chip method, 12.4% of the total biomass (25 green metric tons/ha) may be economically recovered; the tree-length method produced 17.2 green metric tons/ha, 8.5% of the total biomass, as gate delimbing residue that may not be economically recoverable.

Each method has certain advantages over the others. The flail-and-chip alternative allows more economical handling of small trees such as those from thinnings. Chips are more economical to handle and haul than small, short stems. Besides the increased utilization and product recovery, the flail-and-chip method offers some flexibility for woodyard, procurement, and logistics problems in balancing wood flow to a mill. Tree-length harvesting allows mill merchandizing and improved recovery of sawlogs. Also, there are some advantages to leaving forest residuals on the site to avoid site degradation. The whole-tree method can easily handle small stems since there is no in-woods processing and some of the biomass can be used as energywood.

Our analysis is based on preliminary data and averages. More detailed information and a statistical analysis is needed before formulating definitive conclusions. At this stage, it is more important to understand that wood flow from stump to the mill digester pile can differ significantly among harvesting methods and should be considered carefully in the selection and implementation of alternatives.0

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