HARVESTING WHOLE TREES WITH PROCESSING AND LOG ALLOCATION IN THE FOREST TO CONVENTIONAL AND ENERGY PRODUCTS

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RECOVERY EFFICIENCY OF WHOLE-TREE HARVESTING[1]

by

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INTRODUCTION

The recovery of total tree biomass and most components of a stand is a practical economic and management alternative to tree-length harvesting. First, the increased utilization of woody biomass provides additional revenues from the site. Second, the removal and utilization of the stems and crowns reduces site preparation costs and makes tree planting easier. Third, from a different perspective, better utilization helps provide an additional resource of raw materials from an already declining inventory of standing timber in the Southern United States.

A typical stand can produce several products, including sawtimber, pulpwood, and energywood. Ultimately, the objective is to recover stand and tree components at the highest product value given the economics of the harvest, transport, and process methods. In typical tree-length operations, the trees are delimbed and topped in the woods. Sawlogs are usually bucked, and pulpwood is usually loaded tree-length. Whole-tree chips have been limited to energywood production because a high bark content restricts their use as pulp. However, improved flail delimbing and debarking technology allows economical processing and chipping of whole trees in the woods as pulp furnish.

Processing of whole trees in the woods has many advantages. From the harvesting perspective, flail processing and chipping is potentially more economical for small diameter trees than delimbing and hauling tree-length wood. The primary advantage over tree-length logging is increased biomass recovery, assuming that the limbs, top, and bark can be utilized. In-woods flailing and chipping allows the recovery of a higher-valued product for a larger portion of the whole tree.

This analysis was completed to evaluate the recovery efficiencies of tree-length harvesting and in-woods flail delimbing and debarking with chipping. Products were determined for a typical stand as a percentage of whole-tree biomass and as green tons per acre for each harvesting option.

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[1]Paper presented at International Energy Agency Workshop, Project Al, "Harvesting Whole Trees with Processing and Log All'ocation in the Forest to Conventional and Energy Products." June 6-10, 1988. Garpenberg, Sweden.

METHODS

The quantity of pulp furnish and residues produced were determined for each harvesting and processing function during wood flow from the stump to the digester. Percentages of recovery for the processes in the woods were based on field data from a case study (see Appendix). This approximates the wood flow for comparable stand conditions. Mill recovery efficiences were based on averages for typical wood flow through a pulpmill in the South. Actual recovery levels would depend on the tree size and type of processing equipment.

The analysis was completed for a slash pine (*Pinus elliottii*) plantation, located in the coastal plains of the Southeastern United States. The stand was clear-cut at age 21, and all the trees were utilized as pulpwood.

Stand volume per hectare on a weight basis was estimated by diameter class using whole-tree (aboveground biomass) weight equations (Reams and others 1982). As the wood went through each harvesting and mill process, the products were determined for each function as a percentage of whole-tree biomass. This analysis resulted in an evaluation of the amount of tree components recovered as fiber for pulp and as residues suitable for boiler fuel.

TREE-LENGTH HARVESTING--MILL PROCESSING

A product flow diagram for tree-length harvesting is shown in Figure 1. In our analysis, it was assumed that the trees were gate-delimbed. For plantation slash pine, the delimbing process left 10.1 percent of the whole tree in the forest as residues. The remaining 89.9 percent of the wood, in the form of tree-length product, was hauled to the mill.

At the mill, the tree-length wood was slashed and drum debarked. Recovery efficiencies were based on the assumption of no loss from hauling or handling at the mill. Ninety percent of the tree-length product was converted to debarked shortwood that was fed into the chipper at the mill (Flathmann 1988). At this point, almost 81 percent of the whole tree should have been processed through the slasher and drum, ending up at the chipper. Ten percent of the stem (9.0 percent of the whole tree) was recovered as drum residue. This material was mostly bark, but contained wood fibers and tops of the stems and required additional processing.

After going through the chipper, the chips will have a bark content of less than 1 percent -- usually less than 0.5 percent. Chips.used in pulp processing are required to be uniform in size and free from contaminants (Berlyn and Simpson 1988). These requirements are met by controlling length of time in the drum, maintaining chipping quality, and using a series of screening processes.

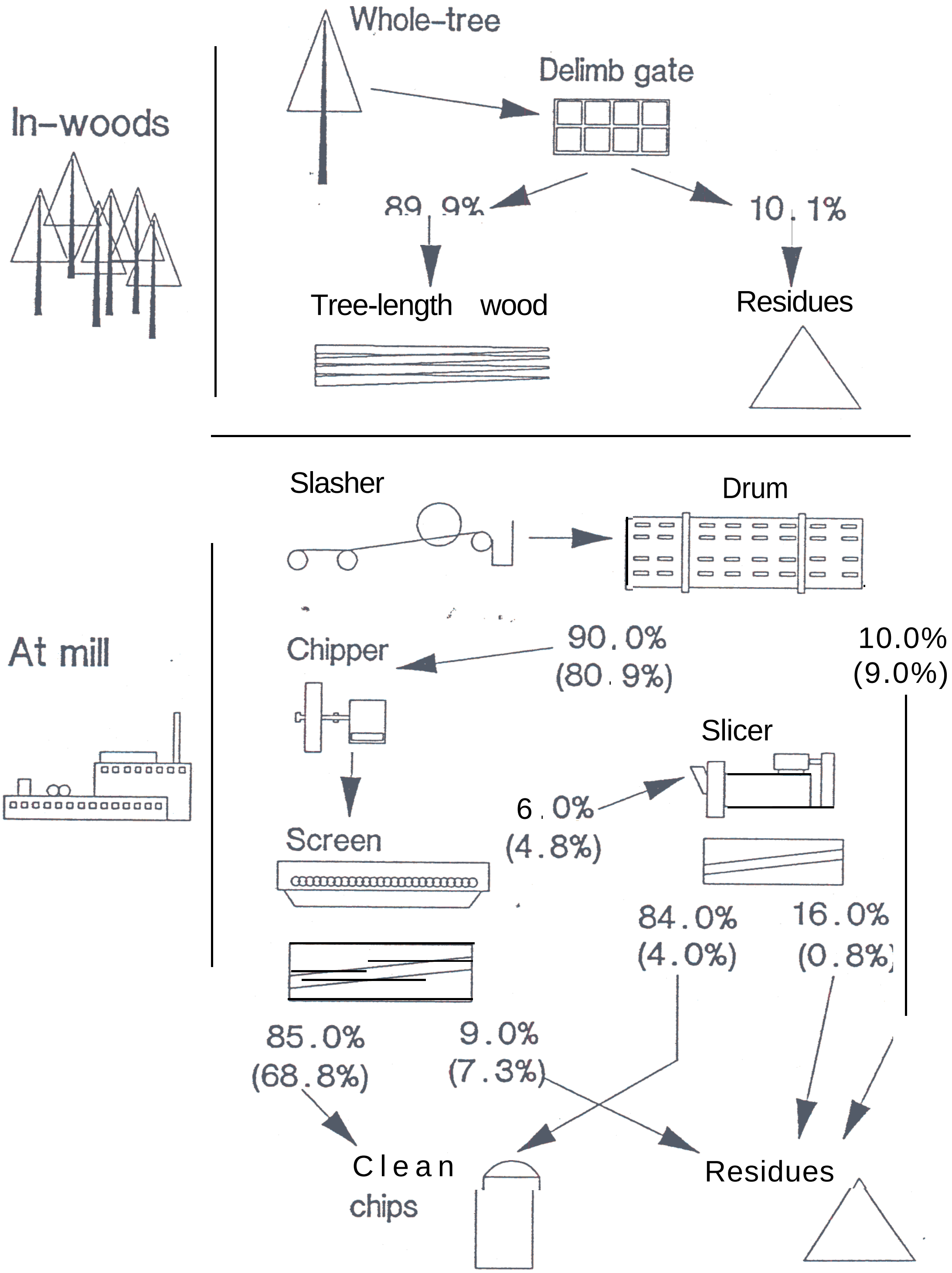

Figure 1 . Product flow--tree-length option (value in parentheses represents percentage of whole tree).

Screening removed the over-sized ("overs") and under-sized 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 (Hoff 1988). Acceptable chips are 7 mm or greater in length and width after the overs have been removed ("pin" chips are less than 7 mm, but greater than 3 mm, while "fines" are less than 3 mm).

The screening process recovered 68.8 percent of the whole tree as acceptable chips, ready for the digester. Nine percent of the flow that went through the screens ended up as mill residue. This was 7.3 percent of the whole tree. Residues at the mill are usually used in the boiler.

In our analysis it was assumed that the over-sized chips would be sent to a slicer for further reduction. This process would recover 84 percent of its wood flow as acceptable chips. After slicing and rescreening, an additional 4.0 percent of the whole tree would be recovered as clean chips.

FLAIL/CHIP HARVESTING--MILL PROCESSING

Although not a new concept, flail delimbing and debarking has recently emerged as a feasible harvesting technology, and several flail machines are available on the market. The principle is to use chains attached to revolving drums, either horizontal or vertical, to strike the stems and remove the limbs and bark.

For our analysis, recovery efficiencies were based on a field study using a Peterson Pacific[1] model 4800 log debarker and Morbark model 22 chipper (Stokes and Watson 1988). The whole tree was first fed into the flail and then fed into the chipper (Fig. 2). Three products resulted from the combined flail/chip process: flail residues, chipper rejects, and chips. The flail residues, characterized as limbs, tops, foliage, and bark, accounted for 14.7 percent of the whole-tree biomass. Chipper rejects from the chipper separator accounted for 3.2 percent of the whole tree. Chips, the remaining 82.1 percent, went into the chip van and were transported to the mill.

At the mill, the same processes were used as in the tree-length option. However, the screening percentages changed because the chip characteristics of chips produced at a mill are different from those produced by a field chipper. With the assumption of no loss for handling, 89.3 percent of the screened chips were acceptable. This was 73.3 percent of the whole-tree biomass. An additional 2.9 percent of the whole tree was recovered as clean chips after slicing and rescreening. The bark content of clean chips produced with the flail/chipper usually averaged less than 2 percent, often less than 1.5 percent. The bark content depends on the flailing quality, tree size, and screening process.

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

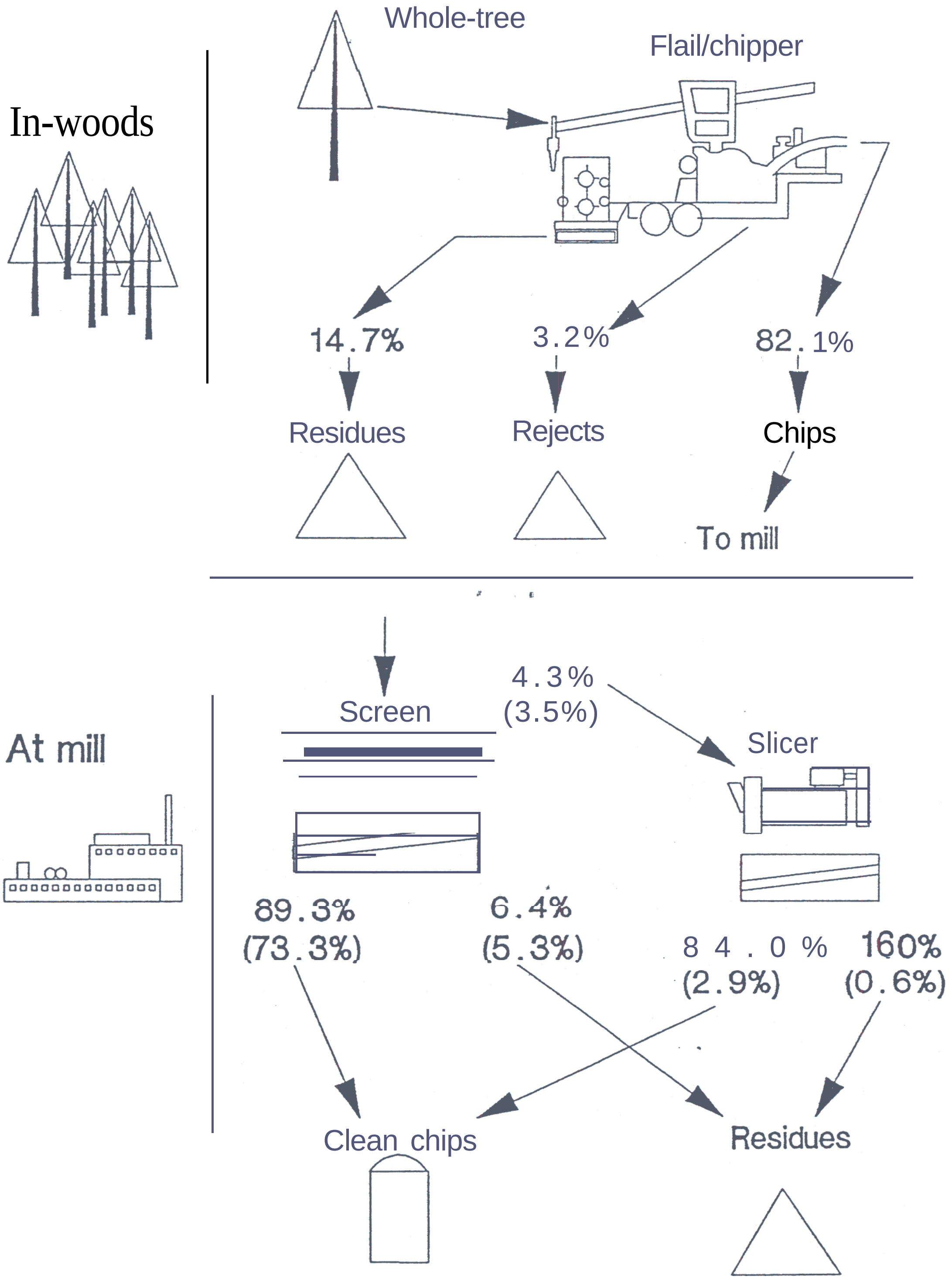

Figure 2. Product flow--in-woods flail/chip option (value in parentheses represents percentage of whole tree).

Initial screening diverted 5.3 percent of the tree to the residue pile. From the slicer and rescreen process, another 0.6 percent of the tree ended up as mill residues.

RESULTS

The three products, clean chips, mill residues, and forest residues, are summarized as whole tree percentages in Table 1. The flail/chip option recovered the highest percentage of clean chips, 3.4 percent more with the flail/chip method than the tree-length method. Over three times more mill residues were generated from tree-length wood (mill residues are usable as energywood at a minimal cost for transport and handling). Over 17 percent of the tree was usable as mill residues for energywood from the tree-length option. Even the flail/chip method produced 5.8 percent of the whole tree as mill residues.

All the forest residuals from tree-length harvesting were in the form of limbs, tops, and foliage. Over 10 percent of the tree remained in the forest as piles of slash and debris. Because this residue is bulky and spread,out over the site, it is usually considered uneconomical to recover. For the flail/chip option, it is often feasible and economical to recover the 14.7 percent of the tree ejected from the-flail delimber-debarker. However, this material may need further processing before it is usable. In some instances it may be impractical to recover chipper rejects.

The stand used in our analysis had 201.2 green tonnes of standing biomass per hectare (Table 2). Whole trees were defined as all tree components (including foliage) except the stump. Average tree d.b.h. was 17.5 cm, and average total height was 15.9 m.

When the stand was harvested using the tree-length method, 180.5 green tonnes per hectare were removed as wood and bark and taken to the mill (Table 3). Over 20 tonnes per hectare remained on site as delimbing slash. At the mill, another 18.4 tonnes, were removed as slasher and drum residues. At this point, 162.4 green tonnes of chips per hectare had been recovered.

After screening, the stand had produced over 138 green tonnes of acceptable chips per hectare (Table 4). An additional 8.1 tonnes were recovered from the slicing and rescreening process for a total recovery of 146.5 green tonnes of chips for pulp fiber per hectare.

Almost 165 tonnes per hectare of chips were produced by the flail/chip option (Table 5). This method left 36.1 tonnes per hectare in the form of flail residues and chipper rejects. At the mill (Table 6), 153.1 tonnes per hectare were recovered as clean chips.

A direct comparison of the two harvesting methods is shown in Table 7. The flail/chip option recovered an additional 6.6 green tonnes of acceptable chips per hectare compared to the tree-length method. The tree-length method had 34.1 tonnes per hectare in mill residues while the flail/chip option produced 11.9 tonnes per hectare. As a result of

Table 1. Summary of products by process and harvest method.

Product/process	Harvest method	
	Tree-length	Flail/chip
	-- percent of whole-tree --	
Clean chips		
First screening	68.8	73.3
Slice overs/rescreen	4.0	2.9
Total	72.8	76.2
Mill residues		
Drum debarker	9.0	-
First screening	7.3	5.3
Slice overs/rescreen	0.8	0 6
Total	17.1	5.9
Forest residues		
Gate delimb	10.1	
Flail delimb/debark		14.7
Chipper rejects	-	3.2
Total	10.1	17.9
Total	100.0	100.0

Table 2. Composition of representative slash pine plantation.

DBH class	Total height	Harvested trees	Whole-tree[1]	Stem: Wood only	Stem: Bark only	Stem: 5-cm top wood & bark
cm (in)	m (ft)	no./ha (no./acre)	---- green tonnes/ha ---- (green tons/acre)			
10 (4)	10 (32)	161 (65)	6.5 (2.9)	4.5 (2.0)	1.1 (0.5)	5.4 (2.4)
13 (5)	14 (46)	230 (93)	20.6 (9.2)	14.8 (6.6)	2.7 (1.2)	17.2 (7.7)
15 (6)	16 (54)	299 (121)	44.8 (20.0)	32.5 (14.5)	5.6 (2.5)	37.8 (16.9)
18 (7)	18 (58)	249 (101)	54.6 (24.4)	39.6 (17.7)	6.5 (2.9)	46.1 (20.6)
20 (8)	19 (62)	143 (58)	43.7 (19.5)	31.8 (14.2)	5.2 (2.3)	37.0 (16.5)
23 (9)	20 (65)	57 (23)	23.1 (10.3)	16.8 (7.5)	2.7 (1.2)	19.2 (8.6)
25 (10)	20 (65)	12 (5)	6.3 (2.8)	4.5 (2.0)	0.7 (0.3)	5.2 (2.3)
28 (11)	21 (70)	2 (1)	1.6 (0.7)	1.1 (0.5)	0.2 (0.1)	1.3 (0.6)
Total		1,153 (467)	201.2 (89.8)	145.6 (65.0)	24.7 (11.0)	169.2 (75.6)

[1] Includes foliage.

Note: Weight equations are from Reams and others 1982.

Table 3. Tree-length slash pine recovery efficiencies: stump to drum.

DBH class	Whole-tree[1]	Gate delimb: Tree-length (wood & bark)	Gate delimb: Residues	Slasher/Drum: Clean wood	Slasher/Drum: Residues
cm (in)	green tonnes/ha (green tons/acre)				
10 (4)	6.5 (2.9)	5.8 (2.6)	0.7 (0.3)	5.2 (2.3)	0.7 (0.3)
13 (5)	20.6 (9.2)	18.4 (8.2)	2.0 (0.9)	16.6 (7.4)	1.8 (0.8)
15 (6)	44.8 (20.0)	40.3 (18.0)	4.5 (2.0)	36.3 (16.2)	4.0 (1.8)
18 (7)	54.6 (24.4)	49.0 (21.9)	5.6 (2.5)	44.1 (19.7)	4.9 (2.2)
20 (8)	43.7 (19.5)	39.4 (17.6)	4.5 (2.0)	35.4 (15.8)	4.0 (1.8)
23 (9)	23.1 (10.3)	20.6 (9.2)	2.2 (1.0)	18.6 (8.3)	2.0 (0.9)
25 (10)	6.3 (2.8)	5.6 (2.5)	0.7 (0.3)	4.9 (2.2)	0.7 (0.3)
28 (11)	1.6 (0.7)	1.3 (0.6)	0.2 (0.1)	1.3 (0.6)	0.2 (0.1)
Total	201.2 (89.8)	180.5 (80.6)	20.4 (9.1)	162.4 (72.5)	18.4 (8.2)

[1] Includes foliage.

Table 4. Tree-length slash pine recovery efficiencies: chipper to pile.

DBH class	Whole-tree[1]	Acceptable chips: First screen	Acceptable chips: Over sliced/rescreened	Acceptable chips: Total	Pins'	Fines
cm (in)	------------- green tonnes per hectare (green tons per acre)					--------------
10 (4)	6.5 (2.9)	4.5 (2.0)	0.2 (0.1)	4.7 (2.1)	0.4 (0.2)	0.2 (0.1)
13 (5)	20.6 (9.2)	14.1 (6.3)	0.9 (0.4)	15.0 (6-7)	1.3 (0.6)	0.4 (0.2)
15 (6)	44.8 (20.0)	30.9 (13.8)	1.8 (0.8)	32.7 (14.6)	2.9 (1.3)	0.9 (0.4)
18 (7)	54.6 (24.4)	37.6 (16.8)	2.2 (1.0)	39.9 (17.8)	3.4 (1.5)	0.9 (0.4)
20 (8)	43.7 (19.5)	30.0 (13.4)	1.8 (0.8)	31.8 (14.2)	2.7 (1.2)	0.7 (0.3)
23 (9)	23.1 (10.3)	15.9 (7-1)	0.9 (0.4)	16.8 (7.5)	1.3 (0.6)	0.4 (0.2)
25 (10)	6.3 (2.8)	4.2 (1.9)	0.2 (0.1)	4.5 (2.0)	0.4 (0.2)	0.1 (0.0)
28 (11)	1.6 (0.7)	1.1 (0.5)	0.1 (0.0)	1.1 (0.5)	0.2 (0.1)	0.0 (0.0)
Total	201.2 (89.8)	138.4 (61.8)	8.1 (3.6)	146.5 (65.4)	12.8 (5.7)	3.6 (1.6)
Percentage of whole-tree	100.0	68.8	4-o	72.8	6.3	1.8

[1] Includes foliage.

Table 5. Flail/chip slash pine recovery efficiencies: stump to mill.

DBH class	Whole-tree[1]	Residues (crown & bark)	Chipper rejects	Chips
cm (in)	---------- green tonnes per hectare ---------- (green tons per acre)			
10 (4)	6.5 (2.9)	0.9 (0.4)	0.2 (0.1)	5.4 (2.4)
13 (5)	20.6 (9.2)	3.1 (1.4)	0.7 (0.3)	16.8 (7.5)
15 (6)	44.8 (20.0)	6.5 (2.9)	1.3 (0.6)	36.7 (16.4)
18 (7)	54.6 (24.4)	8.1 (3.6)	1.8 (0.8)	44.8 (20.0)
20 (8)	43.7 (19.5)	6.5 (2.9)	1.3 (0.6)	35.8 (16.0)
23 (9)	23.1 (10.3)	3.4 (1.5)	0.7 (0.3)	18.8 (8.4)
25 (10)	6.3 (2.8)	0.9 (0.4)	0.2 (0.1)	5.2 (2.3)
28 (11)	1.6 (0.7)	0.2 (0.1)	0.1 (0.1)	1.3 (0.6)
Total	201.2 (89.7)	29.6 (13.2)	6.5 (2.9)	164.9 (73.6)
Percentage of whole-tree	100.00	14.7	3.2	82.1

1 Includes foliage.

Table 6. Flail/chip slash pine recovery efficiencies: chipper to pile.

DBH class	Whole-tree[1]	Acceptable chips: First screen	Acceptable chips: Overs sliced rescreened	Acceptable chips: Total	Pins	Fines
cm (in)	green tonnes per hectare (green tons per acre)					
10 (4)	6.5 (2.9)	4.7 (2.1)	0.2 (0.1)	4.9 (2.2)	0.2 (0.1)	0.1 (0.1)
13 (5)	20.6 (9.2)	15.0 (6.7)	0.7 (0.3)	15.7 (7.0)	0.9 (0.4)	0.4 (0.2)
15 (6)	44.8 (20.0)	32.9 (14.7)	1.3 (0.6)	34.3 (15.3)	1.8 (0.8)	0.9 (0.4)
18 (7)	54.6 (24.4)	40.1 (17.91	1.6 (0.7)	41.6 (18.6)	2.2 (1.0)	0.9 (0.4)
20 (8)	43.7 (19.5)	32.0 (14.3)	1.3 (0.6)	33.4 (14.9)	1.8 (0.8)	0.7 (0.3)
23 (9)	23.1 (10.3)	16.8 (7.5)	0.7 (0.3)	17.5 (7.8)	0.9 (0.4)	0.4 (0.2)
25 (10)	6.3 (2.8)	4.5 (2.0)	0.2 (0.1)	4.7 (2.1)	0.2 (0.1)	0.1 (0.0)
28 (11)	1.6 (0.7)	1.1 (0.5)	0.2 (0.1)	1.3 (0.6)	0.1 (0.0)	0.0 (0.0)
Total	201.2 (89.7)	147.3 (65.8)	5.8 (2.6)	153.1 (68.4)	8.3 (3.6)	3.6 (1.6)
Percentage of whole-tree	100.0	73.3	2.9	76.2	4.1	1.8

[1] Includes foliage.

Table 7. Summary of slash pine stand recovery by harvesting method.

DBH class	Whole-tree[1]	Clean chips: Tree-length	Clean chips: Flail/chip	Mill residues: Tree-length	Mill residues: Flail/chip	Forest residues: Tree-length	Forest residues: Flail/chip
cm (in)	green tonnes per hectare (green tons per acre)						
10 (4)	6.5 (2.9)	4.7 (2.1)	4.9 (2.2)	1.1 (0.5)	0.3 (0.2)	0.7 (0.3)	1.1 (0.5)
13 (5)	20.6 (9-2)	15-o (6.7)	15.7 (7.0)	3.6 (1.6)	1.3 (0.6)	2.0 (0.9)	3.6 (1.6)
15 (6)	44.8 (20.0)	32.7 (14.6)	34.3 (15.3)	7.6 (3.4)	2.7 (1.2)	4.5 (2.0)	8.1 (3.6)
18 (7)	54.6 (24.4)	39.9 (17.8)	41.6 (18.6)	9.4 (4.2)	3.1 (1.4)	5.6 (2.5)	9.8 (4.4)
20 (8)	43.7 (19.5)	31.8 (14.2)	33.4 (14.9)	7.4 (3.3)	2.5 (1.1)	4.5 (2.0)	7.8 (3.5)
23 (9)	23.1 (10.3)	16.8 (7.5)	17.5 (7.8)	4.0 (1.8)	1.3 (0.6)	2.2 (1.0)	4.0 (1.8)
25 (10)	6.3 (2.8)	4.5 (2.0)	4.7 (2.1)	1.1 (0.5)	0.2 (0.1)	0.7 (0.3)	1.1 (0.5)
28 (11)	1.6 (0.7)	1.1 (0.5)	1.3 (0.6)	0.2 (0.1)	0.1 (0.0)	0.2 (0.1)	0.2 (0.1)
Total	201.2 (89.7)	146.5 (65.4)	153.1 (68.4)	34.1 (15.2)	11.9 (5.3)	20.4 (9.1)	35.8 (16.0)

[1] Includes foliage.

APPENDIX

Summary of percentages for in-woods processing[1].

Item	No. of obs.	Mean	Std. dev.	Range
		---- percent of whole tree ---		
Delimbing loss[2]	10	10.1	4.1	4.2 - 18.9
Flail components[3]				
Residues	8	14.7	1.0	13.5 - 16.1
Rejects (chipper separator)	8	3.2	0.6	2.5 - 4.2
Chips	8	82.1	1.2	80.1 - 83.5

1 Stokes, B. J. and W. F. Watson. 1988. In-house final report - evaluation of Peterson Pacific flail log maker. USDA Forest Service, Southern Forest Experiment Station, Auburn, Al.

2 Weights were taken on bundles of whole trees before and after iron gate delimbing.

3 Bundles of whole trees were weighed before entering horizonal, double-drum flail (Peterson Pacific) and Morbark Model 22 chipper with integral dirt separator. All residues from flail and rejects from chipper were collected and weighed. These components were subtracted from the whole tree weights to determine the weight of the chips.

processing in the woods with the flail/chipper, 35.8 tonnes per hectare of residues were left on the site. The tree-length method produced 20.4 tonnes per hectare of limbs and tops.

CONCLUSIONS AND DISCUSSION

The analysis showed that 72.8 percent of the whole-tree biomass was recovered as clean chips from the tree-length harvesting and 76.2 percent was recovered as acceptable pulp chips from the flail/chip option. A higher percentage of the total biomass was diverted to residues in the delimbing and debarking process for tree-length compared with the delimbing and debarking process for the flail/chip method (19.1 vs. 17.9 percent). More acceptable chips were recovered from the flail/chip option, primarily due to the chip quality.

For the slash pine plantation, an additional 6.6 tonnes of acceptable chips per hectare were recovered with the flail/chip alternative. Of the forest residues produced with the flail/chip method, 29.6 tonnes per hectare may be economically recovered, whereas the tree-length method produced 20.4 tonnes per hectare of residues that may not be economically recovered due to being bulky and spread over the site.

Each method has certain advantages over the other. The flail/chip alternative allows more economical handling of small trees such as from stand thinnings. Chips are more economical to handle and haul than small short stems. Besides the increased utilization and product recovery, the' flail/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.

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