Ecological Technologies for Small-Diameter Tree Harvesting

Bryce J. Stokes
John F. Klepac

Abstract

Production, costs, and merchantable chip recovery values were developed for a tree-length, flail/chip, and cut-to-length system. The systems were evaluated for three representative stands: early thinning, late thinning, and a clearcut. A sensitivity analysis was completed for the three systems over a range of tree diameters. Recovery was affected by stand type and by system. Tree-length wood had the least cost to the digester and cut-to-length wood had the highest cost. All systems were sensitive to tree diameter.

Introduction

The southern United States is becoming the "wood basket" of the nation. Although growing volumes are continuously increasing for the South, so is the harvest volume (Figs. 1 and 2). With greater demand on the resource, as expected, the trees are harvested earlier and the average harvested tree size is decreasing (Fig. 3). Like several other regions of the nation, the South has a high number of trees in the smaller diameter classes. For many decades, the cut diameters have been relatively small in the South and this problem has been faced often, if not continuously.

Harvesting costs are inversely proportional to tree size: small-diameter trees result in small piece sizes with low volumes and are more costly to handle. Individual harvesting function and system productivities are a function of many stand and site parameters, but are most sensitive to tree

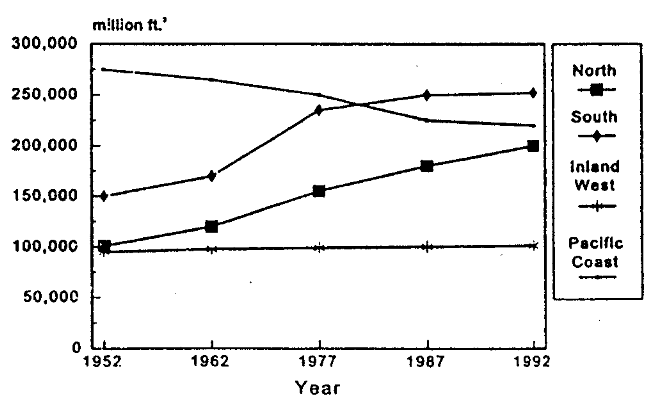

Figure 1.—Tree volume change by region from 1952 to 1992.

Stokes:
Project Leader, USDA Forest Serv., Southern Res. Sta., Auburn, Alabama
Klepac:
Research Support Engineer, USDA Forest Serv., Southern Res. Sta., Auburn, Alabama

size. Utilization and recovery also affect harvest costs, as well as product values. Recovery of more merchantable volumes or higher valued products per unit area help to reduce harvest costs or allow higher cut and haul costs to still be profitable. Finally, reimbursements and credits can also be used to make harvest costs affordable. Some examples are incentives for good ecological performance, value added from thinning, energywood produced as a by-product, etc.

This paper only addresses harvest system production and cost as affected by tree size and by recovery. Three typical systems were evaluated for a range of stand conditions (i.e., tree size as a function of stand type and structure, for early and late thinning, and clearcut operations). A spreadsheet simulation was used to evaluate the systems. A sensitivity analysis was completed for the three systems over a range of tree diameters.

Harvest systems

The most prevalent harvest system in the South is the tree-length system. Highly productive feller-bunchers are used to fell, collect, and bunch many small stems into piles. Since residual stand quality is a major concern in thinnings, smaller machines are usually used to make the selective cuts. A larger machine may be used to cut rows or corridors and if the stand density is significantly reduced may be used to perform the selective cutting. Some operators are using swing feller-bunchers on tracks to reduce residual soil and stem damage. The trees are delimbed and topped in the woods either using a chainsaw or delimbing gate with chainsaws at the deck. Grapple skidders are used to extract the trees and the stems are usually loaded tree-length onto trailers. Current modifications to these systems include the addition of mechanical processors and slashers. In thinnings, the boles may be slashed into shorter lengths at the deck to increase highway payloads.

The second selected system is the flail/chip system; a variation of the tree-length system where full trees are skidded to the deck and processed with a flail delimber/debarker and then chipped. This process makes it feasible to produce clean, acceptable chips (7,8). In-woods processing of whole trees has several advantages over tree-length operations. Flail processing and chipping is 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 for a larger portion of the whole tree and the smaller diameter stand components. A disadvantage is the high-capital investment and restricted product.

Forwarders and cut-to-length systems are becoming more widely used today, especially in thinnings. Harvesters are used for felling and processing at the stump. The harvester/forwarder system can potentially reduce residual site and stand damage, can work with less roads and landings, and require fewer workers. Such systems can improve value recovery when using computer sys-

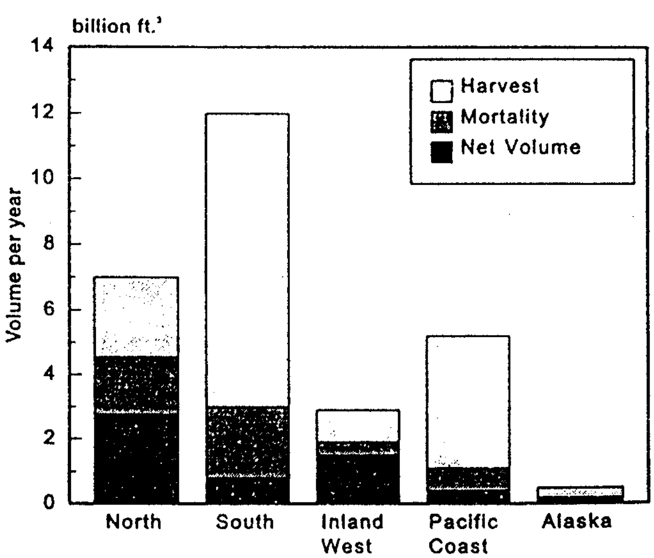

Figure 2.—Harvest, mortality, and volume increase by region.

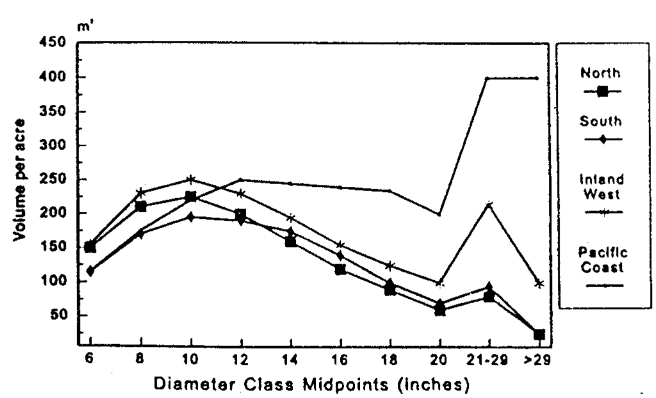

Figure 3.—Tree size distribution in each region.

tems for processing. However, the harvester/forwarder system has a high capital cost and such systems are limited to markets that accept such wood lengths. To reduce costs in early thinnings, options include the use of feller-bunchers and processors to get away from single-stem processing. Drive-to-tree harvesters are being marketed at less capital cost.

Stand descriptions

Three loblolly (*Pinus taeda*) stands were selected as typical pine plantations to analyze the productivity and cost of the three selected systems. Table 1 summarizes the composition of the representative stands used for a range of structure and removal levels. The stand information was only for pine trees 5 inches diameter at breast height (dbh) and larger; these were considered merchantable. The 13- to 15-year-old stand, as an early thinning, had an initial basal area of 82 ft.^{2}/acre and a removal of 32 ft.^{2}/acre. The 16- to 18-year-old stand was considered to be a late thinning and had an initial basal area of 93 ft.^{2}/acre. A total of 33 ft.^{2}/acre were removed. In the thinnings, every fifth row was harvested and the rest were removed by selection. The clearcut stand had 100 ft.^{2}/acre harvested. Merchantable tons per acre was calculated to a 4-inch top.

Utilization

A study was conducted at a local pulpmill in Alabama to estimate the recovery and utilization for the three representative stands. Five tree-length truckloads of loblolly plantation pine were processed through a tree-length (longwood) drum debarker to determine merchantable chip recovery. Additional laboratory work was completed to determine chip quality and size distribution. The same procedure was used to determine the recovery of cut-to-length wood. Four loads of random length wood were processed on the same longwood yard as the tree-length wood was processed. One load of the cut-to-length wood was processed at a shortwood drum, after being slashed into 5-foot lengths.

The authors have completed several studies on the recovery of loblolly pine plantation wood using a flail delimber/debarker and chipper (2,7, 10–12). This published information concerning the recovery of products from flail/chipper was used in this analysis.

The wood flow and utilization of various harvesting products are shown in Figures 4 to 7. The wood flow recovery for the tree-length and cut-to-length are for the roundwood delivered to the mill, drum debarked, chipped, and screened for merchantable chips to the digester. The wood

Table 1.–Stands used for harvesting cost analysis.

Stand	Initial				Harvested			
	Diameter at breast height	Trees per acre	Basal area	Tons per acre	Diameter at breast height	Trees per acre	Basal area	Tons per acre
	(in.)		(ft.^{2}/acre)	(tons)	(in.)		(ft.^{2}/acre)	(tons)
Thinning (13 to 15 years)	7.2	277	82	43	6.3	129	32	15
Thinning (16 to 18 years)	7.6	279	93	53	6.8	124	33	18
Clearcut (23 years)	8.1	263	100	61	8.1	263	100	61

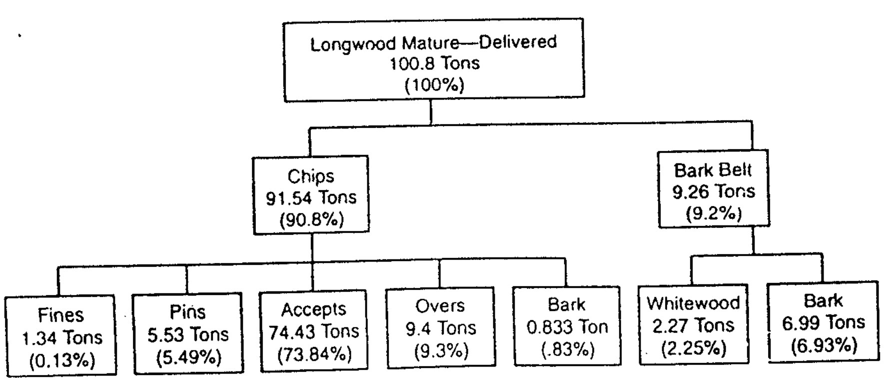

Figure 4.–Utilization of tree-length wood processed through a tree-length drum debarker.

flow for the chips produced in-woods with the flail/chipper includes the whole tree converted to chips and then screened for merchantable chips to the digester.

Almost 91 percent of the delivered tree-length wood resulted in chips (Fig. 4). Nearly 73.8 percent of these chips met acceptable size requirements after screening. When the cut-to-length wood was slashed and processed through the shortwood drum, almost 92 percent of the roundwood was converted into chips (Fig. 5). The percentage of acceptable chips was 75.9. When the cut-to-length wood was processed through the longwood drum without slashing, there was a lot of breakage that resulted in 89.9 percent of the delivered wood resulting in chips. When screened, these chips produced many overs and resulted in only 68.4 percent of the chips grading as acceptable (Fig. 6).

Figure 7 illustrates the wood flow and recovery for the flail/chip process. Over 60 percent of the whole tree that goes through the flail goes to the chip van. When screened at the mill, recovery of acceptable chips is 82.1 percent.

Mills handle the overs in many ways, and for this simplistic analysis overs were added to the accepts. These recovery percentages for the three harvesting systems (cut-to-length had two processing options) were used to convert the stand data into clean, acceptable chips to the digester (Table 2). These recovery figures should be used with caution since they are based on a small sampling. Also, the problem of breakage associated with processing cut-to-length wood in a longwood drum may only be associated with the test mill. The flail/chip system had less recovery than the other methods. The flail does not improve recovery of tree components, but smaller diameter trees can be recovered. In this analysis, we used the same stand table for all systems and did not account for potential stand recovery improvement with the flail.

Results

Productivity and cost of the various functions of the selected systems were developed using production and cost information from published sources (3,4,6–8,10,11). Comparisons between systems were made with the use of a spreadsheet

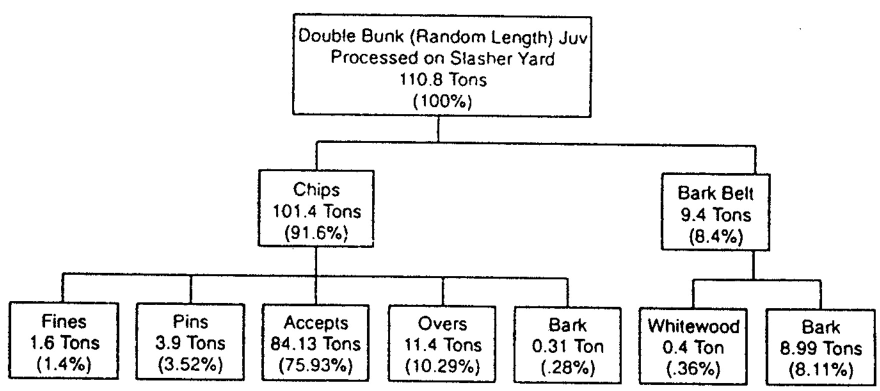

Figure 5.—Utilization of cut-to-length wood slashed to 5-foot lengths and processed through a shortwood drum debarker.

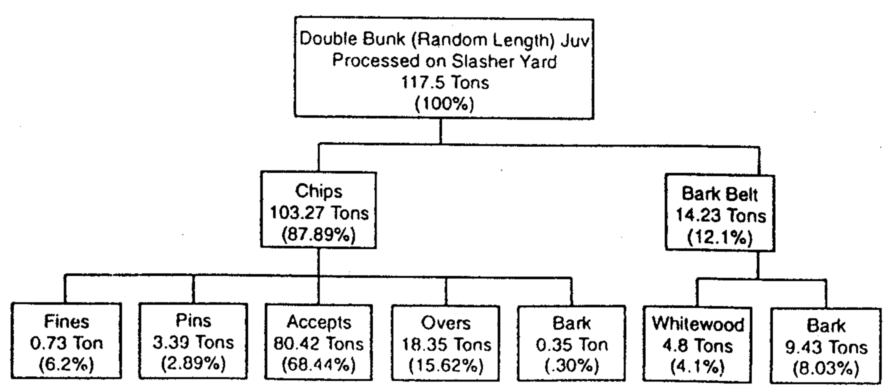

Figure 6.—Utilization of cut-to-length wood processed through a tree-length drum debarker.

template based on the Auburn Analyzer (9) and modified by Stokes (6). The comparison simulated the various systems operating on a typical stand receiving a first thinning, using a fifth-row with selective cutting method. The spreadsheet was used to estimate the productivity of the various components and the system as a whole working in this stand. The cost of the components and the system cost were estimated using machine rates.

Machine productivity in tons per scheduled machine hour, along with fixed, operating, labor, and total costs per scheduled machine hour are summarized in Table 3. These costs do not include crew transport, support equipment and tools, profit, etc. They are not absolute and are only useful for making relative comparisons.

The tree-length wood was delivered on tree-length trailers. The cut-to-length wood, 14 to 20 feet in length, was delivered as double bunked wood. The assumed haul cost for this wood was $5.44 per ton for a 30-mile haul distance. An assumed haul cost for the chips was $6.01 per ton. Chip haul cost was assumed higher because of extra unloading time and capital for chip vans.

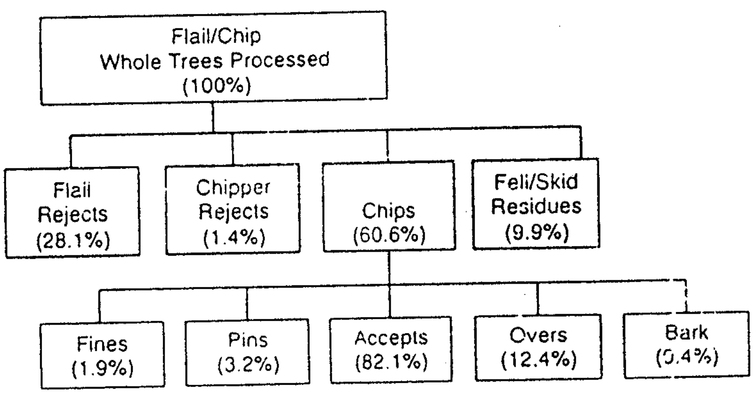

Figure 7.—Utilization of whole trees processed through a flail delimber/debarker and chipper.

Table 2.—Recovery of representative stands.

	Thinning (13 to 15 years)				Thinning (16 to 18 years)				Clearcut (23 years)			
	Cut-to-length		Tree length	Flail/ chipper	Cut-to-length		Tree length	Flail/ chipper	Cut-to-length		Tree length	Flail/ chipper
	5-foot	NS[a]			5-foot	NS[a]			5-foot	NS[a]		
	(tons/acre)											
Delivered chips	15.4	15.4	15.4	13.3	17.7	17.7	17.7	15.2	61.4	61.4	61.4	50.0
Residuals at mill	2.5	2.5	2.6	0.8	2.8	2.8	3.0	0.9	9.8	10.4	14.4	3.0
Merchantable chips	12.9	12.9	12.8	12.5	14.9	14.9	14.7	14.3	51.6	51.0	47.0	47.2

[a] NS means that the cut-to-length was not slashed and was processed in a tree-length drum.

Table 3.—Equipment production and cost summary.

Machine	Tons per scheduled machine hour	Cost per scheduled machine hour: Fixed	Operating	Labor	Total
	(tons)	($)			
Valmet 503B FB	18	15	10	13.5	39
Hydro-AZ 411B FB	26	22	14	13.5	50
TJ 450C Skidder	30	18	9	13.5	41
Peterson 5000 Flail/Chipper	50	54	40	13.5	108
Prentice Loader	49	10	6	13.5	30
CTR Processor	49	4	1	--	5
Franklin 3000 Harvester	16	21	12	13.5	47
Valmet 546 Forwarder	13	23	14	13.5	51

Table 4.—Systems production and cost summary.

Stand	System	Tons per scheduled machine hour	Cost per scheduled machine hour	Cost per ton: To roadside	Cost per ton: Delivered	Cost per ton: Merchandizable chips[a]
		(tons)	($)			
Thinning (13 to 15 years)	Cut-to-length	12.9	99	7.67	13.11	15.65
	Tree-length	48.0	231	4.83	10.27	12.36
	Flail/chip	48.0	302	6.30	12.31	13.03
Thinning (16 to 18 years)	Cut-to-length	13.3	98	7.39	12.83	15.24
	Tree-length	48.8	227	4.66	10.10	12.16
	Flail/chip	50.0	300	6.01	12.02	12.72
Clearcut (23 years)	Cut-to-length	13.2	95	7.21	12.65	15.05
	Tree-length	48.8	214	4.39	9.83	11.83
	Flail/chip	50.0	287	5.75	11.76	12.44

[a] Does not include drum debarking, handling, and screening costs at mill (i.e., harvesting and transport cost of chips to digester).

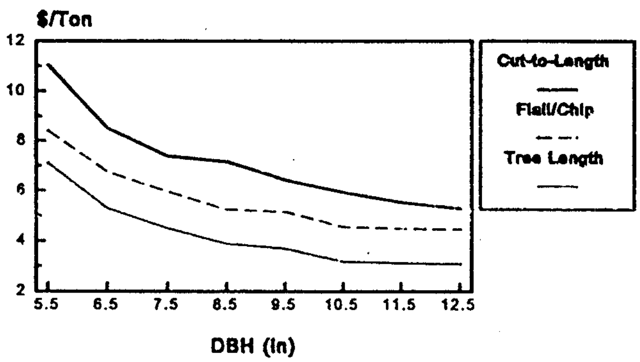

Figure 8.—Sensitivity of selected systems for 13- to 15-year-old pine thinnings.

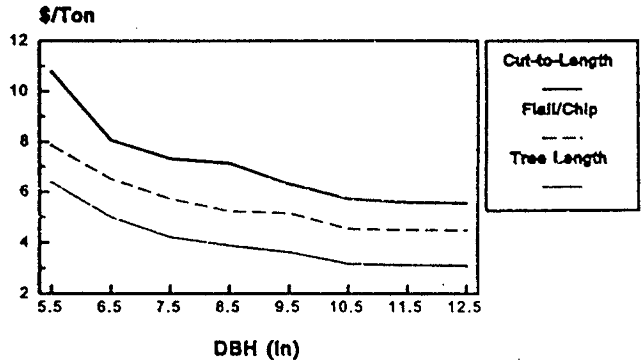

Figure 9.—Sensitivity of selected systems for 16- to 18-year-old pine thinnings.

A systems analysis was completed and the summary is shown in Table 4. The systems were balanced so that all functions had comparable production. The tree-length systems had three feller-bunchers and two skidders for the 13- to 15-year-old and 16- to 18-year-old thinned stands. Two feller-bunchers and two skidders were used for the 23-year-old clearcut stand. The cut-to-length systems were balanced with one harvester and one forwarder. The flail/chipper systems had three feller-bunchers and two skidders for the 13- to 15-year-old and 16- to 18-year-old thinned stands. Two feller-bunchers and two skidders were used for the 23-year-old clearcut stand. The tree-length system was slightly less costly than the flail/chip system in all stands. The cut-to-length system was the most costly.

A sensitivity analysis was completed on the three systems as a function of tree diameter for the three stands (Figs. 8–10). The trend was the same: tree-length was the least expensive and cut-to-length was the most expensive over the range of tree sizes. The costs were determined by extrapolating the production functions beyond their input values and are only useful for looking at the

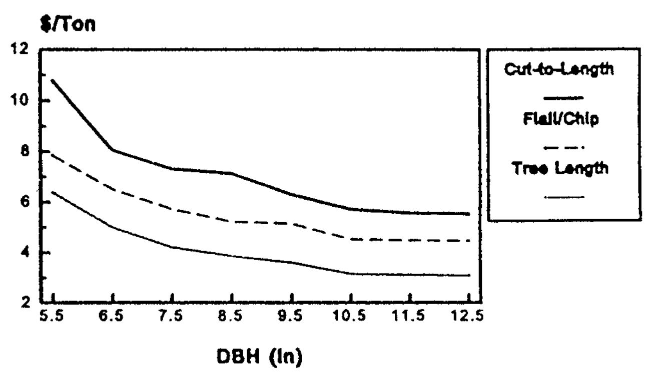

Figure 10.—Sensitivity of selected systems for 23-year-old clearcut.

trends. A more detailed analysis is needed to determine how efficient these systems operate at a wider range of tree diameters.

As tree size decreases, new and innovative techniques are being developed to handle larger numbers of small stems. Harvest costs are affected by tree size and utilization. In the future, there will be concern on improving product value, recovering more higher valued products, and providing credits and incentives for performing specific treatments.

Literature cited

1. Congressional Report. 1997. Report on forest health of the United States by the forest health science panel. Center for Int'l. Trade in Forest Prod., Univ. of Washington, College of Forest Resources, Seattle, Wash.
2. Flowers, R.K., W.F. Watson, B.K. Wharton, M.L. Belli, and B.J. Stokes. 1992. Utilization and yield of chips from loblolly pine in central Arkansas. *In:* Proc. 1992 TAPPI Pulping Conf. TAPPI Press, Atlanta Ga. Book 2, pp. 467–471.
3. Holtzscher, M.A. 1995. Cut-to-length logging: a comparison of thinning systems. M.S. thesis. School of Forestry, Auburn Univ. 167 pp.
4. Lanford, B.L. and B.J. Stokes. 1996. Comparison of two thinning systems. Part II. Productivity and Costs. Forest Prod. J. 46(11/12):45-53.
5. Miyata, E.S. 1980. Determining fixed and operating costs of logging equipment. Gen. Rept. NC-55. USDA Forest Serv., Northcentral Forest Expt. Sta., St. Paul, Minn. 16 pp.
6. Stokes, B.J. 1987. Harvesting systems for first commercial thinning of southern pine plantations. Ph.D. diss. School of Forestry, Auburn Univ. 205 pp.
7. __________ and W.F. Watson. 1988. Flail processing: an emerging technology for the South. Paper No. 88-7527, Am. Soc. of Agric. Engineers, St. Joseph, Mich. 18 pp.
8. __________ and __________. 1996. Plantation thinning systems in the Southern United States. *In:* Problems and prospects for managing cost-effective early thinnings. A report from the concerted action "Cost Effective Early Thinnings." P. Mitchell, E. Stevens, and P.D. Kofman, eds. AIR2-CT93-1538. Danish Forest and Landscape Res. Inst., Horsholm, Denmark. pp. 107–121.
9. Tufts, R.A., B.L. Lanford, W.D. Greene, and J.A. Burrows. 1985. Auburn harvesting analyzer. Compiler 3(2):14–15.
10. Watson, B. and B. Stokes. 1994. Cost and utilization of above ground biomass in thinning systems. *In:* Proc. COFE Meeting on Advanced Technology in Forest Operations: Applied Technology in Action; Oregon State Univ., Corvallis, Oreg. pp. 192–201.
11. Watson, W.F., B.J. Stokes, L.N. Flanders, T.J. Straka, M.R. Dubois, and G.J. Hottinger. 1992. Cost comparison at the woodyard chip pile of clean woodland chips and chips produced in the woodyard from roundwood. *In:* Proc. 1991 TAPPI Pulping Conf. TAPPI Press, Atlanta, Ga. pp. 183–189.
12. Wharton, B.K., R. Alabach, W.F. Watson, and B.J. Stokes. 1993. A model for chip yield of northern Arkansas plantation loblolly pine. *In:* Proc. COFE Meeting on Environmentally Sensitive Forest Engineering, 16th Annual Meeting. Council on Forest Engineering, Corvallis, Oreg. 8 pp.