Chipping Whole Trees for Fuel Chips: A Production Study

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ABSTRACT

A time and motion study was conducted to determine the productivity and cost of an in-woods chipping operation when processing whole small-diameter trees for biomass. The study removed biomass from two overstocked stands and compared the cost of this treatment to existing alternatives. The treatment stands consisted of a 30-year-old longleaf pine stand and a 37-year-old loblolly pine stand. In the longleaf pine stand, 71% of the trees removed were less than 5 in. dbh. In the loblolly pine stand, approximately 81% of the stems removed were less than 5 in. dbh. The harvesting system consisted of conventional ground-based harvesting equipment and a three-knife chipper that processed the biomass into fuel chips. The average production time to fill a chip van was 24.61 minutes. The chip moisture content averaged 94.11% (dry basis). Using machine rates and federal labor wage rates, the in-woods cost of producing fuel chips was $9.18/green ton (gt). The cost of the biomass chipping operation ($15.18/gt), including transportation, compared favorably to existing alternative treatments of cut-and-pile or mulching.

Keywords: biomass, hog fuel, harvesting, production

In response to the HFRA (Healthy Forests Restoration Act 2003), some National Forests are removing unmerchantable material from overstocked stands, including small-diameter trees with no current market value. The many purposes of these operations include reducing the risk of wildfire (fuel treatments), enhancing wildlife habitat, and increasing the vigor of the remaining trees in a stand. Examples of these treatments include mulching the unmerchantable stems with specialized equipment, leaving a mixture of wood, bark and foliage scattered in the forest, or paying contractors to cut and pile stems. Most of these healthy forest contracts result in a net cost to the federal government.

The Oakmulgee District of the Talladega National Forest has been experiencing some of these same forest health concerns (C. Ragland, personal communication, July 22, 2005). An overabundance of small-diameter trees has contributed to a decline in the number of red-cockaded woodpeckers (*Picoides borealis*) and an increase in southern pine beetle (*Dendroctonus frontalis* Z.) infestations. The district was unable to market the scattered larger timber in some areas of the forest, which would normally generate revenue to pursue these healthy forest treatments with more traditional operations. This study was installed to determine whether biomass chipping operations are cost-effective and could meet the objectives of the healthy forest treatments. As a result, the income from the sale of biomass material will help offset some of the costs to allow federal budgets to stretch further and treat more acres.

This study was part of a pilot project by the Oakmulgee District to examine using service contracts for small-diameter tree removal. The service contract with an embedded timber sale would create income from the sale of the fuel chips (biomass) as opposed to the traditional methods of using cut-and-pile or mulching service contracts that do not generate revenue for the National Forest. This project did not remove any products other than fuel chips. Specifically, this project analyzed production rates and costs related to small-diameter whole-tree chipping for fuel chips. This study was installed in March 2006 with the objective of determining the productivity and costs of a chipper when processing whole small-diameter trees.

Methods

Study Site

Two 10-ac stands were identified by Oakmulgee District personnel for small-diameter removal and chipping. One stand (Unit 1) was a 30-year-old longleaf pine (*Pinus palustris* Mill.) plantation. This stand was planted, but the rows were not defined (Figure 1). The other stand (Unit 2) was naturally regenerated 37-year-old loblolly pine (*Pinus taeda* L.) (Figure 2). The understory species to be removed included sweetgum (*Liquidambar styraciflua* L.), yellow-poplar (*Liriodendron tulipifera* L.), and water oak (*Quercus nigra* L.). Biomass was the only product to be removed from these stands and was identified as all stems less than 7.5 in. dbh in Unit 1 and less than 8.5 in. dbh in Unit 2. In addition, all sweetgum, regardless of size, was to be removed. The pretreatment basal area in each unit was 130–150 ft^2/ac. The desired result was a residual basal area of 70–80 ft^2/ac in each treatment unit.

The treatment areas were sampled by Oakmulgee District personnel using 0.02-ac plots, measuring trees in 1-in. dbh classes from 1 to 7 in. in Unit 1 and up to an 8-in. dbh class in Unit 2. Eight plots were inventoried in each unit, resulting in a cruise intensity of 1.6% for each of the treatment areas (Table 1). Aboveground biomass weight per stem for hardwood and pine was calculated using prediction tables developed by Clark et al. (1986) and Clark and Saucier (1990). All stems identified for biomass removal were cruised, with

Received January 26, 2007; accepted July 27, 2007.

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Figure 1. Longleaf pine stand before treatment.

Figure 2. Loblolly pine stand before treatment.

Table 1. Preharvest inventory of stems to be harvested on a longleaf pine stand and a loblolly pine stand on the Talladega National Forest, Alabama, March 2006.

dbh (in.)	Stems/ac.	Volume/ac. (green tons)
Unit 1, longleaf pine		
1	56	0.1
2	31	0.3
3	63	1.1
4	106	3.7
5	81	5.7
6	75	7.6
7	63	10.4
Total	475	29.0
Unit 2, loblolly pine		
1	88	0.2
2	69	0.6
3	38	0.8
4	75	3.0
5	38	2.8
6	19	2.2
7	38	6.8
8	19	4.8
Total	381	21.2

the exception of sweetgum. Sweetgums, regardless of size, were included in the biomass removals but not tallied in the volume estimates.

Operation Studied

Stems to be cut were designated by description (diameter-limit) in the service contract. Oakmulgee District personnel measured stump diameters for determining contractor performance of tree selection. A Hydro-Ax 670 feller-buncher was used to cut and bunch the stems. Bunches were skidded to the landing by a John Deere 648 G-III grapple skidder. The bunches were delivered directly to the Prentice 210D loader, where the stems were picked up individually or in groups and fed into the 450-horsepower, three-knife Precision 1858 chipper. The loader operator used a remote control to operate the chipper. The remote allowed the loader operator to reverse the rollers to aid in feeding the chipper. All personnel were experienced and capable. The business owner operated the loader and chipper and had more than 20 years of experience in logging and in-woods chipping in the area. A mechanic was on site for several hours each day for repairs and maintenance. A John Deere 750C dozer was also on site for road maintenance, if needed.

Seven trucks and trailers were used to haul the loaded chip vans to two mills. Each mill was approximately 60 miles from the site. The contractor frequently set out the loaded trailers approximately 30 miles from the site, located halfway to each of the two delivery points. Trucks from the company's other logging operation were used to complete the hauls to the mills when they were available. Overall, 13 loads were removed from Unit 1, and 15 loads were removed from Unit 2.

Data Collection

An observation was defined as the time it took to process enough material to fill a chip van. Twelve loads (observations) from Unit 1 and eight loads from Unit 2 were video recorded and analyzed.

Elemental time-motion data were collected by use of video cameras. The operator turned the chipper on each time he started the loader. Since the chipper was either chipping stems or not and was started or turned off in conjunction with the loader, the elemental cycle data were collected on the loader. The elements identified were as follows: stems (feeding stems into chipper), debris (feeding small branches and other small material into chipper), clean (clearing debris from working area), and delays (skidder/loader interactions, repair, and administration). The Observer (Noldus Information Technology 1997) software was used to analyze the cycle elements. A loader sheet was used to record the delivered green tons (gt) for each load.

Samples of processed material were collected periodically during the study for determining moisture content. Six samples were taken from each unit. A chip collection tube made of PVC pipes and elbows was used to obtain samples from the chipper's spout. The samples were captured in buckets, then transferred to labeled plastic zippered bags to limit moisture loss during transport. Laboratory procedures outlined by Simpson (1999) were used for determining moisture content.

Results and Discussion

Over the course of 4 days, we observed the contractor processing 20 van loads of chips. The weather was favorable for production, and the roads were dry during the study. The data are summarized in Table 2. A statistical package (SAS Institute 2002) was used for the data analysis unless otherwise noted.

Table 2. Summary of time study and production data from a biomass chipping operation on the Talladega National Forest, Alabama, March 2006.

	Loader operations
Total observed shift-hours	32.75
Productive time (pmh)[a]	8.20
Van loads produced	20
Chips produced (gt)[b]	540.14
Average gt/pmh	66.65

[a] pmh, productive machine-hour.
[b] gt, green tons.

Table 3. Summary of means for loader working time on a biomass chipping operation on the Talladega National Forest, Alabama, March 2006 (minutes per van; n = 20 van loads).

Cycle elements	Mean	SD	Range
Stems	22.97	2.83	19.38–29.53
Debris	0.93	0.64	0–2.20
Clean	0.70	0.56	0–2.13
Delays	5.52	9.08	0.81–32.59

Production Rate

The utilization rate observed during the study was only 25% because of the system imbalance with transportation. The two available delivery points were 60 miles from the study site, and mill turnaround times of up to an hour were experienced. To compound this problem, the chip dump at one of the delivery points malfunctioned and was unavailable for several hours during the first day of the study.

The loader operator spent 93% of total productive time in one activity, feeding stems. During the stem element, the loader continuously fed stems into the chipper. As one set of stems was still feeding through the chipper's rollers, more stems were placed on top of them. When the loader swung back to the pile to gather more stems, the chipper continued to feed the stems from the previous swing through the rollers.

Elemental cycle data were not collected for the skidder, but it experienced delays waiting for the loader to finish cleaning or stem feeding cycles. When a chip van was not available for loading, the skidder collected bunches from the longer skidding distances and brought them to the edge of the landing area. This prebunching reduced the skidder cycle time during chipping cycles.

Only one recorded delay during the production cycle was due to data collection. The loader operator quit chipping when the research workers collected the first chip sample from the spout of the chipper. All other recorded delays were related to communications between workers on the contract crew and a repair problem. Delays, not included in the productive time, accounted for an average of 5.5 minutes/load. These delays ranged from less than 1 minute to 32.6 minutes/load. The longest delay recorded was due to a chipper repair.

Analysis of variance revealed that the mean total processing times between the two units was not significantly different (one-sided P value = 0.5874). Therefore, the production data for both units were grouped in the summary data displayed in Table 3.

The average production time to fill a chip van was 24.61 minutes (95% confidence interval [CI] = 20.07–32.19 minutes; n = 20). The logging contractor produced an average of 66.65 gt/productive machine-hour (pmh) (95% CI = 63.19–70.10 gt/pmh). Observations documented during the chipping operation help explain some

Figure 3. Longleaf pine stand after treatment.

of the variation in the production rates. Additional handling of stems was occasionally required when stems were set aside to have large limbs sawn off. If the operator noticed metal signs nailed to logs as he swung them toward the chipper, production was reduced when he set these aside to have the signs removed. Other times, the loader was slowed by setting down stems with swelled butts or sweeps to turn them so that the narrowest measurement was in the vertical position for easier feeding into the chipper.

Volume Estimates

The Oakmulgee District's total cruised volume estimate for Unit 1 was 290 tons, with an average dbh of 4.26 in. and average height of 26.45 ft, not including the sweetgum trees. The actual volume chipped from Unit 1 was 349 tons, resulting in a 20% overrun. The total cruised volume estimate for Unit 2 was 212 tons (Table 1). The average tree size from the cruise was 3.54 dbh, with a height of 27.05 ft, not including the sweetgum trees. The total amount removed was 488 tons, resulting in a 130% overrun. This discrepancy between estimated and actual volumes could have been caused by several factors. They include the low cruise intensity, additional timber removed as a result of logging, and the impact of volume from sweetgum trees that was unaccounted for in the preharvest cruise.

Figure 4. Loblolly pine stand after treatment.

Table 4. **Machine costs for a biomass chipping operation on the Talladega National Forest, Alabama, March 2006.**

Model	Precision 1858 chipper	Prentice 210 D loader	John Deere 648GIII skidder	Hydro-Ax 670 feller-buncher
Purchase price ($)	268,000	145,000	175,224	215,000
Life (years)	5	5	5	4
Utilization (%)	25	25	60	65
Fixed ownership costs ($·smh^{-1})[a]	34.98	16.65	23.90	34.12
Variable operating costs ($·pmh^{-1})[b]				
Fuel cost ($)	37.62	6.43	10.97	11.28
Lube cost ($)	15.05	2.57	4.39	4.51
Repair and maintenance ($)	21.44	10.15	13.14	21.50
Tires ($)			2.25	2.25
Knives ($)	10.59			
Total variable operating costs ($·pmh^{-1})	84.70	19.15	30.76	39.54
Operator labor and benefits ($·smh^{-1})		19.27	19.27	19.27
Total machine costs				
Total cost ($·smh^{-1})	56.15	40.71	61.63	79.09
Total cost ($·pmh^{-1})	224.61	162.82	102.71	121.68

[a] smh, scheduled machine-hour;
[b] pmh, productive machine-hour.

In Unit 1, 71% of the trees inventoried were smaller than the typical pulpwood specifications (less than 5 in. dbh), but because of their small size, they accounted for only 38% of the total estimated removal volume. In Unit 2, 81% of the trees inventoried were smaller than the pulpwood specifications and accounted for approximately 35% of the volume removal estimates.

The district did not reduce the basal area by as much as planned in either unit (Figures 3 and 4). The target basal area was 70–80 ft^2/ac. The district measured 90–100 ft^2/ac basal area after treatment in each stand. One explanation for the higher residual basal area was that some smaller trees designated for removal were too close to leave trees to be removed by the feller-buncher without risk of damaging the leave trees. In addition, the type of contract used may have affected the selection of trees for removal. In a designation by description contract, the trees are not marked. The logger removed trees on the basis of dbh limits, but the administration of the contract was by inspecting the butt diameters. Because of butt swell and stem taper, some trees were left standing that should have been removed.

Fuel Chip Moisture Content

Six chip samples were collected from each unit. There was no difference found between the units for mean moisture content (two-sided t test P value $= 0.3583$). The average moisture content (dry basis) for the chip samples ($n = 12$) was 94.11% (coefficient of variation = 9.19%).

Machine Costs

The hourly costs for the equipment were calculated (Table 4) using the machine rate approach with assumptions described in Brinker et al. (2002). Because this operation was implemented on federal land, federal wage rates were used (US Department of Labor 2006).

Utilization rates used in this analysis and shown in Table 4 were based on Brinker et al. (2002) for the skidder and feller-buncher. The loader and chipper machine rates were calculated using the utilization rate (25%) observed in this study.

Although the productivities of the feller-buncher and skidder were not included in this analysis, it appeared that the production of the harvest system may have been limited to the rate of the chipper/loader operation, which was 66.65 gt/pmh. On the basis of this production rate, the cost of the harvesting system was estimated to be $611.82/pmh or $9.18/gt. With a 60-mile one-way haul, transportation costs added $6.00/gt (based on $0.10/gt/loaded mile) to this price (Figure 5). The use of machine rates in this cost analysis does not include considerations of profit, overhead expenses (maintenance shop, moving, ancillary equipment and operators, office personnel, utility bills, etc.), risk, or taxes.

At the time of the study, Timber Mart South (2006) reported a mill price of $19.00/gt for pine fuel residue in the northern Alabama region. If the cost of logging and hauling is subtracted from the mill price, $3.82/gt remains for profit, overhead expenses, risk, taxes, and landowner payments.

Harvesting costs are negatively affected by tree size (Stokes and Klepac 1998). It was reasonable to expect that the overall productivity of the feller-buncher (in terms of tons/hour) was negatively affected by the number of small stems to cut. It is also difficult to accumulate a large load with small stems to maximize the efficiency of a grapple skidder (Tufts et al. 1988). Therefore, the costs associated with these two machines could be underestimated in this study. The interaction between the skidder and loader resulted in additional delays for the skidder that negatively affected production that were not captured by this analysis.

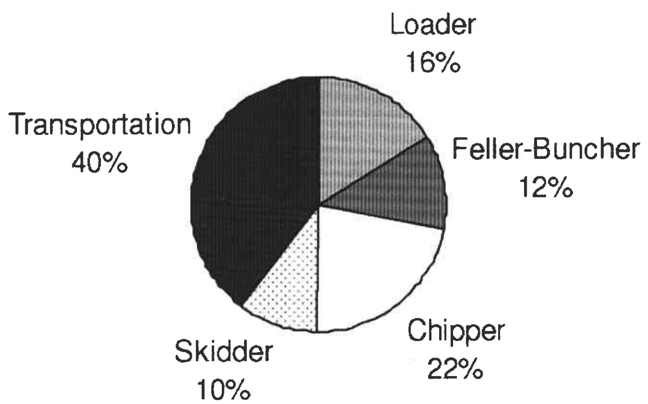

Figure 5. Percentages of machine and transportation costs for delivered biomass.

Cost Comparison between Treatment Alternatives

Twenty acres were treated with in-woods fuel chipping under a service agreement with an embedded timber sale. The Oakmulgee District paid the contractor \$75/ac. The contractor paid the US Forest Service \$0.27/gt on the basis of the preharvest volume estimates (lump-sum). The result was a net cost to the US Forest Service of \$68.24/ac. The typical costs for the alternative treatments are \$125/ac for cutting and piling or \$285/ac for mulching the unmerchantable stems.

The total volume overrun was 335 tons. Using the appraisal value of \$0.27/gt, the district lost \$91.26 in revenues because of the inaccurate volume estimates, hardly enough to justify a higher cruise intensity. If the biomass were sold on a per-unit basis rather than lump-sum, this additional revenue could have been received without incurring additional cruising costs. Had this revenue been received, the net cost for the treatment would have been \$63.68/ac.

Conclusions

The cost of producing fuel chips was \$9.18/gt. Including transportation costs for 60 miles, the delivered cost was \$15.18/gt. The market rate for fuel chips in Alabama's northern counties for March 2006 (Timber Mart South 2006) was \$19.00/gt, allowing \$3.82/gt for additional expenses of profit, overhead, taxes, and risk.

On the basis of this study, costs for removing small-diameter material and unwanted sweetgum trees from National Forest land could be near the breakeven point when using conventional equipment and reasonable utilization rates. Minimizing delays will be key to attaining these production rates and cost estimates. If the price paid for delivered biomass covers the costs of harvesting, transportation, overhead, profit, and risk, contractors could successfully operate without the service contract payment of \$75/ac.

Under the service contract used, in-woods chipping of unmerchantable stems compared favorably to the costs of the alternative treatments. In-woods chipping resulted in a cost savings of \$56.76/ac compared with cutting and piling and a savings of \$216.76/ac compared with mulching. By implementing this pilot project, the US Forest Service was able to treat these two stands at a lower cost than the traditional alternatives. Depending on timber markets in other areas, this type of operation may be applicable on other southeastern National Forests.

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