PRODUCTIVITY AND COST OF TWO METHODS OF TRANSPORTING ENERGYWOOD FROM STUMP TO LANDING IN A TREE-LENGTH SOUTHERN PINE CLEARCUT

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ABSTRACT

There are three systems of harvesting wood for energy using conventional harvesting equipment: 1) pre-harvest systems (2-pass), 2) post-harvest systems (2-pass), and 3) integrated systems (1-pass). Past research indicates that integrated systems are most efficient in terms of both cost and biomass utilization. We conducted a designed operational study on an integrated harvest to compare the productivity and cost of delivering wood to the landing when energywood is separated at the stump and when energywood is separated at the landing. The study was conducted in a southern pine clearcut in Bertie County, NC and consisted of three treatments: 1) roundwood is felled and skidded to the landing and energywood is left standing (control), 2) energywood and roundwood are felled and separated at the stump by the feller-buncher and skidded separately to the landing, 3) energywood and roundwood are felled and skidded together to the landing and separated by the loader. Harvesting energywood reduced felling productivity by 22.3 tonnes per productive machine hour (pmh) (28%) when energywood was separated at the stump and by 12.5 t pmh^{-1} (16%) when energywood was separated at the landing compared to the control treatment. Skidding productivity per machine was reduced by 17.5 t pmh^{-1} (46%) when energywood was separated at the stump and by 9.5 t pmh^{-1} (25%) when energywood was separated at the landing compared to the control treatment. Overall, stump-to-landing costs increased by \$4.23 t^{-1} (87%) compared to the control when energywood was separated at the stump and by \$1.61 t^{-1} (33%) when energywood was separated at the landing. These results indicate significant additional costs for loggers when small-diameter stems are harvested for energy and the cost of delivering wood to the landing is higher when energywood is separated at the stump than when energywood is separated from merchantable roundwood at the landing.

INTRODUCTION

Increasing the use of wood for energy has the potential to reduce oil imports, improve sustainability, and stimulate rural economies (National Research Council 1999, Perez-Verdin et al. 2008, Alavalapati et al. 2009). Therefore, state and federal governments have enacted incentives, subsidies, and regulatory measures that promote the use of wood and other renewable energy sources. Thirty-six states and the District of Columbia have enacted renewable portfolio standards or goals that mandate or set goals for utilities to produce a certain amount or percentage of electricity from renewable sources by a target date (Database of State Incentives for Renewables and Efficiency 2011). The U.S. South has developed fewer regulatory measures and incentive programs than other states (Becker et al. 2010); nonetheless, each southern state has developed policies promoting bioenergy (Alavalapati et al. 2009).

In 2009, wood and wood-derived fuels accounted for just 1.2% of the U.S. South's electricity generation (Figure 1). However, it has been suggested that wood's contribution to America's energy portfolio, including electricity and transportation fuels, could be increased to 10% (Zerbe 2006).

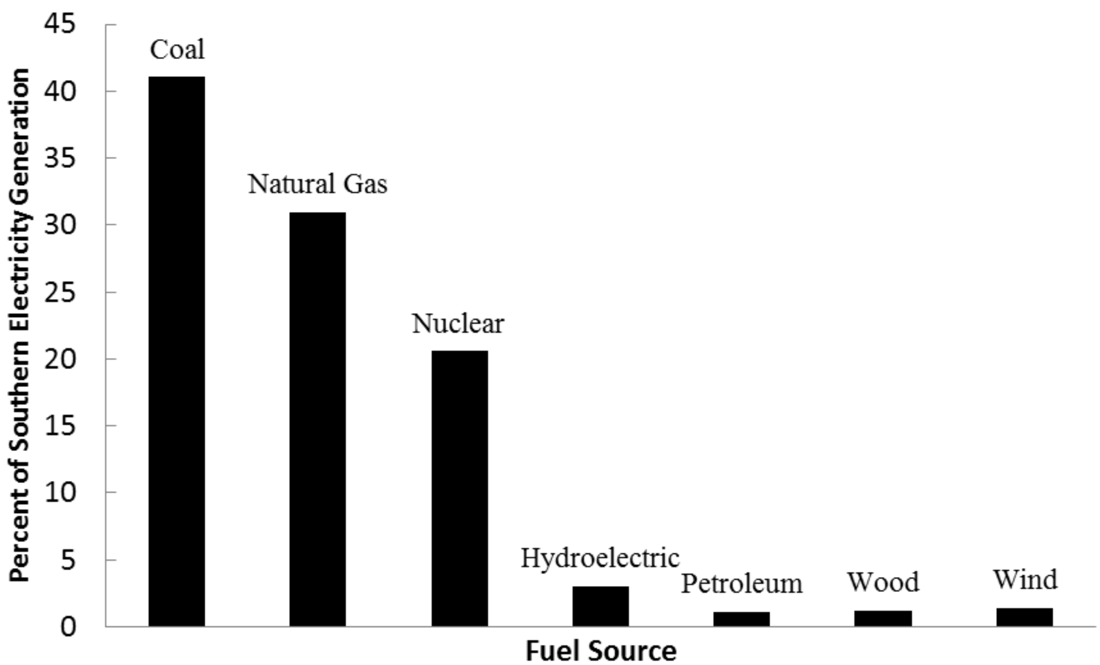

Figure 1: Electricity generation in the southeast by fuel source (Energy Information Administration 2011).

In order for wood to make significant contributions to the United States' energy portfolio, harvesting contractors must be able to economically harvest and transport energywood to processing/conversion facilities. Watson and Stokes (1989) recognized four methods of harvesting woody biomass for energy: 1) specialized machines that harvest logging slash and non-commercial stems, 2) post-harvest operations following conventional harvesting, 3) pre-harvest operations prior to conventional harvesting, and 4) integrated operations harvesting roundwood and energywood simultaneously.

Past research indicates that 1-pass systems are significantly less expensive per tonne than 2-pass systems (Stuart et al. 1981, Stokes et al. 1984, Miller et al. 1987). Stokes et al. (1984) found that the integrated approach resulted in the least cost and highest biomass utilization. Chipping costs, however, were higher for the one-pass system than the two-pass system because chipper utilization was lower. Watson and Stokes (1989) found that the cost of energywood was reduced by 30% using an integrated harvesting system compared to a pre-harvest system (\$17 t^{-1} preharvest vs. \$11 t^{-1} integrated). However, the cost of harvesting roundwood pulpwood and sawlogs was reduced following pre-harvesting (\$6-\$11 t^{-1} preharvest vs. \$9 t^{-1} integrated). Miller et al. (1987) found that the cost of energywood was 40% less using integrated harvesting compared to a pre-harvest system (\$16 t^{-1} preharvest vs. \$9 t^{-1} integrated). Post-harvesting systems are the most expensive option for harvesting energywood and typically recover less biomass than integrated systems, but typically recover more of the available biomass than the pre-harvest method (Stokes and Sirois 1989).

Within 1-pass systems, there are two ways to transport wood from the stump to the landing. Harvesting contractors can fell and skid merchantable and non-merchantable stems together and separate them at the landing. Or, they can fell and bunch merchantable and non-merchantable stems separately and skid them separately to the landing. The purpose of this study was to compare the cost, stump-to-landing, of separating energywood from merchantable pulpwood and sawtimber at the stump vs. separating energywood at the landing.

METHODS

Three replications of three harvest treatments (9 experimental units) were conducted in the Coastal Plain of North Carolina arranged as a randomized complete block design. The three treatments were: 1) a Conventional treatment in which sawtimber, chip-n-saw, and roundwood pulpwood were felled and skidded to the landing and non-merchantable stems were left standing, 2) an Integrated-Stump treatment in which merchantable and non-merchantable stems were felled and separated by the feller-buncher and skidded separately to the landing, and 3) an Integrated-Landing treatment in which merchantable and non-merchantable stems were felled and skidded together to the landing to be separated by the loaders.

This study was conducted in Bertie County, North Carolina during the summer of 2010 on a 51 ha loblolly pine (*Pinus taeda* L.) plantation. The plantation was divided into three blocks and a complete set of treatments were applied to each block. The blocks were designed so that skid distance was equal within blocks, but varied between blocks (Table 1). Blocks 1 and 3 were 22 years old, while Block 2 was 26 years old; with the exception of a portion along the boundary with Block 1 that was also 22 years old.

A preharvest inventory was conducted using fixed radius plots to estimate both merchantable and non-merchantable biomass. Merchantable stems were defined as those stems $\geq$ 10 cm in diameter at breast height (dbh) and non-merchantable stems had diameters < 10 cm dbh. Standing biomass was estimated using published weight equations (Clark et al. 1985, Saucier and Clark 1985, Clark et al. 1986, Baldwin 1987, Bullock and Burkhart 2003). Following harvest, an inventory was conducted to estimate standing and down biomass. Standing biomass was estimated as in the pre-harvest inventory, and down-woody biomass was estimated by measuring large-end diameter, small-end diameter and length of the stem within the plot for stems with a large-end diameter of at least 5 cm and a minimum length of 0.3 m. Weight of down material was estimated by determining volume using the equation of a cone and multiplying this value by previously published weight per unit volume values (Clark et al. 1985, Visser and Stampfer 2003).

The harvesting contractor observed in this study typically delivers 2,200-2,700 t per week, and is capable of wet-site harvesting. The contractor's felling and skidding equipment included one Tigercat 822C tracked feller-buncher, one 625C grapple skidder with dual tires, and one Tigercat E620C grapple skidder with dual tires.

Table 1: Harvest area (ha) within each experimental unit (treatment), total area within each block, and average skid distance (m) within each experimental unit and block.

Block	Treatment	ha	Average Skid Distance (m)
Block 1	Conventional	6.7	335
	Integrated-Stump	7.9	365
	Integrated-Landing	4.0	335
	Total	18.6	345
Block 2	Conventional	7.0	245
	Integrated-Stump	5.0	275
	Integrated-Landing	4.0	260
	Total	16.0	260
Block 3	Conventional	6.9	290
	Integrated-Stump	5.9	275
	Integrated-Landing	4.7	290
	Total	17.5	285

Felling and skidding productivity were estimated using elemental time studies. One hundred seventy-five felling cycles were observed in each experimental unit, with the exception of one that had 151 felling cycles observed. A felling cycle began when the feller-buncher dropped a bunch of stems and ended when the next bunch was dropped. Time per bunch, number of merchantable and non-merchantable stems per bunch, and delay time were recorded for each felling cycle. Felling productivity in t per productive machine hour (pmh) was calculated by dividing weight per bunch by time per bunch. Weight per bunch was estimated using weight values obtained from the preharvest inventory and the number of merchantable and non-merchantable stems per bunch.

A minimum of 25 skidding cycles were observed in each experimental unit. Time per turn, number of merchantable and non-merchantable stems per turn, skid distance, and delay time were recorded for each turn. Skidding trees from stump to landing involved two steps. First, stems were skidded to a staging area. Second, stems were skidded from the staging area to the landing. The time and skid distance for both steps were combined to estimate total turn time and skid distance. Skidding productivity (t pmh^{-1}) was estimated by dividing payload by turn time, excluding delays. Skidder payload was estimated using weight values obtained from the preharvest inventory and the number of merchantable and non-merchantable stems per turn. In the Integrated-Stump treatment, skidding productivity and cost were estimated using a weighted average productivity based on the proportion of time spent skidding merchantable roundwood and energywood.

Equipment costs were estimated using the machine rate method (Miyata 1980). For each machine we assumed a salvage value of 20% of the purchase price, economic life of 5 years, interest rate of 8% of average yearly investment, 2,000 scheduled machine hours (smh) per year, and a lube rate of 40% of fuel consumption (Brinker et al. 2002). The average hourly wage rate for logging equipment operators in North Carolina of $13.92 (Bureau of Labor Statistics 2009) was assumed for all equipment operators. Labor overhead was assumed to be 40% of the base rate (Bolding et al. 2009). Other cost assumptions are listed in Table 2. Harvesting costs (US$ t^{-1}) were estimated by combining productivity estimates with machine costs in the Auburn Harvesting Analyzer (AHA) (Tufts et al. 1985). Because we only examined the felling and skidding functions of the harvesting system, we did not constrain productivity with a system rate. Therefore, the cost of delivering wood to the landing is simply the sum of felling and skidding costs in US$ t^{-1}, assuming availability of 90% for the feller-buncher and 85% for the skidders. All costs and prices are listed in US$ and all weights are reported on a green basis.

Harvesting productivity and cost were analyzed using analysis of variance (ANOVA) and the Tukey HSD test. Statistical analysis was conducted using SAS v9.1 software (SAS Institute 2004) using the Proc GLM procedure for a randomized complete block design with three blocks and three experimental units per block.

Table 2: Machine rate assumptions used to calculate hourly costs for each piece of equipment.

Cost factors	Tigercat 822C Feller-Buncher	Tigercat E620C Skidder	Tigercat 625C Skidder
Purchase Price[a]	$400,000	$225,000	$285,000
Insurance & Taxes (% of average yearly investment)[b]	3.50%	5%	5%
Maintenance & Repair (% of Depreciation)[b]	75%	90%	90%
Fuel consumption (liters/hr)[b]	29.9	23.3	27.6
Fuel cost ($/liter)	$0.63	$0.63	$0.63
Utilization rate (%)	60%[b]	60%[b]	60%[b]

[a]Purchase prices were estimated through consultation with equipment dealers familiar with this harvesting system.
[b]Source: Brinker et al. (2002).

RESULTS AND DISCUSSION

Felling productivity was reduced by approximately 22.3 t pmh^{-1} when energywood was separated at the stump compared to the Conventional treatment (Table 3). Felling productivity was reduced by just 12.5 t pmh^{-1} when energywood and merchantable timber were felled together. One observation from the Integrated-Landing treatment was removed from the data set because productivity was unusually low, and was not representative. Overall, separating energywood and merchantable timber at the landing yielded the highest variation (Coefficient of Variation = 17%). Felling costs increased by \$0.77 t^{-1} when energywood was separated at the stump and by \$0.45 t^{-1} when energywood was separated at the landing compared to the Conventional treatment (Table 3).

Table 3: Skidding and felling cost (US\$ green t^{-1}) and productivity (green t pmh^{-1} machine^{-1}) with descriptive statistics.

			Productivity (green t pmh^{-1} machine^{-1})			
Function	Treatment	Function Cost (US\$ green t^{-1})	Mean	Min.	Max.	Std. Error
Felling						
	Conventional	1.82[a]	77.21[a]	76.01	78.52	0.73
	Integrated-Stump	2.59[a]	54.90[a]	46.37	59.68	4.28
	Integrated-Landing	2.27[a]	64.74[a]	51.22	78.27	11.04
Skidding						
	Conventional	3.02[a]	38.02[a]	33.77	45.68	3.84
	Integrated-Stump	6.48[b]	19.35[b]	15.80	24.34	2.56
	Integrated-Landing	4.18[ab]	28.53[ab]	16.99	40.43	6.77

a,b Means not connected by the same letter are significantly different ($\alpha = 0.10$).

Skidding productivity per machine was reduced by nearly half (18.7 t pmh^{-1}) when energywood was separated at the stump compared to the Conventional treatment (Table 3). Productivity was reduced by approximately 9.5 t pmh^{-1} compared to the Conventional treatment when energywood was separated at the landing. Separating energywood at the landing also had the highest level of variability of the three treatments (Coefficient of Variation = 24%).

Skidding costs were over \$6 t^{-1} when energywood was separated at the stump, compared to just over \$3.02 t^{-1} in the Conventional treatment, an increase of 114% (Table 3). Skidding energywood and merchantable stems separately increased the number of passes required compared to the other two treatments because of very low payloads when energywood was being skidded. Skidding costs were 38% higher when energywood was separated at the landing compared to the Conventional treatment. Even when handling energywood and merchantable stems together, skidder payload was still reduced compared to the Conventional treatment, and this reduced productivity and increased costs.

Overall, stump-to-landing costs were \$4.84 t^{-1} in the Conventional treatment, \$9.07 t^{-1} when energywood was separated at the stump, and \$7.66 t^{-1} when energywood was separated at the landing. These data suggest important increases in harvesting costs when large wet-site loggers attempt to harvest energywood. Low skidder payloads, especially when energywood was separated at the stump, reduced skidder productivity and significantly increased costs. These data suggest that harvesting contractors that produce energywood in an integrated system should separate roundwood and energywood at the landing rather than at the stump. However, this will reduce loader productivity and loggers may not be willing to risk increasing truck turnaround time as a result. This study did not quantify the reduction in loading productivity when handling energywood.

Separating energywood at the landing vs. the stump did not make a significant difference in biomass utilization. Residual woody biomass following the Conventional treatment was 18 t ha^{-1}, compared to 4 t ha^{-1} when energywood was separated at the stump, and 3 t ha^{-1} when energywood was separated at the landing.

CONCLUSION

This study documented important felling and skidding cost increases when harvesting woody biomass for energy. These increases were amplified in this study because of expensive equipment that burned more fuel than the equipment used by many harvesting contractors. Past research by Westbrook et al. (2007) and Baker et al. (2010) suggests that loggers with lower capitalization and more fuel efficient equipment can harvest energywood in an integrated system more profitably than the logger observed in this study.

Past research indicates that harvesting energywood in an integrated system is less expensive than pre-harvest and post-harvest systems (Stuart et al. 1981, Stokes et al. 1984, Miller et al. 1987). For harvesting contractors harvesting energywood in an integrated system, this study suggests that costs can be reduced by felling and skidding merchantable roundwood and energywood to the landing together and separating the energywood at the landing. Furthermore, this study found that residual woody biomass does not differ following the two approaches. Nonetheless, separating energywood at the landing will reduce loading productivity, and some harvesting contractors may be hesitant to risk increasing truck turnaround time. This study only examined stump-to-landing costs, and depending on the system being observed, reductions in loading/processing productivity may or may not be of concern. For example, if the loading function is underutilized when handling only merchantable stems, then reducing loading productivity would not significantly increase system costs.

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