Harvesting Forest Biomass by Adding a Small Chipper to a Ground-Based Tree-Length Southern Pine Operation

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ABSTRACT

We looked at the addition of a small chipper (Conehead 565) to a mechanized, tree-length system to also harvest tops, limbs, and understory (dbh 1-4 inch) biomass. Three replicates of three treatments were evaluated in a 33-year-old slash pine plantation on a flatwoods site in the lower coastal plain of Echols County, GA. Treatments included A – roundwood harvest only, B – roundwood harvest and chipping of limbs and tops, and C – roundwood harvest with chipping of limbs, tops, and understory. The site contained an estimated 7.7 tons per acre of understory biomass with an average dbh of 2 inches. Water oak, swamp bay, and red maple accounted for 73% of the stems. Roundwood production averaged 65.8 tons per acre and did not differ significantly across the three treatments. A load of chips was produced for every 18 and 5 loads of roundwood in Treatments B and C, respectively. There were significant differences in the chips produced between treatment B (3.8 tons per acre) and treatment C (10.8 tons per acre) at the 10% level but not at the 5% level. Harvest of understory stems did not significantly increase fuel consumption per ton in treatment C. Chips took twice as much fuel per ton to produce due entirely to the addition of the chipper. Chips averaged 50% moisture content (wet basis) when produced and lab results showed heat content values of 19.1 MJ/kg, comparable to other woody biomass. All chips were used in an electricity co-generation unit at a local OSB mill with satisfactory results. Nutrient removals from the site were relatively low with losses associated with Treatment B comparable to annual atmospheric deposition. Cost projections suggest that this method of producing chips can be competitive if no more than 10 loads of roundwood are harvested to produce a load of chips or at least one load of chips is produced daily.

INTRODUCTION

The southern USA currently has an abundance of pine pulpwood in many areas, reflected by stumpage prices that have not increased in real terms for years. In this market, landowners and forest managers often find it difficult to have thinnings of pine plantations performed at a time that maximizes the biological response to thinning. This soft market for small trees can also lead to more selective product specifications for pulpwood, leaving smaller trees in the woods after clearcuts and requiring site preparation steps to deal with these residual standing stems. With more limited use of fire and mechanical treatments as site preparation tools, dealing with residual material prior to regeneration is becoming more expensive and problematic. Additional markets for small stems that are currently unmerchantable and for residues such as limbs and tops could turn what is currently a cost item into a potential revenue stream for the forest landowner and reduce the investment required for reforestation. This material could serve as a feedstock for biorefinery or biomass energy facilities.

Most southern harvesting systems move full trees or merchantable tree-length stems to roadside (Greene *et al.* 2001). These systems evolved during the 1970s when it was common for hardwood pulpwood to be left standing in the woods (no market) while a few pine products (pulpwood, chip-n-saw logs, and large sawtimber/plylogs) and one hardwood log product were typically handled. During the late 1970s several projects examined ways to modify the tree-length systems of that time to allow them to recover forest biomass and smaller stems for energy (Puttock 1987, Miller *et al.* 1987, Watson *et al.* 1986, Stuart *et al.* 1981). All four studies identified the need for a single felling and skidding pass to collect both merchantable and residual material. Making two passes across the site – one to collect conventional products and a second to collect forest residues – was too expensive then and remains so today.

Today's product markets and logging equipment are quite different from those observed during the 1980s. For example, Watson *et al.* (1986) defined a "conventional" harvest as one that removed all pine 6 inches or greater and all hardwood 12 inches and greater in diameter. This implied no market at all for hardwood pulpwood while in today's market hardwood pulpwood often commands a higher price and enjoys more stable demand than pine pulpwood. The logging systems they examined did not employ sawhead feller-bunchers, used much smaller grapple skidders (measured by either horsepower or grapple size), did not evaluate mobile log loaders, and did not observe mechanized delimbing (pull-through delimbers, chain flails, or grapple processors) at the landing. All of this equipment is common today in southern forests.

The objective of this study was to use today's harvesting equipment to capture the smaller stems and harvesting residue that we typically leave in the woods after using tree-length systems. We were interested in how the addition of a small chipper to a tree-length operation would affect weekly production and delivered cost per ton of roundwood and chips. We also wanted information about the quality of the chips produced for use in a co-generation electricity facility at a forest products plant.

METHODS

This study was conducted cooperatively with Langdale Industries – a major privately owned forest products company – and Lott Logging Inc., one of their harvesting contractors. Lott Logging leased a Conehead 565 chipper during our study to evaluate its potential purchase. The Conehead 565 chipper has a 260 horsepower Cummins turbocharged diesel engine, a 21" diameter capacity, and a feed rate of 100 feet per minute. In addition to the chipper, Lott operated a Tigercat 718 feller-buncher, a John Deere 640D grapple skidder, and a Prentice 280 loader with a pull-through delimber. Lott typically performed thinnings, delimbed with a delimbing gate and the loader-mounted delimber, and set out loaded trailers for hauling by both owned and contract trucks. Their operation is very typical of ground-based, mechanized tree-length pine systems operated across the USA South.

The study location was a slash pine (*Pinus elliottii*) plantation on a flatwoods site in Echols County, Georgia that was 33 years old and had been thinned once. We divided the tract into 10 blocks (about 20 acres each) that would each take approximately five working days for Lott Logging to clearcut. Each block was randomly assigned one of three treatments. Treatment A was the conventional ground-based tree-length harvesting system with no attempt to harvest limbs, tops, or unmerchantable stems. Treatment B was the conventional harvesting system with the addition of the Conehead chipper to chip all limbs and tops. Treatment C was the conventional system with the addition of the chipper to chip limbs, tops, and non-merchantable woody biomass of all species that was between one and four inches at diameter breast height (DBH) that could be harvested by the feller-buncher and skidder.

To estimate unmerchantable biomass we measured 0.05-acre circular plots that were located using a four chain by four-chain grid across each block. In each plot we tallied all unmerchantable stems that were defined as woody stems of any species with a dbh between one and four inches with a total height of at least eight feet. Species, dbh, and total height were recorded for each stem within a plot. We used weight equations to estimate total green weight tons of biomass (Franchi *et al*. 1984). We also used the USDA Forest Service photo series for quantifying natural fuels to assess the woody biomass available on the site (Ottmar *et al*. 2003).

From the 10 blocks, nine were randomly assigned a treatment (three replicates per treatment) and one was retained as a backup. The blocks were then harvested according to treatment. All the B's were cut first, followed by the C's, and last the A's. This sequence was used to minimize the time Lott needed to lease the chipper. Prior to cutting any of the study blocks, Lott used the chipper for a full working week on another tract to get accustomed to its use. Each study block assigned treatment A or B had a work sample collected during one full day of operation while treatment C blocks had two days monitored. Daily production in loads and tons was collected for each product class harvested on each block.   Daily fuel usage and equipment operating hours were recorded for each piece of woods equipment. A 5-gallon chip sample was obtained from each study block and sealed for transport to a lab. A subsample of these chips were weighed and then dried to obtain moisture content, particle distribution, and bulk density. Chips were also evaluated to determine their elemental content (N, P, and K) and their potential heat content per unit of dry weight.

We estimated the cost of chips produced assuming the chipper cost $100,000 to purchase and was operated for 5 years with a residual salvage value of 20%. We assumed interest, insurance and taxes to be 9%, 6%, and 2 %, respectively. The maintenance and repairs cost are assumed at 100% of depreciation. Off-road diesel averaged $2.58 per gallon during our study. We also figured the chipper would have 90% availability. Chips were hauled from the woods at a cost of $0.12 per ton-mile. For Treatment B, chip cost per ton only included the cost of the chipper, loader costs associated with feeding the chipper, and trucking. For Treatment C, we also proportioned the cost of felling and skidding as this treatment required additional felling and skidding to perform.

RESULTS

Our inventory of the study blocks sampled an average of 16 plots in each block (Table 1). We found 220 stems per acre with an average DBH of 2.0 inches that comprised 7.7 tons per acre of understory biomass. Biomass estimates ranged from 4.9 to 11.4 tons per acre. Tallied species included water oak *(Quercus nigra)*, swamp bay (*Persea palustris*), red maple *(Acer rubrum)*, waxmyrtle (*Myrica cerifera*), slash pine, blueberry (*Vaccineum* sp.), yaupon (*Ilex vomitoria*), and titi (*Cyrilla racemiflora*). Water oak, sweet bay, and red maple together accounted for 73% of stems (Figure 1). Waxmyrtle, blueberry, yaupon, and titi are not commercial timber species, but the other species are commonly harvested when of acceptable size. USDA Forest Service methods for visually predicting fuel loads in a slash pine stand with similar understory species suggested that there would be 4.5 tons per acre of woody species with diameters of 4 inches or less. It also predicted that the forest floor load was 30.0 tons per acre.

Table 1. Inventory statistics and preharvest conditions of unmerchantable stems and underbrush of 1-4 inches DBH on 10 study blocks of 33-year old planted slash pine, Echols County, GA.

Block	Treatment	No. of Plots	Stems/Acre	Mean DBH	Biomass
				(inches)	(tons/acre)
1	C	15	154	2.1	4.9
2	B	17	212	2.1	7.6
3	A	18	204	2.3	9.9
4	B	15	220	2.0	8.3
5	C	18	302	1.9	11.4
6	Spare	14	190	1.8	6.0
7	B	16	292	1.9	9.3
8	C	15	198	2.0	7.3
9	A	16	194	2.0	5.6
10	A	16	206	1.9	5.2
ALL		160	220	2.0	7.7

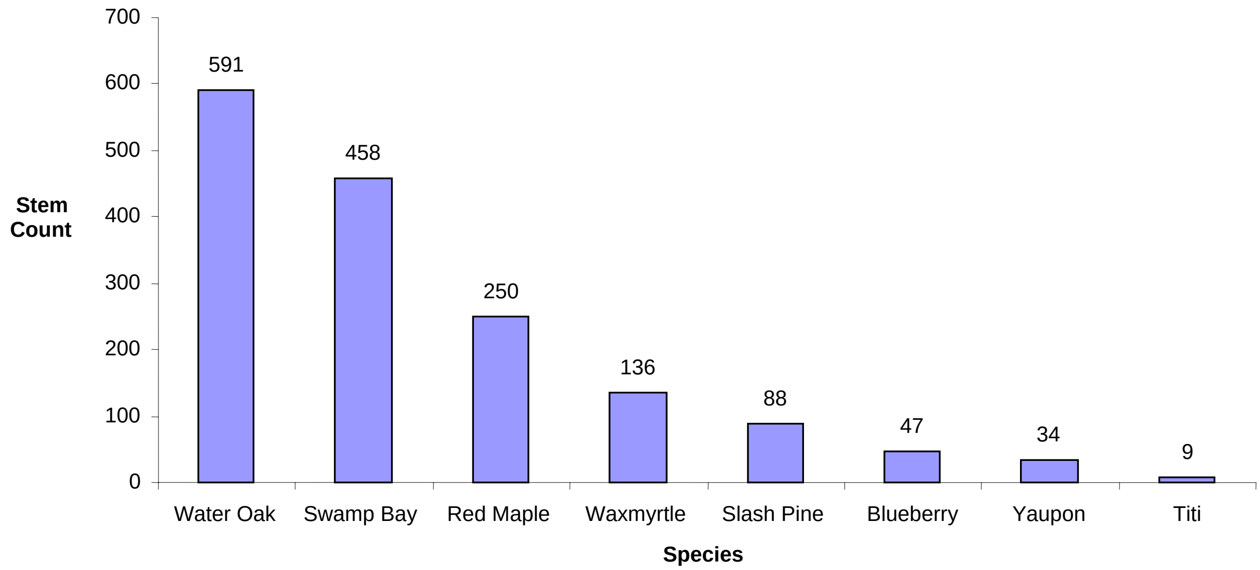

Figure 1. Frequency distribution by species of trees tallied in study blocks.

The amount of roundwood per acre produced by each treatment was not significantly different (Table 2). Treatment B also produced 3.8 tons of chips per acre compared to 10.8 tons produced by treatment C. These values were significantly different at the 10% level, but not at the 5% level. Treatment B used limbs and tops to produce chips while Treatment C used understory material as well. The difference between these two treatments – approximately 7 tons/acre – compares favorably with our preharvest estimates of available understory biomass (7.7 tons/acre). Production rates were similar across treatments with no significant differences found in hourly production (tons/SMH). The crew produced an average of 8 loads per day in the chipper treatments and 9 loads per day in the conventional roundwood treatments. The chips produced were an addition to the roundwood production and did not appear to significantly reduce roundwood production. A load of chips was produced for every 18 loads of roundwood in Treatment B and for every 5 loads of roundwood in Treatment C blocks. The roundwood to chip ratio for Treatment B would be closer to 12 if the results from block 2 were excluded where wet weather required use of some logging slash for an operating mat.

Fuel consumption (gallons per ton) of woods equipment (felling, skidding, and loading) was not significantly higher for the chipper treatments than the roundwood treatments (Table 3). Both conventional logging (Treatment A) and the chip treatments (B&C) consumed an average of 0.41 gallons of diesel per ton of wood produced for the felling, skidding, and loading activities. To produce a ton of chips also required another 0.40 gallons for chipping, thus a ton of chips required 0.83 gallons of diesel compared to 0.41 for a ton of roundwood.

Table 2. Summary of data collected by treatment and by block.

Treatment	Loads	Tons	Days	SMH	Acres	Tons /load	Tons /day	Tons /acre	Loads /day	Loads/ acre	Round Wood Tons/Ac	Chip Tons/Ac	Tons/SMH	Fuel Use Gallon/Ton
A - Conventional Harvest														
Block 3	68	1785	6	52.25	22.63	26.2	297.5	78.9	11	3	78.9	--	34.2	0.4
Block 9	46	1406	7	59.00	23.85	30.6	200.9	59.0	7	2	59.0	--	23.8	0.5
Block 10	43	1279	5	42.50	19.85	29.8	255.9	64.4	9	2	64.4	--	30.1	0.4
Totals	157	4470	18	153.75	66.33	86.6	754.2	202.3	27	7	202.3	--	88.1	1.3
Average	**52**	**1490**	**6**	**51.25**	**22.11**	**28.9**	**251.4**	**67.4**	**9**	**2**	**67.4 Aa**	**--**	**29.4 Aa**	**0.4 Aa**
B -Tops and Limbs														
Block 2	66	1699	8	62.25	23.92	25.7	212.4	71.0	8	3	70.0	1.0	27.3	0.8
Block 4	58	1448	8	60.75	21.93	25.0	180.9	66.0	7	3	62.4	3.7	23.8	0.9
Block 7	60	1637	7	61.00	19.98	27.3	233.9	81.9	9	3	75.3	6.6	26.8	0.8
Totals	184	4784	23	184.00	65.83	78.0	627.2	219.0	24	8	207.7	11.3	78.0	2.5
Average	**61**	**1595**	**7.7**	**61.33**	**21.94**	**26.0**	**209.1**	**73.0**	**8**	**3**	**69.2 Aa**	**3.8 Aa**	**26.0 Aa**	**0.8 Bb**
C - Tops, Limbs, & Understory														
Block 1	63	1698	7	50.50	21.68	26.9	242.5	78.3	9	3	71.1	7.2	33.6	0.9
Block 5	77	2052	10	78.75	25.02	26.6	205.2	82.0	8	3	68.1	13.9	26.1	0.8
Block 8	49	1333	6	42.50	24.63	27.2	222.2	54.1	8	2	42.9	11.3	31.4	0.8
Totals	189	5083	23	171.75	71.33	80.8	669.9	214.4	25	8	182.0	32.4	91.0	2.5
Average	**63**	**1694**	**7.7**	**57.25**	**23.78**	**26.9**	**223.3**	**71.5**	**8**	**3**	**60.7 Aa**	**10.8 Aa**	**30.3 Aa**	**0.8 Bb**

Means with the same letter are not significantly different at the alpha=10% (AB) or 5% (ab) level.

Table 3. Fuel usage per ton by type of woods equipment and study treatment.

Treatment	Feller-buncher	Skidder	Loading	Chipper	Totals
	Gallons/Ton				
A - Conventional logging					
Block 3	0.11	0.15	0.10	--	0.36
Block 9	0.17	0.17	0.12	--	0.47
Block 10	0.15	0.15	0.11	--	0.42
Average	0.15	0.16	0.11	--	0.41 Aa
B – Tops/limbs					
Block 2	0.14	0.18	0.13	0.38	0.83
Block 4	0.15	0.15	0.13	0.46	0.88
Block 7	0.15	0.18	0.14	0.35	0.82
Average	0.15	0.17	0.13	0.40	0.84 Bb
C – Tops/limbs/understory					
Block 1	0.13	0.15	0.13	0.44	0.85
Block 5	0.14	0.15	0.13	0.34	0.76
Block 8	0.15	0.15	0.10	0.45	0.84
Average	0.14	0.15	0.12	0.41	0.82 Bb

Means with the same letter are not significantly different at the alpha=10% (AB) or 5% (ab) level.

Chips averaged approximately 50% moisture content as produced in the woods (Table 4). Lab analyses showed the chips to be primarily carbon with heating values comparable to those reported for other forms of woody biomass. One concern often expressed about utilization of logging residues involves nutrient removals from the site. Foliage and small limbs contain a disproportionate amount of nitrogen (N), phosphorous (P), and potassium (K). Our chip analyses indicated higher percentages of N, P, and K in chips from Treatment C than from Treatment B. Results from our chip analyses combined with the tons removed per acre suggest that in the most intensively harvested Treatment C blocks less than 24 lb/ac of N was removed. Removals of P and K were approximately 2.5 lb/ac and 7.1 lb/ac, respectively, in Treatment C. Treatment B nutrient losses due to biomass removal were estimated at 6.48 lb/ac of N, 0.52 lb/ac of P, and 1.73 lb/ac of K. Annual atmospheric deposition of nitrogen through rainfall and particulate matter is 5.9 lbs per acre per year (Boring *et al.* 1988). Carter *et al.* (2004) state that 0.36 lbs P and 1.5 lbs K are average annual inputs per acre.

The market for fuel chips varies with local supply and demand across the South but delivered prices of $14-19 per ton are common (Timber Mart South 2006). We project that chips can be produced from limbs and tops (Treatment B) at costs ranging from $11 per ton and up (Figure 2). Also pursuing understory for use in making chips (Treatment C) is approximately $1 per ton more expensive. These per ton costs increase as the volume chipped decreases. We represent this as the ratio of roundwood production to chip production. As this ratio increases, fewer chips are produced. Our estimates suggest that if no more than 10 loads of roundwood are produced

Table 4. Properties of chips sampled in the two chipping treatments.

Treatment	MC	C	N	P	K	HHV	
	Percent					MJ/kg	BTU/lb
B –Tops and limbs							
Block 2	46.2	50.4	0.119	0.0148	0.0458	19.6	8015
Block 4	51.9	52.0	0.204	0.0129	0.0412	18.2	8296
Block 7	48.9	51.8	0.211	0.0156	0.0554	19.5	8394
Average	49.0	51.4	0.178	0.0144	0.0475	19.1	8235
C – Tops/limbs/understory							
Block 1	46.8	50.7	0.127	0.0111	0.0311	18.6	8419
Block 5	29.6	50.6	0.304	0.0407	0.1158	19.3	7859
Block 8	49.0	50.8	0.195	0.0135	0.0435	19.5	8381
Average	41.8	50.7	0.209	0.0217	0.0635	19.1	8219

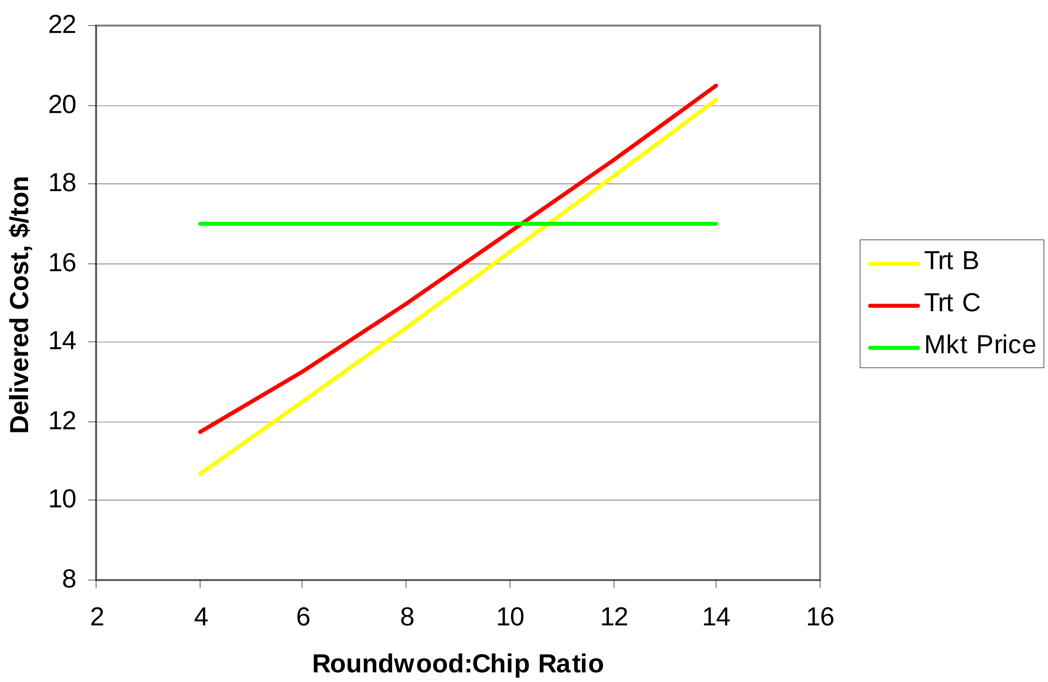

Figure 2. Estimates of delivered chip costs for treatments B (limbs & tops) and C (limb/top/understory) as the number of loads of roundwood required to produce one load of chips varies.

before a load of chips is made that this modified system will break even if the market price for fuel chips is $17 per ton. Lower or higher market prices will affect the projected breakeven point.

CONCLUSIONS

We did not see a significant difference in roundwood production per acre or per hour after adding a chipper to a ground-based tree-length southern pine harvesting operation. Under the right conditions, it appears that a small chipper can be added to obtain additional chip production without adversely impacting roundwood production. Our study involved relatively low volumes of biomass removals (3.8 and 10.8 tons per acre) and the chipper easily handled this volume. Our cost projections suggest that removing only limbs and tops may be marginal in terms of cost as one load of chips was produced for about every 15 loads of roundwood. When small understory stems on the site were also harvested and chipped with the residual limbs and tops, total chip production increased to 10.8 tons per acre or one load of chips for every 5 loads of roundwood. While this approach required additional work from the felling and skidding operation, roundwood production did not suffer significantly and costs appear favorable for this treatment.

The chips produced from these biomass sources worked well in the electricity co-generation plant where they were burned and our lab analyses suggest that the chips also have very competitive heating values. Future work will focus on potential site preparation savings as the sites are raked prior to bedding and replanting. Treatment C sites should require less of this practice due to the higher volume of material removed. We will also monitor the site to see if nutrient issues result from this biomass removal. We also plan to replicate the study on an upper coastal plain site more typical of southeastern forests and to evaluate these chips and those from other sources as a potential feedstock for pyrolysis, gasification, and fermentation processes.

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