CHIP PROPERTIES FROM OPERATIONAL HARVESTS OF PINE STANDS IN THE SOUTHERN US

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ABSTRACT

A thorough body of literature exists to describe the characteristics of tree components (wood, bark, and foliage) for use in bioenergy production. Relatively little information is available, however on the characteristics of wood biomass feedstocks gathered directly from the forest. We designed a controlled experiment to assess the characteristics of operationally harvested wood chips across a variety of stand ages, species, and soil types in the coastal plain of Georgia. A whole tree chipping crew harvested ten stands, five loblolly pine (*Pinus taeda*) and five slash pine (*P. elliotti*), in the coastal plain of Georgia. Five samples of chips were taken from each tract during harvesting from trees dispersed across the sites. Size classification and bark, foliage, and moisture content were assessed, as well as full nutrient content analyses and both energy and ash content. Site and stand factors impacted moisture content of samples, as well as operational factors such as time between felling and chipping.

INTRODUCTION

The rapid development of wood-based bioenergy markets in the southern United States has created a need for detailed understanding of the properties of the forest resources readily available for bioenergy production. Many lab-based analyses on the properties of wood, bark, and foliage have been performed to determine the characteristics of both hardwood and softwood fuels. Howard (1973) showed that pine needles typically produce more energy per pound than does pine bark while bark has slightly higher energy per pound than wood.

While this information is extremely useful to understanding the energy characteristics of the resource, biomass delivered to consumption facilities can be a combination of all three components of the tree in addition to any possible contaminants that may be introduced during the harvesting process. Extensive, field-based sampling is needed to assess the range of possible feedstock characteristics and successfully match feedstocks to potential markets. A careful analysis will ideally identify correlations between site, stand, and operating conditions and both desirable and undesirable feedstock properties.

This report details an extensive analysis of wood samples collected over five weeks from a whole-tree chipping crew operating across a range of timber stand types in southeastern Georgia. This analysis will further improve the level of knowledge regarding the characteristics of woody biomass produced by in-woods chipping.

METHODS

Ten tracts were selected from the Coastal Plain of Georgia. Tract acreage ranged from 5.5 to 42.2 acres, with ages ranging from 8 to 17 years. Five tracts were loblolly pine (*Pinus taeda*) plantations and five were slash pine (*P. elliotti*) plantations. On each tract, five plots were established covering the range of topography and soil types represented. Twenty-five trees were marked for removal in each plot. A different color of paint was used on each plot within a tract to differentiate them. A subset of painted trees was measured for diameter and height.

Each tract was thinned by a logging operation using one feller-buncher and two grapple skidders. Stems were fed into a Morbark 30/36 drum-style chipper. In each painted plot, all marked stems were felled and placed into a single bunch for extraction by the skidder. As each painted bunch was brought to the landing and fed to the chipper, we sampled the chips using a chip sampling tube placed near the throat of the chipper. At roughly 20-second intervals during the chipping of the painted trees, we placed the sampling tube into the stream of chips for 5-10 seconds to collect a sample of roughly twenty gallons. All painted trees were fed to the chipper with the limbs intact. This sample was thoroughly mixed, and three subsamples of approximately 2 kg each were placed in heavy-duty paper bags. Each bag was immediately placed on a scale and exact weight was recorded. Temperature and humidity at the time of sampling was recorded, as well as the duration of time between the felling of stems and their chipping.

Two of the sample bags were placed in a 105 degree C oven for 24 hours drying. Oven-dry weight and moisture content were recorded. One of the sample bags was kept intact as a backup, while the other was processed in a hammermill through 1mm screens and sent to the University of Georgia Soil, Plant and Water Analysis Lab for total mineral analysis as well as combustion in a bomb calorimeter to determine energy and ash content. The third sample bag was sorted in a chip classifier to determine the size distribution of the chips. Samples were sorted into seven size classifications: <3 mm, 3-5 mm, 5-7 mm, 7-15 mm, 15-45 mm, 45-63 mm and >63mm. Foliage and bark content were also recorded with foliage removed from the full sample, and bark weighed separately from wood down to 7 mm. Inner and outer bark were not differentiated. For the purposes of this report, chips sized 15-63 mm were deemed acceptable or "Accept", >63mm were oversized or "Overs", 7-15mm were considered undersized "Under", 3-7 mm were considered "Fines", and <3mm "Dust". It should be noted that adjustments to the chipper anvil and sharpened angle of the knives were not made, which could have a substantial impact on the size distribution.

We examined the chip properties to determine if any significant differences occurred between the samples. Samples were collected from trees growing in seven different soil types; however, many of the soils were only represented by a small number of samples. To draw meaningful comparisons between properties of wood chips from different soils, statistical tests were performed on characteristics of the soils, such as texture, drainage class, and site quality, as determined by the soil classification. Energy, ash, and moisture content were regressed against site and stand parameters to determine which conditions were influential in determining feedstock properties. Stand and harvest conditions were also examined to determine if they were useful in predicting the size distribution of chips produced.

RESULTS

Moisture content did not vary significantly between species (Table 1). A regression of moisture content against recorded stand and site parameters yielded the following equation:

$$MC (\%) = 64.08 - 0.177 * SI - 0.571 * Age + 0.075 * Temp$$

$R^2 = 0.478$
$P < 0.001$
SI = Site Index for loblolly pine, base age 25, feet
Age = Current age of the stand, years
Temp = Ambient air temperature at time of sampling, degrees F

The equation suggests that younger stems have higher moisture content and faster growing stems (higher site index) have lower moisture content. It also shows a very weak positive relationship between the temperature at the time of sampling and the moisture content of chips. As none of the stems processed were on the ground for more than four days prior to chipping, the expected result of higher temperatures driving moisture content lower was not observed.

Moisture content tended to have a weak but significant positive correlation with most of the chemical properties tested. Exceptions were energy, carbon, manganese, sodium, and silicon levels. Foliage content also correlated with moisture content, which may explain some of the nutrient level impacts, as foliage correlated with many of the nutrient levels tested.

Table 1: Chip properties compared between loblolly and slash pine (n = 50).

Wood Chip Characteristic	Loblolly	Slash	*P* - value
Moisture Content (% wet basis)	51.8	50.5	*0.122*
Energy Content (BTU/lb)	8304	8394	*0.031*
Ash Content (%)	0.53	0.46	*0.222*
Accepts (% 63-15 mm)	48.5	44.4	*0.031*
Foliage Content (% of wet weight)	1.2	1.3	*0.725*
Bark Content (% of wet weight)	10.5	14.8	*0.001*
Carbon (%)	48.0	47.8	*0.687*
Nitrogen (%)	0.10	0.09	*0.352*
Phosphorous (ppm)	113.3	110.1	*0.792*
Potassium (ppm)	423.8	403.9	*0.599*
Silicon (ppm)	174.2	58.9	*0.001*

Energy and Ash Content

Energy content of chips ranged from 7866 to 8656 BTU/lb. A small but significant difference in average energy values was seen between loblolly pine and slash pine (Table 1). The higher heating values (HHV) calculated for chip samples are slightly lower than many reported values for wood, bark, and needles of southern pines individually, but are consistent with reported averages for pine limbs and tops (Howard 1973). Wang et al. (1982) reported average energy content around 8500 BTU/lb for slash pine stem and bark wood in northern Florida. Two samples produced HHV below 7900 BTU/lb, while all other samples were above 8050 BTU/lb.

Ash content of samples varied between 0.24% and 1.32% of dry weight. Ash did not vary between species (Table 1). Ash levels correlate with age of the stand (Figure 1), but did not correlate with foliage content (Figure 2) or bark content.

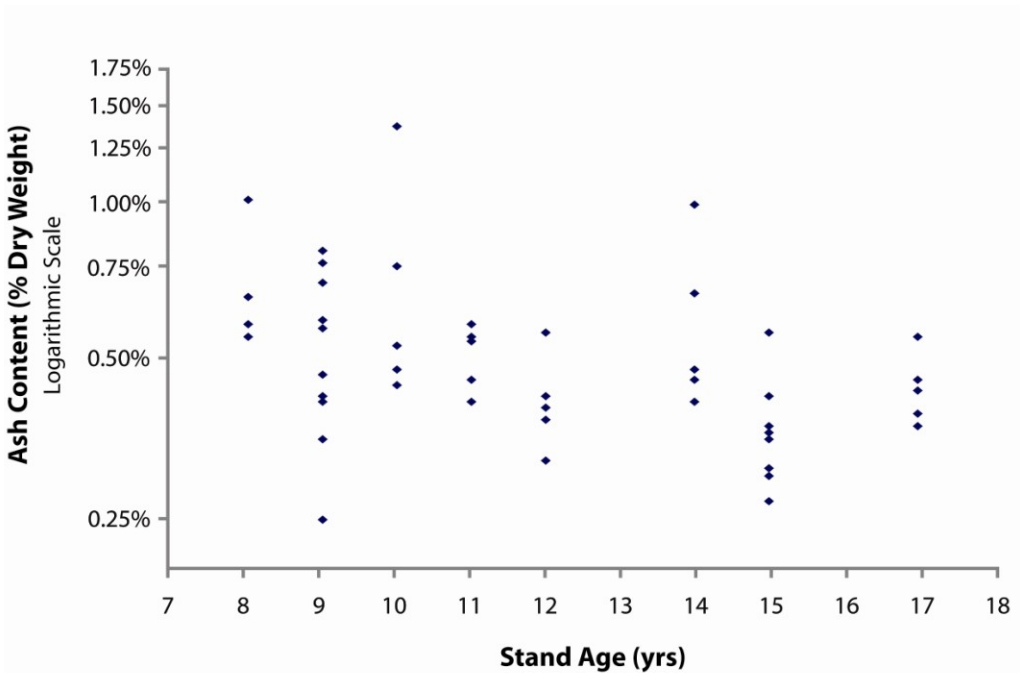

Figure 1: Relationship between stand age and ash content of chips as a percent of the dry weight. Ash content is represented on a logarithmic scale to more clearly represent the differences at lower values.

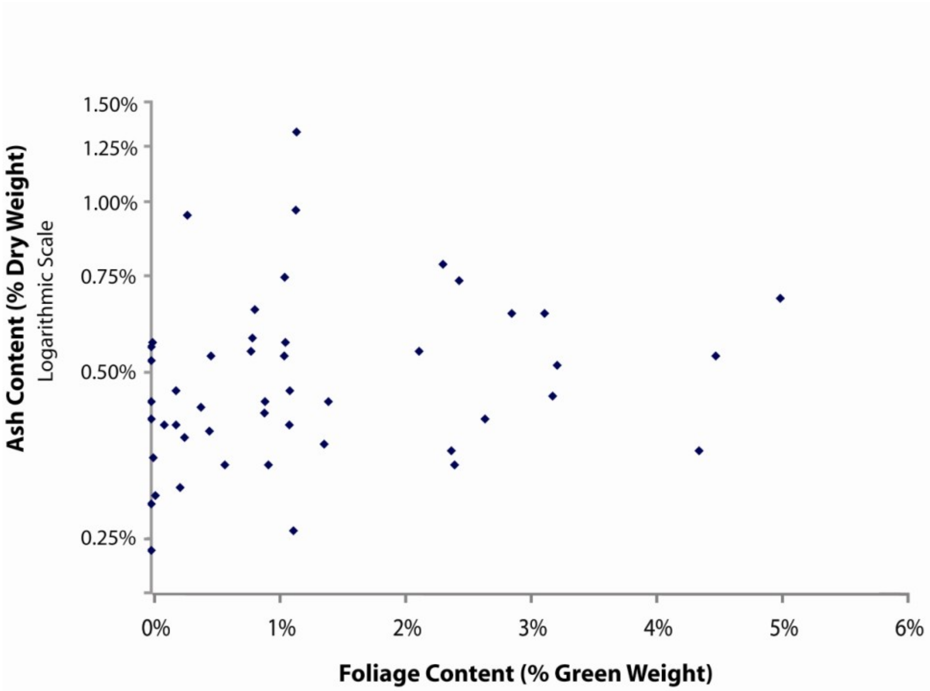

Figure 2: Relationship between measured foliage content and ash content of chips as a percent of the dry weight. Ash content is represented on a logarithmic scale to more clearly represent the differences at lower values.

Soil Properties

A number of chip properties appear tied to soil properties. Energy content differed between soil drainage classes, with "poorly drained" soils representing the highest energy levels. Examining closer, slash pine samples taken from poorly drained soils produced the highest HHV, while loblolly pine samples taken from similar sites were among the lowest. Site quality as indicated by soil type did not correspond in any meaningful way with energy content, nor did soil texture indicators; though both were correlated with moisture content of wood chips. Samples taken from spodic soils had higher average moisture contents than other soils, but it should be noted that only one site had soils of this type, corresponding to the youngest stand of trees sampled. Nutrient levels in the chip samples were often correlated to soil properties. Potassium levels tended to increase with increasing site quality or decreasing soil drainage class. Carbon and nitrogen levels were significantly different between differing site quality and drainage classes, but did not exhibit any consistent patterns. Ash and silicon levels in the chips were independent of any tested soil properties.

Size Distribution

Chips sized 63-15 mm averaged 48% of the total weight of chips, with loblolly pine averaging roughly 4.6% higher accepts than slash pine (Figure 3). Slash samples had approximately 3% greater proportion of chips as fines (3-7 mm) and 1% greater as dust (<1 mm).

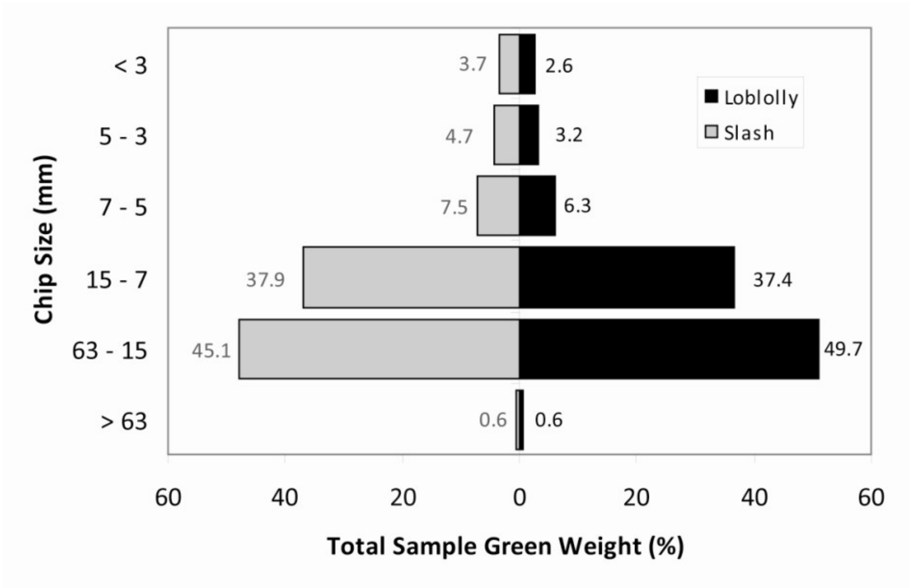

Figure 3: Size distribution of wood chips from loblolly pine and slash pine stands.

Knife wear had very little impact on chip size distribution (Figure 4). Samples chipped within the first five truckloads processed by a set of knives averaged 52% accepts, 4% greater than samples chipped by knives with greater wear. No differences in the percentage of acceptable chips were seen after five loads had been chipped on a set of knives. The majority of the shift in acceptable chips resulted in an increasing proportion of undersized chips (15-7 mm). No consistent changes were observed in smaller sized chips.

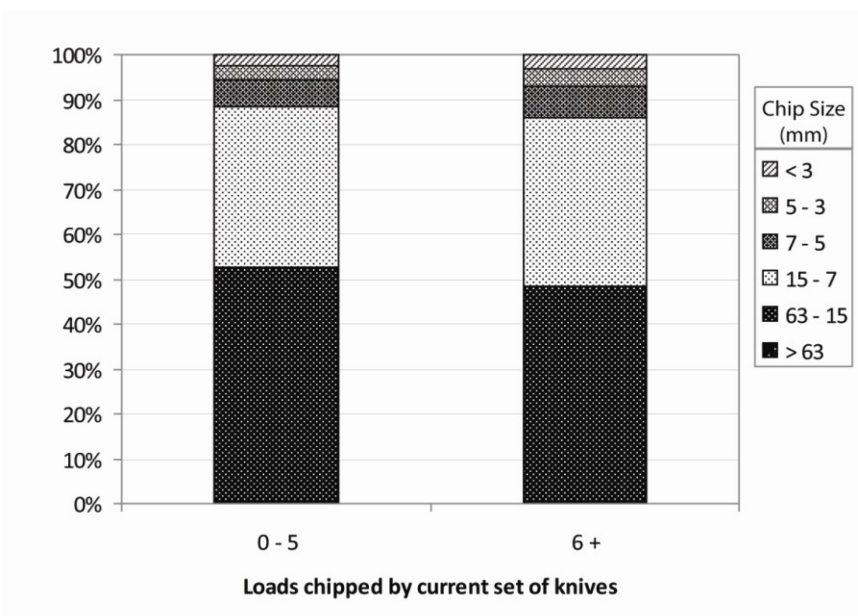

Figure 4: The impact of knife wear, as measured by the number of truckloads of chips processed prior to sampling, on the size distribution.

Foliage and bark levels were correlated with phosphorous, sulfur and nitrogen concentrations in the wood samples (Table 3). None of the correlations were particularly strong (the strongest is between bark and sulfur contents and corresponds to an r^2 of only 0.30), but they were significant despite the numerous other sources of variability in the data, such as species, age, and site differences.

Table 2: Correlation (Pearson's *R*) between foliage and bark content and chip properties. Statistically significant correlations are highlighted in bold font ($p < 0.05$).

	Foliage Content		Bark Content	
	Correlation (*R*)	*P* - Value	Correlation (*R*)	*P* - Value
Moisture Content (% wet basis)	0.319	*0.008*	0.192	*0.114*
Energy (BTU/lb)	-0.100	*0.491*	0.063	*0.666*
Ash (% dry wt)	0.182	*0.206*	0.206	*0.151*
Carbon (% dry wt)	0.082	*0.571*	0.215	*0.133*
Nitrogen (% dry wt)	0.408	*0.003*	0.338	*0.017*
Sulfur (% dry wt)	0.449	*0.001*	0.550	*< 0.001*
Aluminum (ppm)	0.148	*0.303*	0.100	*0.488*
Calcium (ppm)	0.244	*0.088*	0.223	*0.119*
Iron (ppm)	0.076	*0.599*	-0.113	*0.434*
Manganese (ppm)	0.003	*0.984*	-0.321	*0.036*
Magnesium (ppm)	0.227	*0.113*	-0.062	*0.669*
Phosphorous (ppm)	0.448	*0.001*	0.394	*0.005*
Potassium (ppm)	0.116	*0.422*	0.236	*0.099*
Silicon (ppm)	0.186	*0.196*	-0.256	*0.073*
Zinc (ppm)	0.070	*0.658*	-0.101	*0.523*

DISCUSSION AND CONCLUSIONS

Moisture content of the samples agreed with previous studies showing "fresh" chips between 50 and 55% moisture. The lack of a correlation between moisture content and the amount of time between felling and chipping of stems was unexpected. Previous studies examining field drying of stems have suggested that reductions in moisture content will occur following harvest (Klepac *et al*. 2008). The trees left to dry longest in this study remained on the ground four days prior to chipping, while the quickest were chipped within an hour of felling. All of the harvests were thinnings, so most of the felled stems sat under at least partial shade as well. No difference was seen in moisture content when comparing the ten samples which had been felled longest and the ten which were chipped the quickest (p = 0.416). This implies that within a conventional harvesting operation, separating felling and skidding by as many as three or four days does not seem to offer a distinct moisture content advantage.

In general, older stands had lower ash and moisture content. Slash pine stands exhibited decreased energy content in older stands (slash pine stands ranged in age from 10 - 17 years old), while loblolly pine stands showed no pattern (age range 8 – 15 years old). There is no previous research to suggest a negative correlation between age and energy content, which implies there may be other factors causing this result for slash pine stands.

Ash content in all samples was similar to levels found in whole-tree chip samples from previously reported studies. Aman *et al*. (*in review*) found ash content of 0.6% in whole tree chips. Chips produced solely from limbs and tops of pine stems, by comparison, averaged 1.5% in previous studies (Baker 2010). The top of the tree appears to be the portion most likely to gather dirt during ground-based extraction, so when a substantial portion of the stem is included in the chipping material, a smaller percentage of the total volume will contain high ash contents.

The size distribution of chips varied from sample to sample, but was fairly stable overall. Given the knife setup on the chipper, roughly half of the weight of chips produced was within the 16 – 63 mm range. A slight adjustment on the knife arrangement could likely increase this proportion significantly. The percentage of acceptable chips only decreased 4.5% as the knives became worn, with no significant reductions after five loads had been chipped. A significantly higher proportion of loblolly pine chips were within the acceptable size range, despite no differences in the average knife wear between stands of the two species. If stringent size requirements for chips are in place, this may warrant further investigation.

ACKNOWLEDGEMENTS

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