TRANSPIRATIONAL DRYING EFFECTS ON ENERGY AND ASH CONTENT FROM WHOLE-TREE CHIPPING OPERATIONS IN A SOUTHERN PINE PLANTATION

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ABSTRACT

Newly announced North American bioenergy projects will likely increase the demand for woody biomass substantially over the next five to ten years. High harvesting and transportation costs for woody biomass from forests are commonly identified as key constraints to expanding this new industry and meeting expected wood fiber demand. In addition to a cost-competitive feedstock, wood energy facilities prefer drier raw material to maximize energy content and cleaner material with less dirt or grit to minimize the ash remaining after combustion.

We examined extended transpirational drying times of felled trees to study their correlation with moisture, ash, and energy content. We compared production rates and material properties for three drying treatments of felled trees in a 14-year old planted loblolly pine stand: (1) drying in the field for approximately eight weeks, (2) drying in the field for approximately four weeks, and (3) freshly felled (or green) trees. A range of operational variables including fuel consumption, knife wear, chipper productivity, the number of stems per linear foot of trailer, and tons per linear foot of trailer were also compared.

INTRODUCTION

Higher market prices for fossil fuels as well as proposed policy changes to support renewable energy and reduce carbon emissions have recently led to a large number of bioenergy projects being announced which will consume woody biomass. Projects announced for North America as of September 2009 will substantially increase wood energy capacity and will potentially consume more than 60 million green tons of wood biomass feedstock (RISI 2009). A survey of top state forestry officials recently identified high harvesting and transportation costs for woody biomass from forests as the top constraint to expanding this potential new industry (Aguilar and Garrett 2009).

Harvesting systems that could supply these renewable energy facilities already exist, but each operates with a different incoming feedstock (residues, understory, standing trees, etc.) and produces a product that differs in its characteristics (moisture content, particle size and uniformity, ash content, etc.). Few studies have examined methods that could improve woody biomass characteristics in the field to add value to the feedstock required by bioenergy facilities.

It is important for woody biomass feedstock to have low moisture content to increase its energy value (BTU). A greater energy value results in greater burning efficiency. The amount of ash content is a critical characteristic for woody biomass feedstock. Woody biomass with high ash content is considered to have poor quality because it results in poor combustion performance and additional disposal costs (Sarenbo 2009). The biomass harvesting system employed, type of woody biomass material, and the manner and duration of how woody biomass is stored or piled on-site are all factors affecting moisture and ash content (Pettersson and Nordfjell 2007).

The timber harvesting and wood supply chain in the United States is globally competitive and is well positioned to add woody biomass to the list of products it delivers. However, there are some significant issues to be addressed to support these new wood-using industries. Most traditional forest industries (paper and building products) purchase their raw material today on a green ton basis. In fact, several states in the US South require exclusive use of the green ton as a measurement method when stumpage is purchased on a pay-as-cut basis from landowners. There are several advantages to this method, including ease of automation of the weighing of trucks and the incentive a green ton basis provides to logging contractors to deliver fresh wood to markets. Fresh wood provides higher pulp and tall oil yields in most pulp processes as well as limiting checking and blue stain issues with sawtimber.

Wood energy markets (biorefineries, pellet manufacturers, wood-fired electric plants, and wood to liquid fuel processes) are often interested in procuring raw material that has less moisture content than green wood to obtain a higher energy (BTU) value. Each 10% reduction in moisture content can increase the BTU value of the wood by approximately 850 BTU (Ince 1979). Freshly felled trees have a moisture content of approximately 50% (wet basis) – this varies somewhat by species – but if allowed to dry for four weeks before delimbing and processing, moisture content can be reduced to 30-35% (Stokes *et al.* 1993). This delayed delimbing and bucking is known by several names but we will refer to it as *transpirational drying*. Wider use of transpirational drying could have several significant benefits for wood energy markets. For example, it removes moisture content without consuming any wood or fossil energy. It also eliminates the need to transport the water contained in green material, thus increasing the net energy content of each truck payload. This could lead to fewer truck trips needed to move the same energy content to markets, thus saving fuel and further improving net energy ratios. On the other hand, drier material is commonly reported by logging contractors to drastically increase the need to sharpen chipper knives which increases maintenance costs and reduces knife life. This can also reduce chipper productivity.

While reducing moisture content is critically important, keeping ash content low in combustible woody fuels is also important. This study assesses if increased drying times are correlated with reduced moisture content and increased ash content.

METHODS

The study was conducted from August to October 2010 on a 14 year-old loblolly pine stand in Jones County, Georgia. Trees were felled in rows and allowed to transpirationally dry eight and four weeks prior to chipping. Green stems were felled in conjunction with the chipping operation. A 600 horsepower Morbark 40/36 drum-style chipper was used to chip the material.

Figure 1: 600 horsepower Morbark 40/36 drum-style chipper.

Climate data, including daily temperature and rainfall, were obtained from the National Weather Service for the drying periods. Additionally, a rain gauge located on the study site was used to monitor weekly rainfall during the drying periods.

To quantify production impacts, common work sampling and time study methods were used to record data on the harvesting system (Baker, et al. 2010, Westbrook, et al. 2007). Continuous activity data were recorded separately for the three treatments. Machine activity codes were recorded for the chipper and knuckleboom loader on-site every two minutes for the duration of the field study to establish mechanical availability, utilization, and sources of delay. Loading times and load weights for each truck load were also recorded.

During the loading of each truck, a 6” diameter PVC pipe with an elbow was used to collect samples from the chip stream. Samples were collected several times during the loading of a van and mixed for a composite sample. From this sample a 4-5 lb sample of chips was collected and placed in a kraft paper bag. The bag was immediately weighed to determine the field (or wet) weight of chips. The bags were then transferred to a 105 degree C oven for 24-48 hours and reweighed to determine the field moisture content.

After drying five bags were randomly selected from each harvesting treatment for further analysis. These bags were fractioned, with roughly one-eighth of the sample processed through a 1mm screen Wiley mill and transferred to the University of Georgia Plant, Soil, and Water Lab for determination of energy, ash, and nutrient concentrations. The remaining seven-eighths of the bag was transferred to a chip classifier. The sample was oscillated in one dimension for ten minutes to separate the chips based on their length. Four round-holed classification screens were used to determine the size distribution: 45mm, 15mm, 7mm, and 3mm. Foliage was removed from the sample and weighed separately. Bark was separated and weighed separately from wood for chips collected in the 45mm, 15mm, and 7mm trays.

Production data were compared using analysis of variance with Tukey's range test used for means comparison. Wood chip data were limited to five samples per treatment, necessitating use of Kruskal-Wallis exact test for comparison. Work sampling data were analyzed using chi-square test to look for differences in the distribution of work amongst categories.

RESULTS AND DISCUSSION

Average temperature for the 8 week drying period was 76° F and 71° F for the 4 week drying period. The amount of rainfall obtained from the National Weather Service and verified by the on-site rain gauge was 7.1 inches for the 8 week drying period and 5.2 inches for the 4 week drying period.

Moisture content of the samples varied significantly based on the length of transpirational drying (Figure 2). Each subsequent four-week drying period significantly decreased the moisture content of chips produced ($p < 0.05$), with the largest reduction occurring following the first four-week period. The reduced moisture content had a significant impact on the weight of material able placed in chip trailers (Figure 3). The field weight of chips per linear foot of trailer decreased significantly with each subsequent four-week drying period ($p < 0.05$). When examining the volume of materials in the trailer on a dry-ton basis, there was no significant difference in the tons per linear foot. Thus the volume of material in the trailer appeared to be equal across the treatments, although the weight was reduced.

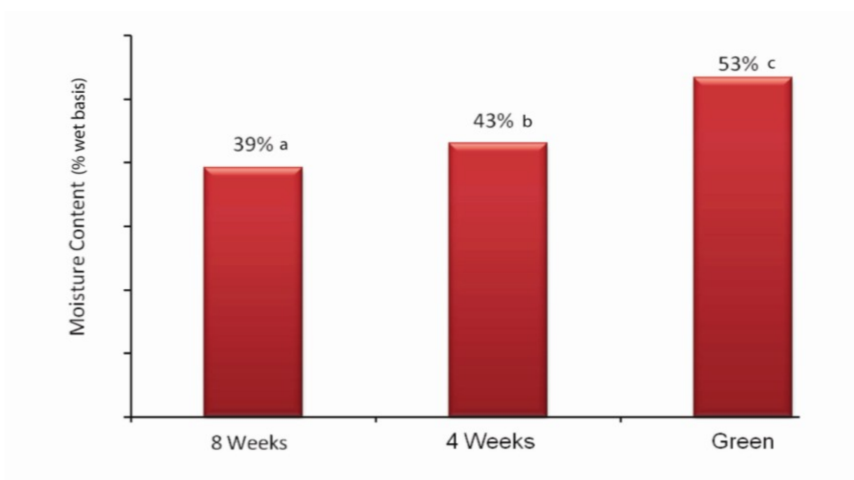

Figure 2: Moisture content of wood chips harvested fresh and allowed to dry four and eight weeks. Different letters indicate significantly different values ($p < 0.05$).

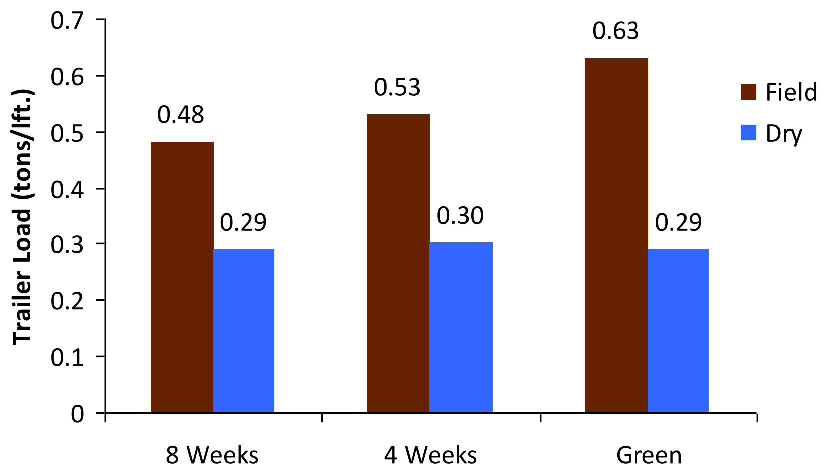

Figure 3: Average weight of chips per linear foot of loaded chip van from stems chipped green, and stems allowed to dry four and eight weeks respectively.

Age of the material had a significant impact on the productivity of the chipper as measured by field tons produced per hour (Figure 3). A significant difference was not observed between material dried eight weeks and material dried four weeks, but chipping productivity of both was lower than for green materials ($p < 0.05$). Converting the material produced to a dry ton basis using the measured moisture content reveals the chipper productivity also varied as measured by dry tons produced per hour; however, now the productivity from the green treatment is significantly lower than from either of the dried treatments (Figure 4). Thus, the chipper is able to produce a slightly (12%) greater volume of material per hour if the feedstock is dried, but it cannot produce an equal weight of material per hour.

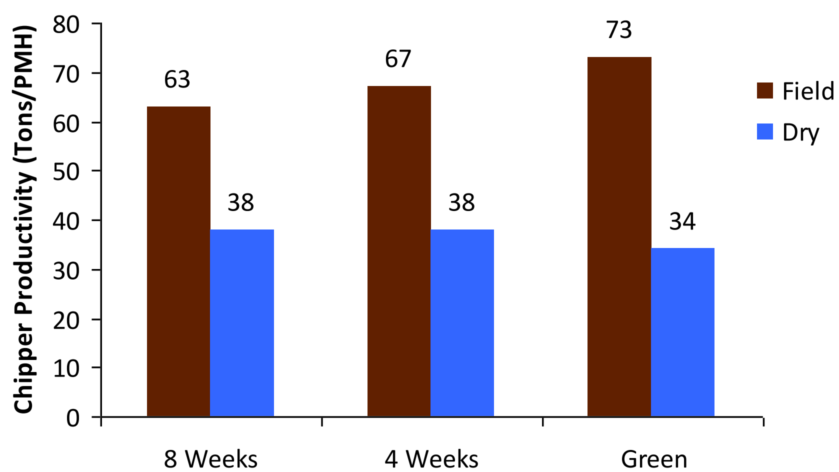

Figure 4: Productivity in green and dry tons produced per productive machine hour of a chipper processing freshly cut stems and stems dried for four and eight weeks respectively.

Utilization data show that the chipper was able to spend a significantly higher percentage of its time chipping in the oldest treatment (eight weeks) compared to either the four-week old or green material (Figure 5, $p < 0.05$). Most of the shift came from time spent working on the chipper in the fresh and four-week old treatment. Given the short timeframe of this study, it is uncertain that this result would be repeated over a longer time period.

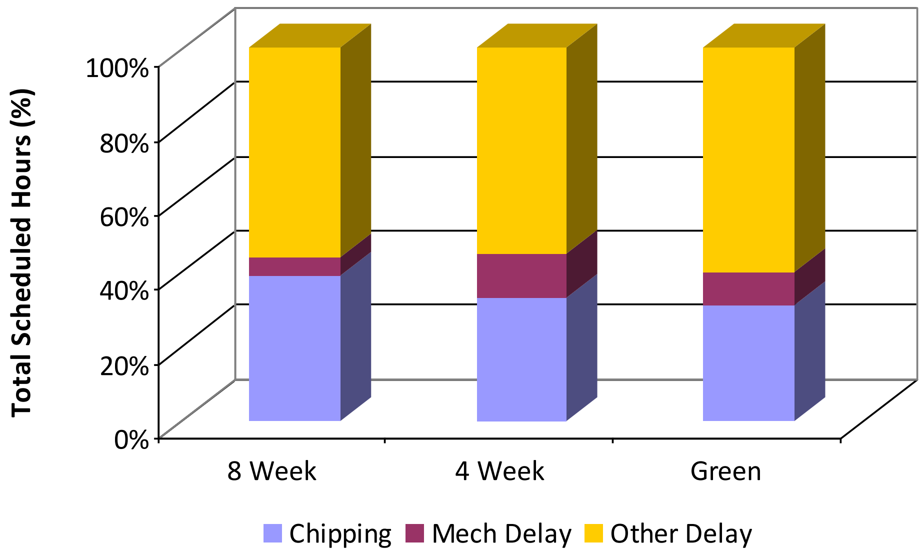

Figure 5: Distribution of total scheduled hours spent chipping the freshly felled four-week old and eight week old treatments.

Insufficient fuel measurements were taken to allow for a statistical test of fuel consumption between the treatments, but observed fuel consumption did not vary substantially (Figure 6). The duration of the study also did not require a sufficient number of knife changes in any treatment to allow for statistical analysis. Both the eight and four week treatments changed knives once during the duration of the study, after ten and fifteen loads respectively, while the knives were not changed during chipping of the green treatment (28 truck loads).

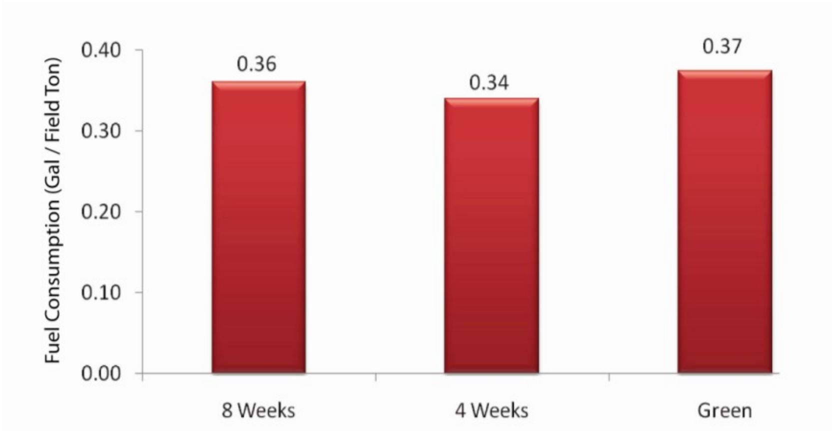

Figure 6: Fuel consumption of the chipper while processing stems harvested fresh and stems which had been allowed to dry for four and eight weeks, respectively.

There were visually noticeable differences in foliage content between dryer stems versus green stems. There were more pine needles on the ground in thinned rows and on chipping decks for in areas where stems had dried (Figure 7).

Figure 7: Pine foliage within rows for dried material (left) versus green material (right).

No significant differences existed between either energy or ash content for chips in the three treatments (Table 1). Energy content for chips are consistent with previous tests on pine feedstocks. Ash contents of less than one percent are also in-line with previous studies on field-run whole-tree chips (Baker, *et al*. 2011).

Table 1: Energy and ash content of wood chips harvested fresh and harvested after drying four and eight weeks, respectively.

Treatment	Energy Content (BTU/o.d. lb)	Ash Content (% o.d. wt)
Green	8200	0.69
Four Weeks	8330	0.54
Eight Weeks	8160	0.60
Average	**8230**	**0.61**

SUMMARY

Moisture content was reduced from 53% for green material to 39% for material allowed to transpirationally dry in the field for eight weeks in late summer. Each four-week drying period resulted in significant reductions in moisture content. There was less truck payload associated with dryer material. The green weight of chips per linear foot of trailer decreased significantly with each subsequent four-week drying period.

The chipper productivity study indicated that the chipper is able to produce a greater volume of material per hour if the feedstock is dried, but it cannot produce an equal weight of material per hour. Fewer tons were produced and loaded for dryer material, which could result in producing material with higher energy content, though there were no significant differences in BTU values for the three treatments. The small sample sizes for BTU values might explain this lack of difference.

ACKNOWLEDGEMENTS

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