Effect of In-Woods Storage of Unprocessed Logging Residue on Biomass Feedstock Quality

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Abstract

An air-drying process was designed to avoid material decomposition and eliminate the high cost involved in other drying and storage methods. This process, which involved no chipping of biomass at the harvest site, was tested at two study sites in Escanaba, Upper Peninsula, Michigan, from June to November 2011. The primary objective of this study was to evaluate the effect of air-drying on biomass moisture content (MC) and higher heating value (HHV) over field storage. In addition the impacts of different positions within a pile, biomass pile sizes, and weather conditions on biomass moisture change were also tested. Results showed that biomass MCs were significantly reduced during the 5-month field storage period. In addition, the biomass MCs at different positions within a biomass pile were found to be statistically uniform. Results further suggested that making a biomass pile smaller is an appropriate way to store woody biomass when it is scheduled for short-term use, while larger piles should be considered as an option for long-term storage. Biomass HHVs were found to be stable during the 5-month storage period. These results indicate that field piling of unprocessed biomass is a reliable solution for year-round biomass supply without incurring additional costs. Regression analysis also showed that field-stored biomass MC can be significantly impacted by air humidity, while the effect of air temperature and cumulative precipitation on biomass MC was minor.

As petrochemical prices rise, there is an increasing interest in replacing fossil fuels with clean, renewable energy. Renewable energy has represented 9 percent of the total energy supply in the United States; 49 percent of the renewable energy production used biomass as a source, where about 57 percent of the biomass is forest-based biomass (Energy Information Administration 2012). As a potential feedstock for renewable energy production, forest-based biomass, including commercial logging residues, must be supplied to the end users in a continuous and reliable way (Perlack et al. 2005).

In most regions in North America, green biomass is directly processed into small chips by mills or other wood-using facilities. This introduces many problems and concerns, such as a risk of self-ignition, health issues caused by the release of high concentrations of allergenic microspores, and most important, dry matter loss followed by the decrease of the biomass quality (Fredholm and Jirjis 1988, Jirjis 1995). Previous studies showed that the dry matter loss in a large green chip pile was approximately 12 percent during a 7-month storage period (Hornqvist and Jirjis 1999). A dry matter loss of 26 percent was also found in large bark piles throughout a 6-month storage period (Fredholm and Jirjis 1988). In addition, the dry matter loss in the large bark pile resulted in a 20 percent reduction in energy content (Fredholm and Jirjis 1988), thus lowering the energy yield and the value of woody biomass feedstock.

Several studies highlighted that the storage of logging residue in bundles can produce high-quality biomass feedstock with low moisture content (MC), increased higher heating value (HHV), and low ash content (Lehtikangas 2001, Pettersson and Nordfjell 2007, Afzal et al. 2010). Patterson et al. (2008) reported that the MC of biomass bundles decreased by 10 to 25 percent within 1 month after piling. Meanwhile, Karha and Vartiamaki (2006) found that the reduction of MCs resulted in a 12 to 28 percent increase in energy content per unit volume. The major problems in producing biomass bundles with a slash bundler is the low productivity and the high hourly cost due to delays caused by saw binding, materials handling, twine spool collapse, and slow movement at the site (Leinonen 2004, Rummer et

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al. 2004, Patterson et al. 2008, Harrill 2010). This makes the economic feasibility of using the savings from transporting low MC and highly compacted biomass to pay for the cost of bundling operations questionable.

Michigan is a state covered with a large area of vigorous and healthy forest. With 84 percent forest cover, forestry is the top industry in the Upper Peninsula of Michigan. Due to weather, ground conditions, or biological constraints, forest harvesting operations are not always possible. With the increased interests in developing wood-based renewable energy production in Michigan, ensuring a year-round supply of high-quality woody biomass feedstock with consistently low MC and high HHV without incurring extra processing cost becomes imperative.

Previous studies found that woody biomass is better stored in a loose form, allowing more air movement to take place within the pile (White et al. 1983, Thornqvist 1985, Sampson and McBeath 1987, Jirjis 2005, Afzal et al. 2010). Given that wood chip quality degrades with time and that new bundling technologies are expensive, an on-site air-drying process was designed and tested in a forest stand in the Escanaba area of northern Michigan in 2011. The objectives of this study were to evaluate the effect of air-drying on biomass MC and HHV over field storage as well as to evaluate the impact of different positions within a pile, biomass pile sizes, and weather conditions on biomass moisture change.

Methods

Study sites

The two study sites were both located in Escanaba, Upper Peninsula of Michigan. The first study site (Site 1) was a mixed-species forest stand containing various hardwood and softwood species, including sugar maple (*Acer saccharum*), red maple (*Acer rubrum*), and white spruce (*Picea glauca*). The second study site (Site 2) was located in a red pine (*Pinus resinosa*) stand, 45.4 miles away from Site 1. The monthly precipitation at both sites averaged from 0.5 to 4.1 inches from June to November 2011 (Fig. 1), and the monthly maximum temperature varied from 53.4°F to 84.2°F (Fig. 2).

A mechanized cut-to-length harvesting system was used to harvest the trees at the two study sites from June 1 to 25, 2011. At Site 1, logging residues, including limbs, tops, and broken logs, were shuttled to the roadside and piled by a Ponsse Buffalo forwarder with 15 tons of loading capacity (Figs. 3 and 4). The resulting residue piles averaged 86 feet long, about 34 feet wide, and 15 feet high (sample size, $n =$ 18). At Site 2, the forwarder piled the logging residues into two different sizes. Small, cone-shaped piles were made with a geometric dimension of 9 to 10 feet in diameter and 2 to 3 feet in height, while the large piles were piled into a shape and size similar with those at Site 1. A total of 60 small piles were established in three rows under partial shade of the residual stands after the thinning treatment, while three large piles were piled without touching any of the residual stand crown shade (Fig. 5).

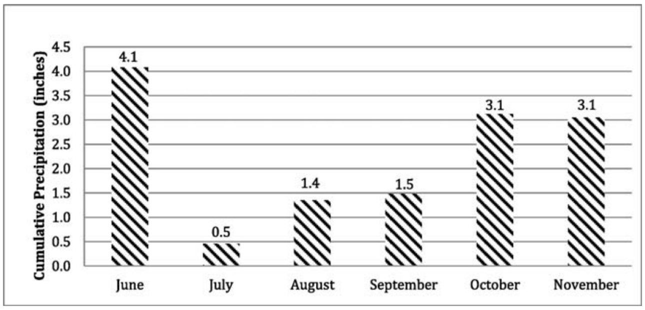

Figure 1.—Local cumulative precipitation at two study sites around Escanaba area, Michigan, from June to November 2011 (Michigan Agricultural Weather Network).

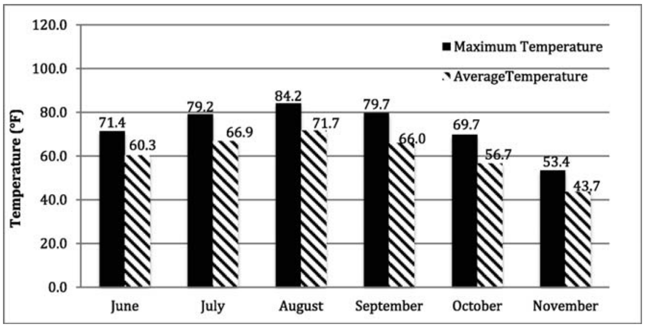

Figure 2.—Monthly average of daily maximum temperatures and overall monthly average temperature at two study sites around Escanaba area, Michigan, from June to November 2011 (Michigan Agricultural Weather Network).

Data collection and analysis

From June to November 2011, biomass was sampled from field-stored piles once every month at both study sites. In each sampling site visit, 13 piles were randomly selected from the 35 piles at Site 1 (Fig. 6). At Site 2, 21 randomly picked small piles and all three large piles were used for collecting samples. In addition, for large piles at both sites, two positions were randomly selected from top, middle, and bottom areas in a pile. A log loader and chokers were used to drag out wood residue samples from the selected areas within a residue pile. Meanwhile, a small mobile chipper was used to immediately convert limbs and tops into wood chips. The MC of the sample wood chips was measured at the Michigan State University Forest Biomass Innovation Center following ASTM E 871-82 (ASTM International 2003a). The HHV of the sampled wood chips was tested at

Figure 3.—Residue forwarding from stump area to the landing by a cut-to-length forwarder in this study.

Figure 4.—Roadside-piled loose logging residues at study Site 1.

Michigan State University using an oxygen bomb calorimeter according to the standard described by ASTM E 711-87 (ASTM International 2003b).

Monthly weather data at both study sites were obtained from the Michigan Agricultural Weather Network. To test whether the biomass MC is significantly reduced by the air-drying process, analysis of variance (ANOVA; $\alpha = 0.05$) was used to compare the initial and final MC. Tukey's pairwise mean comparison test structured within the software SYSTAT 13 (Systat Software, Inc. 2009) was used to compare the differences between biomass MCs and HHVs from each date to detect significant change during the storage period. Multiple regressions using ordinary least squares estimators within the software R-Studio were used to identify the impact of different positions within a pile on biomass MC and to detect the effect of air temperature and humidity on biomass MC (R-Studio 2013). A normality plot, residual plot, White test, Durbin-Watson test, variance inflation factor, and condition index were used to detect whether the Gauss-Markov assumptions were violated. The Wilcoxon signed-rank test ($\alpha = 0.05$) was used to compare the monthly average MC of large and small piles at Site 2 (Higgins 2004).

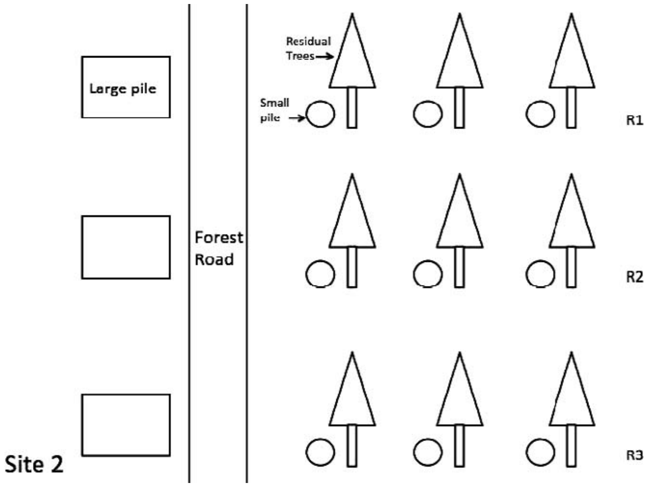

Figure 5.—Sketch map of roadside-piled and stump area–piled loose logging residues at study Site 2.

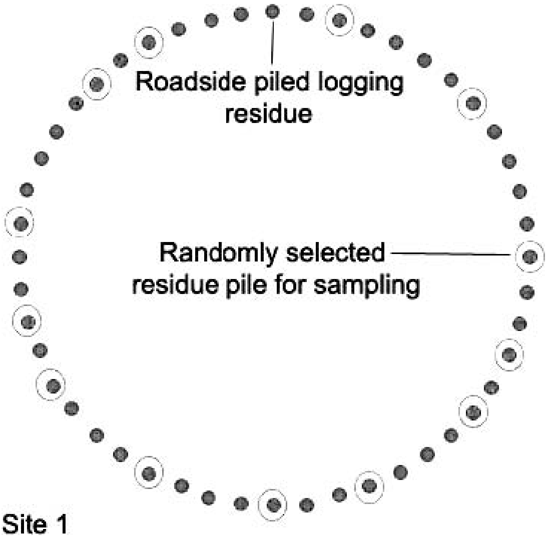

Figure 6.—Sketch map of roadside-piled loose logging residues at study Site 1.

Results

Biomass MC change over storage period

The initial wet-basis biomass MCs at Site 1 ranged from 25.0 to 47.0 percent and averaged 34.0 percent ($n = 78$). ANOVA indicated that after 5 months of field storage, the average biomass MCs were significantly decreased to around 26.3 percent ($P < 0.05$). During field storage, biomass MC continuously decreased from late June to September. The monthly MC (Fig. 7) decreased 9.6 percent from June to July, 2.1 percent from July to August, and 5.1 percent from August to September. The lowest average biomass MC of 17.2 percent was recorded in September, and a statistically insignificant regain of biomass MC ($P = 0.27$) was detected from September to October. The increase of biomass MC became significant from October to November ($P < 0.05$), when the field-stored biomass MC returned to 26.3 percent. The overall pattern of biomass MC change implied that field storage and air-drying of unprocessed logging residues can effectively reduce the biomass MC, especially if residues are collected before October.

Effect of position within a pile on biomass MC

At Site 1, the initial average biomass MCs at different positions within a pile were tested to be 33.7 percent at top, 32.8 percent in the middle, and 35.2 percent at bottom. They were determined to be in a similar range statistically ($P = 0.25$). At the end of the field storage period, the biomass MCs were tested to be 27.3 percent at top, 26.1 percent in the middle, and 25.7 percent at bottom. Even though the overall biomass MC was greatly reduced during the storage period, the differences in wood residue MC among top, middle, and bottom levels of residue piles (Table 1) were small (difference $< 5\%$) and found to be statistically insignificant by multiple comparisons ($P = 0.34$). This result implies that when loose logging residues were piled, gravity and ground soil did not increase the presence of moisture at the bottom of a residue pile.

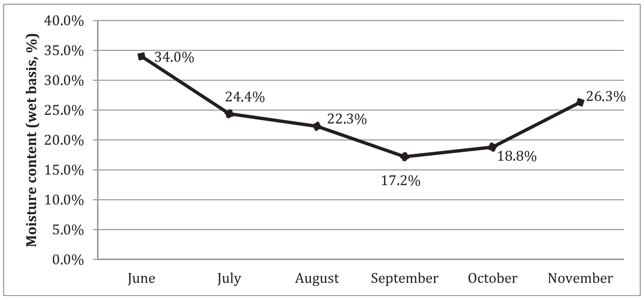

Figure 7.—Field-piled biomass moisture content (wet basis, %) changes throughout the 5-month field storage period at study Site 1.

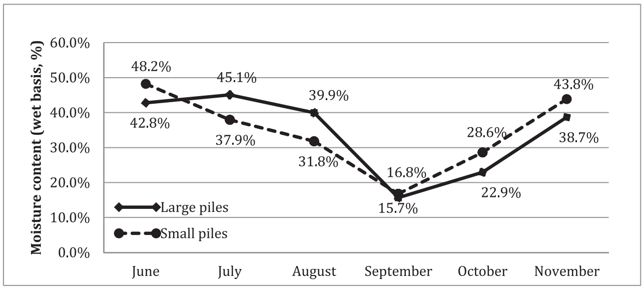

Figure 8.—Field-stored biomass moisture content changes in large and small-sized piles during the 5-month storage period at study Site 2.

Effect of pile size on biomass MC

At Site 2, MC change followed the same pattern as Site 1 (Fig. 7) because of the similar harvesting time and weather conditions. The Wilcoxon signed-rank test (Higgins 2004) indicated a significant difference in biomass MC change between the large and small biomass piles ($P < 0.05$). The initial average MC of small piles was tested to be 48.2 percent, and the large piles' average MC was lower at 42.8 percent. However, MCs of small piles decreased noticeably faster compared with larger piles from June to the end of August. In September, the average MCs of both large and small piles reached the lowest point at around 16.0 percent. Starting in September, the biomass MCs in both large and small piles began to rise, with a faster increase shown in small piles (Fig. 8). At the end of the field storage, the small piles resulted in a higher average MC of 43.8 percent compared with large piles at 38.7 percent. This result suggested that a smaller pile could be used for short-term storage of woody biomass, while larger piles are more suitable for long-term storage because biomass MC in larger piles is less sensitive to weather conditions.

Effect of air temperature and humidity on biomass MC

To examine the impact of air temperature and humidity on biomass MC, regression analysis was performed using biomass MC as the dependent variable and average air temperature and humidity as independent variables. This procedure was repeated using the average air temperature and humidity up to 5 days before the sampling date (Table 2). Regression analysis found that air humidity often influences biomass MC significantly ($P < 0.05$). This result confirms that biomass MC changes are governed by the equilibrium relationship between wood and air, where humidity plays an important role (Gigler et al 2000, Bedane et al. 2011). Regression analyses also showed that compared with humidity, air temperature is not a significant factor affecting the biomass MC ($P > 0.05$). When evaluated independently over a short time period, air temperature could be an important factor affecting the moisture transfer from the interior of wood to the surface and thus the MC. However, the impact of air temperature is not always significant when it is simultaneously evaluated with other factors over longer time periods.

Table 1.—Average biomass moisture content (MC) in top, middle, and bottom areas within a pile over the 5-month field storage period at study Site 1.

	Wet-basis residue MC (%) by sampling date[a]					
Position within pile	Jun	Jul	Aug	Sep	Oct	Nov
Top	33.7	23.6	20.8	14.8	18.0	27.3
Middle	32.8	26.4	23.8	19.7	18.7	26.1
Bottom	35.2	28.0	22.4	18.0	19.6	25.7
P value[b]	0.253	0.167	0.086	0.248	0.097	0.336

[a] Mean values of the 13 randomly sampled piles.

[b] P values resulting from multiple comparisons test.

HHVs change over field storage period

At Site 1, the average HHV for each randomly selected residue pile ranged from 7,610 to 8,344 BTU per dry lb from June to November (Fig. 9). A statistically higher average HHV was detected by multiple comparisons in July compared with the other 5 months ($P < 0.05$), while the HHVs in the other 5 months were statistically similar ($P = 0.26$). Since the biomass HHV in July (8,344 BTU/lb) and the average HHV of the other 5 months (7,811 BTU/lb) bears a difference of only about 6.4 percent, the HHVs throughout the storage period were considered to generally be the same. Over the time course of the study, piling unprocessed, loose logging residue did not significantly alter biomass HHV on a dry basis.

Discussion

The air-dried method tested in this study resulted in a significant reduction in piled biomass MC during a 5-month storage time. The MCs of piled biomass rapidly decreased after harvesting with the lowest MC detected around the end of August at both study sites because of the relatively low air humidity and rainfall. Biomass MC started to increase in September and kept rising until November. The regain of MC can be due to the high precipitation and the low temperature that limited water transfer between wood and air (Gigler et al. 2000, Steele et al. 2008). The resulting biomass MC change during the 5-month field storage is comparable with the findings from other studies (Nurmi 1995, Nellist 1997, Gigler et al. 2000, Steele et al. 2008). Millet (1953) and Gautam et al. (2012) also found that the MC of field-stored biomass would further decrease with longer storage time and become significantly lower in the second storage season. Because of the shorter field storage time and limited data quantity, data from this study cannot support their findings. Evaluating biomass MC change over a longer field storage period is necessary to determine

Table 2.—Multiple linear regression models for field-stored biomass moisture content (MC) and weather factors at study Site 1 ($\alpha = 0.05$).

Regression analysis	Biomass MC (%)	r^2	*P* value	
			Temp.	Humidity
1	= −0.21 − 0.00063(temperature) + 0.69(humidity)[a]	0.91	0.75	0.02
2	= −0.04 − 0.003(temperature) + 0.62(humidity)[b]	0.91	0.07	0.02
3	= −0.08 − 0.003(temperature) + 0.68(humidity)[c]	0.82	0.13	0.07
4	= −0.46 − 0.002(temperature) +1.11(humidity)[d]	0.89	0.14	0.02
5	= −0.38 − 0.002(temperature) +1.05(humidity)[e]	0.87	0.14	0.03
6	= −0.71 − 0.004(temperature) +1.63(humidity)[f]	0.70	0.13	0.14

[a] Average temperature and average humidity on the sampling date.

[b] Average temperature and average humidity of the sampling date and the day before the sampling date.

[c] Average temperature and average humidity of the sampling date and the 2 days before the sampling date.

[d] Average temperature and average humidity of the sampling date and the 3 days before the sampling date.

[e] Average temperature and average humidity of the sampling date and the 4 days before the sampling date.

[f] Average temperature and average humidity of the sampling date and the 5 days before the sampling date.

whether biomass MC cumulatively decreases on an annual basis.

Gigler et al. (2000) reported that biomass MCs within a pile were generally consistent, except that the top part of a pile could be subject to higher MC because of direct exposure to rain. Other studies found that biomass MC in different positions within a pile varied significantly, with a decreasing trend from top to bottom (Heiskanen 1961, Röser et al. 2011). On the contrary, Filbakk et al. (2011) found biomass MCs in bottom layers were consistently higher than other positions in a pile because of limited drying conditions, lower ventilation, and ground moisture. Our study showed that MCs from top to bottom stayed uniform during the entire storage period (Table 1). This may be due to larger void volume between limbs as a result of loose piling. Larger void volume enhances airflow and thus water transfer from wet regions of the pile, serving to create uniform MC.

Pan et al. (2008) concluded that ground biomass MC was heavily affected by rainfall. However, our study found that monthly accumulative precipitation has a weak correlation with unprocessed biomass MC. Linear regression analysis resulted in an r^2 value of 0.30 with precipitation as an insignificant variable ($P = 0.26$). A much lower water absorption rate compared with the evaporation rate could result in this insignificant impact of rainfall on unprocessed biomass (Gigler et al. 2000, Bedane et al. 2011). In addition, a much lower surface area-to-volume ratio in the unprocessed biomass than that in ground biomass may also contribute to this minor effect.

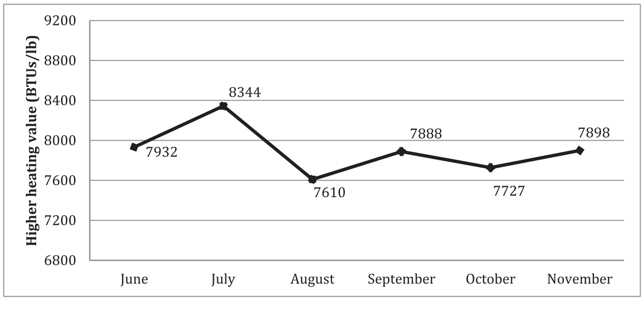

Figure 9.—Field-stored biomass higher heating value changes throughout the 5-month field storage period at study Site 1.

The major species in Site 1 included sugar maple (*A. saccharum*), red maple (*A. rubrum*), and white spruce (*P. glauca*). The HHVs of the three species are 7,739 BTU per dry lb for sugar maple, 8,293 BTU per dry lb for red maple, and 8,530 BTU per dry lb for white spruce (Chang and Mitchell 1955, Millikin 1955, Harder and Einspahr 1976). Due to the variation of the species composition in each sample, the average HHVs of the biomass at Site 1 showed small fluctuations in the 5-month storage period, but they stayed in a comparable HHV range with the reported HHVs of the major species (Fig. 9).

Many studies found that HHV of biomass can be maintained only during the first 4 months of field storage and will decrease after 18 months because of the changes in the chemical composition resulting from biodegradation processes (Nurmi 1995, Brand et al. 2011). Although data from Site 1 in this study is limited in determining the pattern of piled biomass HHV over a longer storage period, it is sufficient to ascertain that maintaining biomass HHVs stable over 5 months in the field is feasible. The fast decrease of biomass MC toward winter can effectively restrict microbial activities, and decay in wood can be minimized (Hudson 1992, Gautam et al. 2012).

Conclusions

This study monitored the MC and HHV change of field-stored, unprocessed, loose logging residues throughout a 5-month storage time. Results show that biomass MCs were significantly reduced during the storage period. In addition, the biomass MCs at different positions within a biomass pile were found to be statistically uniform because ground soil did not increase the presence of moisture at the bottom of a residue pile. Results further suggest that a smaller pile is an appropriate way to store woody biomass when it is scheduled for short-term use, while larger piles are more suitable for long-term storage because biomass MC in larger piles is less sensitive to weather conditions. As an important fuel quality property, biomass HHVs were determined to be generally stable during the 5-month storage period.

Results indicate that the pattern of change in MC during field storage was comparable with other study findings. Regression analysis shows that field-stored biomass MC can be significantly impacted by air humidity, while the effect of air temperature and cumulative precipitation on biomass MC was minor.

Further monitoring of biomass MC and HHV over a longer field storage period will reveal whether biomass MC will cumulatively decrease on an annual basis and whether HHV of field-stored biomass is stable for more than 5 months. In addition, future research will be conducted to develop a biomass field drying model to quantify the relationship between biomass MC change and weather factors and thus to better understand the mass and energy flow in field-stored biomass pile.

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