STRATEGIES FOR REDUCINGMOISTURE CONTENT IN FOREST 1 RESIDUES AT THE HARVEST SITE

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STRATEGIES FOR REDUCING MOISTURE CONTENT IN FOREST RESIDUES AT THE HARVEST SITE

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ABSTRACT.

The moisture content (MC) of biomass derived from forest residues can pose a challenge to biomass utilization. It plays a significant role in determining the cost of transportation and subsequent market price. Additionally, emerging biomass conversion technologies, such as gasification, torrefaction, and briquetting, have very narrow specifications for the MC (e.g. <15%) in their feedstocks. The goal of this study was to develop strategies for reducing moisture content by evaluating different arrangement patterns of forest residues and its effect on MC reduction at the harvest site. The study compared four different arrangement patterns including criss-cross, teepees, traditional piling (processor piled), and scattered residues in three different timber harvest units in northern California. Two of the arrangement patterns (criss-cross and processor piled) were also covered with a plastic cover. Samples were collected from each treatment using a transect method and was recorded for 12 months. There was an overall drop of MC from 52% to 12% over the study period. Models were developed for evaluating the effects on MC factoring variables such as diameter, species, arrangement patterns and weather parameters including average temperature, relative humidity, and amounts of precipitation. The cost of construction per pile averaged $41, 37 and 48 for criss-cross, teepees, and processor piles respectively. Even though, there was no significant difference in MC reduction between piles (except scattered), each pile arrangement of forest residues directly affected biomass feedstock operations, logistics, and costs.

Keywords.

Feedstock quality, Logging slash, Transect sampling method, Woody biomass energy.

INTRODUCTION

Moisture content (MC) in forest residues dictates several features of the feedstock including transportation, market price and utilization (Kofman and Kent 2007; Ochoa 2012). Woody biomass feedstock with less MC is higher priced as well as letting wood dry for up to a year is economically beneficial for the biomass producer provided that the feedstock is priced in terms of MC at delivery. Low MC in woody biomass increases the net energy conversion efficiency (Roise et al. 2013). Studies showed that energy efficiency of feedstock had improved by 1% for each 1% drop in MC above 50% and 0.5% for each 1% reduction in MC below 40% (Liang et al. 1996; Kim and Murphy 2013).Studies in Europe have shown that storing forest residues for eight months can reduce the MC up to 25% and increase the heating value up to 4 KWh kg^{-1}, thereby having an economic gain of $9–15/oven dry ton (Erber et al. 2014).

In transportation phase, reducing the amount of water hauled directly leads to an increased amount of wood per truck load. Biomass operations contractors in western US get commonly paid on a bone dry ton (BDT) basis for the delivered product to an energy plant. Moreover, emerging biomass conversion technologies, such as biochar, torrefaction, and briquetting, can potentially enhance the economic value of the forest residues; however, these technologies require low MC (e.g. <15%) for their feedstocks.

FACTORS AFFECTING MOISTURE REDUCTION IN FOREST RESIDUE PILES

There have been several studies done on MC associated with forest residues throughout the globe. Models have been developed to forecast MC variation under both controlled and in field (Gautam et al. 2012; Ochoa 2012). Research topic also includes the economic evaluation of the storage process, of which drying rates were given priority (Roise et al. 2013; Erber et al. 2014). Yet another focus was on quantifying the drying rates using different strategies to reduce MC reduction, such as debarking, covering the pile, and comminution (Gigler et al. 2000; Filbakk et al. 2011a; Nurmi and Lehtimäki 2011). Generally, favorable storing conditions are sunny, elevated, open, and wind-accessible locations (Erber et al. 2014). Walker (1993) identified seven key factors that affect the rate of MC reduction:

- Relative humidity: Lower relative humidity promotes increased drying rate.
- Temperature: High temperature has a positive effect on the moisture removal
- Air flow: Sufficient air flow circulation on the wood surface helps to remove the humid air which can then be replaced by drier air.
- Moisture gradient: As the steepness of the moisture gradient between the wood and atmosphere increases, MC decreases, diffusion rate increases, thereby increasing the rate of flow of water through the wood.
- Species: Normally softwoods dry faster than hardwoods.
- Initial MC of the sample
- Diameter: Wood with larger diameter requires more time to dry to a given MC, given the same atmospheric conditions in comparison to smaller diameters.

This study investigated the effect of arrangement patterns (different types of pile structures) on moisture content (MC) reduction during storage of forest residues at the harvesting site. The primary objective of this study was to assess the variation in MC related to the different arrangement patterns, and storage period (i.e. time after trees were piled). The next objective was to understand the influence of various weather parameters on the forest residue drying. The study also looked into the operational cost of constructing these piles as a part of the timber harvest.

METHODOLOGY

STUDY SITE

The study was conducted on three similar timber harvest units in Humboldt County, California (fig. 1). The timber harvest units were located approximately 1.6 km apart. According to the Köppen classification, the climate of the study area was characterized as being *Csb* (Coastal Mediterranean climate), mild with a cool and dry summer. The sites were about 500 to 730 m above mean sea-level with terrain slope up to 111% (48°). The climate for the region is characterized by summers averaging 29°C, and winter being cool and wet averaging 8°C. On average, the region receives 1200 mm of rain annually, mostly from December through April (WRRC, 2015).

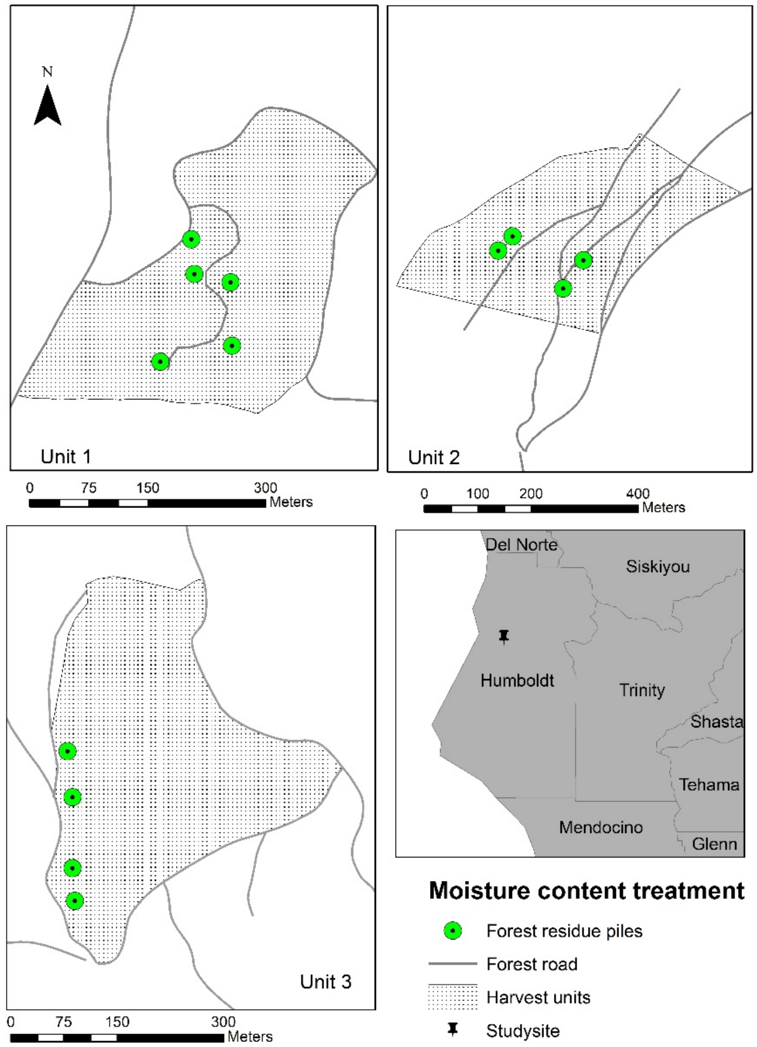


Figure 1. Study units for moisture content reduction in forest residues piles in Humboldt County, California

OUTLINE OF THE EXPERIMENT: PILE BUILDING AND SAMPLING

The materials used to construct the forest residue piles were composed of processed (delimbed) and unprocessed tree tops, broken logs and non-merchantable whole tree of coast redwood (*Sequoia sempervirens*), Douglas-fir (*Pseudotsuga menziessii*), western hemlock (*Tsuga heterophylla*), and tanoak (*Notholithocarpus densiflorus*).

The trees were harvested during July of 2014, the piles were created in August, then stored for 11 months until July 2015. Sampling was conducted every month prior to and after the installation of the experiment. The locations of the piles were designed as to ensure they were on the road side and received minimal shade throughout the day.

The four different arrangement patterns of forest residue piles were (fig. 2):

Figure 2. The forest residue arrangement patterns. 1. Teepees; 2. Processor piles; 3. Criss-cross piles; and 4. Scattered

1. Teepees: The conventional way of piling forest residues in the region. These piles were composed of all forest residues including tree-tops, chunks, branches, broken logs, and small-diameter trees.
2. Processor pile (stacked pile): Uniformly arranged piles created by the processor with the butt-ends placed together during timber production operations. They were composed of delimbed tree-tops generated from processing. Occasionally, broken logs and small diameter trees were also included.
3. Criss-cross: This pile type was designed exclusively for the study purpose. A loader constructed the pile by laying the materials of each layer 90° to the one above, with the intention of maximizing airflow. The platforms were raised from the ground to allow an increased amount of air flow and minimize water stagnation beneath them during a rainstorm event. The materials were predominantly processed (delimbed) tree-tops, broken logs and stems of non-merchantable species.
4. Scattered: These were forest residues left at the harvest units where trees were felled and not brought to the landing during the primary transportation (stump to landing). The materials were mostly broken logs, small diameter trees, and stems of non-merchantable species.

An additional treatment, involved covering two piles (processor and criss-cross) with plastic sheets to evaluate the effect of curtailing water flow during storm event. All arrangement patterns were replicated at least once (except for covered piles) in all the three units.

SAMPLING THE PILES FOR MOISTURE CONTENT

Nine trees were felled prior to the harvest in order to determine the initial MC. The trees represented all the four species and had a diameter at breast height (dbh) ranging from 13–28 cm. Samples were taken every 1-m across the horizontal axis of the main stem.

Transect sampling method was used for collecting sample from the pile (fig. 3). Sampling points of the piles were designed such that they represented the geometric shape of the pile and allowed access to the point of sampling, without affecting the conditions of storage (Kizha and Han 2017). Transects were designated using timber marking paint and/or by hanging flagging tape in specific orientation at equal intervals during the construction of the stack pile. Materials that fell on the transect were then systematically selected based on the required number of samples for each class (eg. diameter class, tree species, etc.) (Filbakk et al. 2011a). For the rest of the study the samples were collected from the same section of the pile. Selected wood pieces were cut with a chainsaw at the point of the intersection to expose the complete diameter to extract the wood discs (Gautam et al. 2012). The remaining materials that were not sampled were left undisturbed for future sampling. This approach ensured that continuous sampling was possible in natural in-field conditions while considering various geometries of the sample piles (fig. 3) (Kizha and Han 2017). Since it was not physically possible to collect a sample from the middle of some piles, sampling was carried out by cutting access points into the pile arrangement. Safety of the personnel operating the chainsaw was given utmost priority during sample collection.

Figure 3. Wood disc being sampled from conventional teepees using transect sampling procedure.

Sample discs were taken every month between 15th to 20th at 12:00 h to 14:30 h. Sampling was not conducted on rainy days or days following rain fall. Wood discs were cut from branches of the selected wood piece with a thickness ranging from 2–5 cm by using a gasoline-powered chain saw (Stihl MS 290). The samples were cut at least one foot away from the end of the branch because wood picks up and loses moisture very rapidly through the end grain; a phenomenon known as edge effect (Reeb and Milota 1999; Erber et al. 2014). Once a sample was taken from a particular wood piece, it was then excluded from sampling for the remainder of the study. The following data were recorded during sample collection: two diameter classes (less than and greater than 7.5 cm), species (hardwood and conifer), sampling location (interior and exterior of pile), parts of the stem (small-end, middle and large-end), and forest residue pile type (criss-cross, teepees, processor pile, scattered, covered criss-cross and covered processor pile).

OVEN DRYING

The wood discs collected were initially weighed on site right after extraction. Later at the laboratory, the diameter was measured using a caliper and MC assessment procedures were carried out by the oven dry method according ASTM standard D 2016 (ASTM 1988). The samples were dried at 103ºC for three days and then re-weighed. The difference in weight was the amount of water present in the sample. Depending on the tree species, extractives can represent a small share of this weight. Needles and twigs hold more extractives than stem wood (Erber et al. 2014). All weight measurements were recorded on an oven dry basis.

WEATHER CONDITIONS

The Little River weather station (Lat. 48º45.667’ N, Long. 91º37.683’W) located about two km away recorded daily weather data, such as ambient temperature (ºC), relative air humidity (%), wind speed (km/hr), wind direction (º), insolation and precipitation (mm) throughout the storage period (Filbakk et al. 2011b; Kim and Murphy 2013). The data was collected on a per hour basis, however was later averaged on a monthly basis to match up with the timing of the MC sampling.

COST OF CONSTRUCTING THE PILES

Different forest harvesting machines were utilized for piles construction. While teepees and, criss-cross were constructed with the loader, the processor piles were created during sawlog processing by the processor. The delay-free cycle times were calculated with detailed time study using standard work study techniques (Olsen et al. 1998). Elemental time-motion data were recorded by a centi-minute stop watch. The cost and productivity was analyzed only for the pile construction phase and did not involve other timber harvesting components (table 1). Purchase prices, salvage values, and all other necessary information for the standard machine rate calculations were obtained from the timberland company which owned and operated the equipment (table 2). Diesel price was set at \$1 L^{-1}, which reflected local market prices during the study. Hourly machine costs in dollars per scheduled machine hour (\$ SMH^{-1}) were calculated using standard machine rate calculation methods (Miyata 1980). All machineries were assumed to have 10-year economic life and worked 2200 scheduled machine hours (SMHs) $year^{-1}$ with a utilization set at 80%. Joint products allocation method was used to estimate the cost of constructing the processor piles, as forest residues were a byproduct of the timber processing (Hudson et al. 1990).

Table 1. Cycle elements and associated predictor variables for each machine used to construct the forest residue piles.

Pile Construction machines	Cycle elements	Recorded predictor variable(s)
Processor	swing empty	tree species
	grapple time	butt-end diameters (cm)
	processing sawlog	logs per cycle
	processing biomass	short length logs
	sorting sawlog	medium length logs
	sorting biomass	long length logs
		number of biomass pieces
		processed tops
		unprocessed tops
Loader	swing empty	pieces per cycle
	grapple time	short length piece
	swing loaded	medium length piece
		long length piece
		Unit

Table 2: Machine rates and other costs of the equipment used in the treatment. Assumptions used for machine rate calculations included 2200 SMH (schedule machine hours) year^{-1} and 80% utilization. The fuel and labor cost was estimated at \$ 1 liter^{-1} and \$47.20 h^{-1} respectively. \$ PMH^{-1} (productive machine hours) rates were calculated using the assumptions of 59% fringe benefits, 10% interest, and 3% insurance.

	Processor	Loader
Model	John Deere 2454D	John Deere 2954D
Purchase price	\$ 610,000	\$ 425,000
Operating cost	\$ 56.49	\$ 41.76
Fuel use (L PMH^{-1})	22.8	22.8
Machine rate (\$ PMH^{-1})	\$ 165.10	\$ 135.45

ANALYSIS OF THE DATA

Analysis of variance tests were carried out using the General Linear Model in IBM SPSS Statistical Software 2. The datasets were initially screened for outliers followed by which the null hypotheses of no significant difference in MC was tested for different storage periods (months) and pile arrangements. Difference within the diameter class (2.5–7.5 cm and greater than 7.5 cm) and species (hardwood and conifers) were tested using t-tests. Paired t-tests were used to test significance between MC values taken from moisture meters and oven drying methods. The experimental designs for all the models were full factorial design, with MC as the dependent variables for each.

The data for each model was tested for normality and homogeneity of variance before conducting the analysis of variance. Any significant differences in the analysis were analyzed using post-hoc tests. Scheffe’s test was preferred because most of the sample populations were not similar in size.

Two regression models were developed for predicting MC. Multivariate linear regression was performed in R statistical package to analyze the significance of different independent variables like: diameter of materials, species, type of pile, and number of months after initial harvesting, on MC of piles (R Core Team, 2016). Among these variables: type of pile, species, and number of months after initial harvesting were categorical variables. R automatically coded these variables as dummy variables during regression analysis. The second regression analysis used monthly weather parameters like: average temperature, average relative humidity, average wind speed, and total precipitation as independent variables along with other previous variables. However, the parameter storage month was dropped in this regression models to remove multicollinearity with monthly weather parameters. A third model was developed for estimating factors that influenced the cost of pile construction based on the loader and processor's delay-free cycle time (table 1).

RESULTS AND DISCUSSION

The study focused on evaluating drying rates of forest residue in different arrangement patterns. More than 2600 discs were collected from 13 piles over the 13 months of sampling. The average initial MC content of the freshly felled trees were 52% (ranging from 46%–62%). The diameter of the discs sampled ranged from 2.5 to 39.4 cm, with an average of 11.7 cm. The thickness of the discs ranged from 2.5 to 3.8 cm. The length of the forest residue from which the wood pieces were collected averaged 7.3 m and had a large-end diameter of 15.2 cm. The average dimensions (height x width x length) for the criss-cross and processor piles were 2.5 x 8.2 x 11.3 and 2.1 x 6.7 x 9.8 m, respectively. The teepees were generally larger in size with some having heights up to 10.7 m. The average dimensions (height x diameter) were 6.5 x 17 m (table 3, fig. 2).

Table 3. Dimensions of the forest residue piles in meter

Pile type	Unit	Height	Width	Length
Criss-cross	1	2.4	8.8	11.0
	2	1.8	7.9	10.0
	3	3.4	8.2	12.5
Criss-cross (covered)	1	2.5	8.2	11.2
Processor pile	1	2.1	6.0	9.5
	2	1.8	5.2	8.2
	3	2.4	9.2	11.9
Processor pile (covered)	1	2.2	6.3	9.1
			Diameter	
Teepees	1	6.1	18.3	
	1	10.7	18.6	
	2	3.7	18.3	
	3	6.7	17.7	
	3	4.9	12.5	

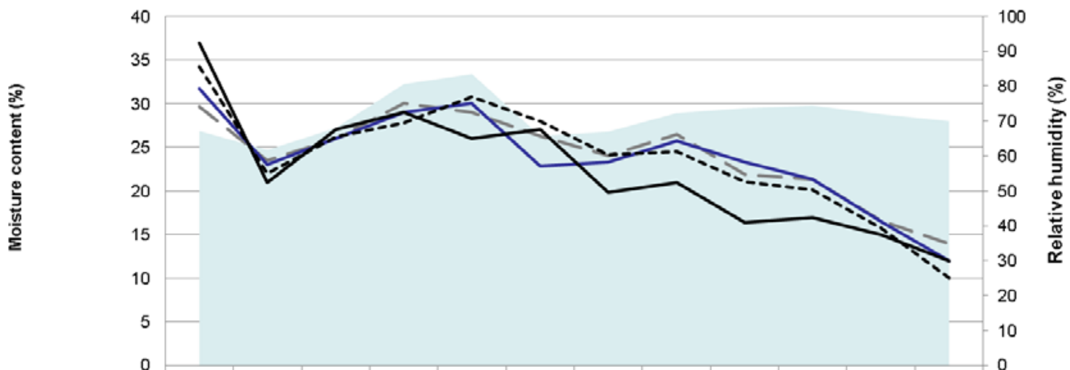
SETTING THE EXPERIMENT TO MONITOR MOISTURE CONTENT CHANGES IN FOREST RESIDUES

Initial T-test results on the MC data obtained from the oven drying method and moisture meter (for the first three months) showed that the values were significantly different ($p< 0.001$). MC measurements using moisture meters were not as reliable as the disc extraction techniques because moisture can vary greatly depending on where the measurement was taken. Even if the chainsaw resulted in minor reduction in MC due to the heat generated during sawing, it is still regarded as an efficient method for MC measurements. Therefore, the oven drying method was adopted for the rest of the sampling.

Wood discs were collected from different parts of the stem (small-end, middle and large-end) in order to understand the variability in MC across the length. ANOVA results indicated that there was no significant difference (p=0.902) suggesting that the wood disc taken from any part of a particular stem would represent the whole stem. However, it should be noted for this study that the small-end and large-end discs were cut one foot from the exposed part. It is known that the MC tends to be higher in the middle of the wood piece compared to the exposed ends (Visser et al 2016).

FACTORS AFFECTING CHANGES OF MOISTURE CONTENT IN FOREST RESIDUE PILES

Erber et al. (2012) observed a MC reduction from 50% to 32% while drying a Scots pine stem wood pile over a 14-month period. Other studies showed varying results from 10%–30% drop (Hakkila 1962, Golser et al. 2005, Nurmi & Hillebrand 2007, Röser et al 2011). In this study the drop was more drastic (from 52% to 12%), which can be attributed to the dry weather condition during the study period (fig. 4).



	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	April	May	June	July
Relative humidity (%)	67	62	68	81	83	66	67	72	74	74	72	70
Teepee	30	23	26	30	29	26	24	26	22	21	17	14
Criss cross	32	23	26	29	30	23	23	26	23	21	17	12
Processor pile	34	22	26	28	31	28	24	24	21	20	16	10
Scattered	37	21	27	29	26	27	20	21	16	17	15	12

Figure 4. Moisture content variation in the four pile arrangement over the storage periods.

MC was modeled to understand the relationship between MC and other variables such as diameter of the wood piece, month/time since harvest, species, and forest residue pile structures. The results are presented in several sections with the intention of examining each.

Storage period

The average MC for the forest residues prior to pile construction was 35% (ranging from 12% to 76%). This was approximately 17% drop from the time trees were felled to the pile construction (after two months). The MC losses due to storage were highest in the beginning of the storage period (July and August 2014), (fig. 4). Once the tree is felled, green wood loses moisture quickly during the period as it loses free water. Another reason was the high temperature during these initial months. Gradually, equilibrium of the MC reduction is attained with the temperature and relative humidity. Thereafter the rate of drying is reduced (Gautam et al. 2012).

ANOVA results showed that there was a significant difference in the MC between the months ($p < 0.001$). Post-hoc tests revealed that the differences were basically between various season (sub-group) and no significant difference existed within the sub-groups, which suggests that the average MC of the forest residues dropped during the period of storage (fig. 4). July and August, 2014 (Month 1 and 2) could be placed under one sub-group having the highest loss in MC (from 52% to 33%). Free water from the freshly felled trees was likely lost in this season. October through March would be another sub-group with no significant difference in moisture loss, between the months. In this sub-group the wood materials had attained equilibrium with the surrounding environment. May to June, 2015 showed the next drop in MC, which could be attributed to the high temperature during the period. These three storage period sub-groups were significantly different from each other ($p < 0.001$).

Species and diameter

Both models developed for factoring MC showed that both species and diameter were contributing factors. There was significant difference between the species ($p<0.001$). Gautam et al. (2012) explained this as the difference between the chemical composition and anatomical structure for hardwood and softwood species. Hardwood species having 25%–40% hemicellulose, as opposed to 20%–30% in softwoods, tends to bond more with water because hemicellulose is the most hygroscopic component of cell wall. The other reasons included were that the cell walls of hardwoods generally have more potential bonding sites for water than softwoods.

T-tests done to determine the effects of the diameter class (2.5–7.5 cm and greater than 7.5 cm) showed that there was a significant difference between the two groups ($p=0.028$). Ten cm diameter was taken as the cut-off limit because the materials with diameter above this, could be potentially chipped for higher quality feedstock. All materials less than 10 cm (minimal diameter materials) will have to be sent to a grinder as a part of comminution because they could clog at the mouth of the chipper. Larger sized wood (average of 28%) tends to hold more water when compared to smaller wood pieces (average of 24%). Visser et al. (2016) explained the reason for the faster drying rate in two parts: a) the smaller wood piece has a larger surface area to mass ratio, and b) a reduced distance between the log center and its surface, which meant water potentially traveled less in order to evaporate.

Arrangement Pattern

The monthly moisture content for each pile was considered to be the average of the MC for the wood disks collected from different transects. Largely, there were no significant difference between the various pile structure in different units ($p=0.310$). However, the processor pile of Unit 3 had a significant difference from the rest ($p=0.001$) during the initial months. Later investigations showed that the particular pile was located on the edge of the unit and was shaded by neighboring trees during later parts of the day.

There was no significant difference between the arrangement patterns, except for scattered species ($p=0.231$).The increased drying rates for scattered can be explained due to more surface area being exposed to the elements, compared to the other pile structures. The wood materials collected from the interior of the pile tended to have lower moisture content than the ones toward outside. Similar results were obtained in other studies too (Casal et al. 2010).

Covering the piles

Unlike other studies which showed a decrease in MC for the covered pile (Erber et al. 2014), no significant reduction was observed in MC reduction between the covered and un-covered piles at the end of study frame. Röser et al. (2011) also were also not able to demonstrate significant difference in drying rates between covered and uncovered piles for certain portion of their study. The potential reason in this study might be a) the exceptional dry season during the period, which dropped MC across all arrangement patterns; and b) a single replicate might not have been able to capture the variation.

Weather parameters

Target variables to predict MC were limited to a small numbers that are closely related, among which the local weather conditions plays a prominent role. The weather data was averaged for each month, as the sampling was done on a monthly basis. As month (variable) was highly correlated with weather data, two models were built using each separately. Results showed all parameter included in the "month" models had a better R-square than the model including weather (R^2= 0.38 and 0.26, respectively). Possible reason for this might have to do with averaging weather parameter over the month. All contributing variable for both models were significant (p<0.001) except for total monthly precipitation (for weather model).

COST OF CONSTRUCTION

On an average it took a loader 18 and 16 min (with a range of 5-32 and 6-31 min) to construct criss-cross and teepees at a cost of $41 and 37, respectively. Teepees which used all forest residue within the stand largely left the harvested unit more cleared than criss-cross, as the later only used tree tops. The loader also observed to have difficulty in handling criss-cross piles during future activities (such as comminution), due to wood pieces tangling between layers. The processor pile was built on an average of 21 min by the processor and at a cost of $48. The forest residues was assumed to have a free ride up to the landing along with the merchantable sawlogs, therefore the cost only represents the cost of pile construction.

There was no cost incurred with the scattered treatment during the harvesting operation. However, collection of these forest residues will require machine re-entry, which can significantly increase the cost of storage, compared to the rest. From a managerial point of view, these forest residues left at the harvested unit can be unsafe to the forest eco-system due to the increased fire risk in the region. Forest residue accumulation also minimizes the area available for re-planting (Michael Alcorn, Green Diamond Company, personal communication, 15 June 2014).

In general, the cost of pile construction depended on a various factors, including the amount of forest residues available, how spread the forest residues was within the unit, distance to the road, slope, accessibility to the site. The regression model developed to analyze the influential factors on the delay-free cycle time showed that number of pieces handled, and unit (dummy variable) as significant contribution factors for the loader. While for the processor pile- number of processed pieces, species and diameter were the prominent contributor (table 4). The model was better explained for the processor compared to loader.

Table 4. Regression models developed for predicting delay-free cycle time (DFC) in centi-minutes using standardized comparison

		R^2	Standardized models predicting DFC
Processor			
Unit 1	LnDFC	0.42	2.73 +0.13(pieces/cycle) +0.12(dbh) +0.07(unit 3) +0.23(processed pieces) + 0.02(unprocessed pieces) –0.42(redwood) +0.16(tanoak)
Unit 2	LnDFC	0.33	3.43 +0.05(dbh) +0.07(unit 3) +0.12(processed pieces) +0.19(unprocessed pieces) –0.04(redwood) +0.21(tanoak)
Unit 3	DFC	0.29	46.75 +0.60(dbh) +0.04(weight/load) +6.41(processed pieces) –5.51(unprocessed pieces)
Loader			
Unit 1	LnDFC	0.26	3.83 –0.25(unit 3) +0.02(pieces/cycle)
Unit 2	LnDFC	0.38	3.91 –0.20(unit 1) –0.38(unit 3)
Unit 3	LnDFC	0.18	3.40 +0.11(unit 1) +0.23(unit 3) +0.05(pieces/cycle)

Where LnDFC is the natural log of DFC, logDFC is the log to the base 10 of DFC

It took a three crew team half a day to cover three piles. The plastic cover used was “all weather poly-ethylene” sheets with an area of 6 x 30 m (weighed 26 kg). Covering of piles was not possible for the teepees due to sheer size as well as safety concerns. Additionally, covering of forest piles was only practiced in the region on piles which were to be comminuted for higher valued end products.

PILE ARRANGEMENTS AND ITS IMPACT ON FOREST MANAGEMENT

Storage of the forest residue for up to a year prior to utilization has been proven to be economical (Erber et al. 2016). This is due to an increase in value due to the MC reduction in the forest residues. In this study on an average there was a reduction in MC from 52% (fresh cut) to 12% (July, 2015). As the secondary transportation component of the biomass feedstock accounts for almost half of the total production costs (McDonald et al. 2001; Kizha. et al. 2015), this practice ensures maximum amount of material being transported per load (Ronnqvist et al. 1998; McDonald et al., 1995). However, storage of the material will tie up capital costs and demand use of piled land area for replanting (Filbakk et al. 2011b). For the region, a three-month storage period would be recommended as the wood material loses free water during this phase. The harvesting season also influences MC retention. For example, wood harvested during winter operation (rainy season) would have minimal water loss compared to harvest in dry summer months.

As there was no significant difference in MC between the arrangement patterns, other features associated with arrangement pattern and forest management were evaluated. Criss-cross and processor piles had minimal amounts of inorganic contamination compared to teepees and scattered arrangement. Therefore, they could be potentially chipped, rather than ground, to produce even sized feedstock which is higher quality and can be utilized in a Biomass Conversion Technology such as gasification, torrefaction, and briquetting. The teepees on the other hand, had a large variation of material sizes, ranging from foliage to umerchentable whole trees and chunks and could only be grinded because separating the tops and stem wood from them would make the operation economically infeasible. The soil contaminations were also very high for these pile structures. These piles were comparatively easier to burn when compared to scattered forest residues and also reduced the risk of forest fire spill outs during burning sessions. Furthermore, piled forest residues can be more efficiently burned under adverse weather conditions, thereby reducing the quantity of smoke emitted. It also can be done with reduced staffing levels (Wright et al. 2010). From a site preparation point of view the teepees cleaned the sites more than the rest. This was because the teepees collected all the forest residues from the vicinity, while the processor and the criss-cross piles only took the tree-tops.

CONCLUSION

The effect of storage on the MC of forest residue piled under natural climatic conditions prevalent in the pacific north coast for 11 months (excluding one month prior to piling) showed that the MC of forest residues decreased with storage time. The highest drying rate was observed for the initial months of storing and as time passed the drying rate was in equilibrium with the atmospheric conditions. There was no significant difference in MC reduction between three of the four arrangement patterns (criss-cross, processor pile, and teepees). However, these three were different from scattered treatment.

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