Moisture and energy content of fire-burnt trees for bioenergy production: A case study of four tree species from northwestern Ontario

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ABSTRACT

With the current energy reform, the Ontario government has taken an initiative to phase out coal-fired generating stations by 2014, and replace coal with biomass as feedstock at the Atikokan Generating Station. This switch to green energy production has opened a new avenue of income for mills and biomass-harvesting companies. However, as the need for biomass increases, harvesting residues may no longer satisfy the needs of cogeneration facilities and new sources may be sought. A potential source of woody biomass in Ontario is from forest fires. On average, an area of 35 460 ha or 3 868 034 m³ of wood is devastated by wildfire every year in the Area of the Undertaking in Ontario and has the potential to be salvaged. However, the fuel quality and feasibility of salvaging wildfire-burnt areas for bioenergy production in northern Ontario has not been investigated so far. In this study, five different-aged fires in the MNR Thunder Bay District—12, 18, 24, 37, and 52 months old—were sampled for moisture content and calorific value of the wood. This sampling was done across four of the most prolific tree species grown in northwestern Ontario—white birch, trembling aspen, balsam fir, and black spruce. The average moisture content (dry weight basis) of the five fires ranged from 27.1% to 34.9% and the average calorific value from 19.0 MJ/kg to 21.1 MJ/kg. Significant differences in moisture content were found between the species and the ages of fire. Hardwood species had significantly higher moisture content compared to softwoods. The results display that wildfire-burnt areas have the potential to supply good-quality fuel for bioenergy production in northwestern Ontario.

Key words: biomass, wildfire-burnt areas, bioenergy production, moisture content, calorific value, northern Ontario

RÉSUMÉ

Avec la réforme actuelle en matière d'énergie, le gouvernement de l'Ontario a entrepris de fermer graduellement les centrales thermiques au charbon d'ici 2014 et de remplacer le charbon par des approvisionnements en biomasse (Atikokan Generating Station). Ce changement vers une production d'énergie verte a permis aux usines forestières et aux entreprises qui récoltent la biomasse d'explorer une nouvelle source de revenus. Cependant, à mesure que les besoins en biomasse s'accroissent, les résidus d'exploitation pourraient ne plus être suffisants pour répondre aux besoins des centrales de cogénération et de nouvelles sources devraient être trouvées. Une source potentielle de biomasse forestière en Ontario réside dans les rémanents après un feu de forêt. En moyenne, une superficie de 35 460 ha ou 3 868 034 m³ de bois sont ravagés par les feux de forêts chaque année dans le Secteur d'exploitation forestière de l'Ontario et pourraient être récupérés. Cependant, la qualité du combustible et la faisabilité de la récupération dans les zones incendiées à des fins de production de bioénergie dans le nord de l'Ontario n'ont pas fait l'objet de travaux de recherche à ce jour. Au cours de cette étude, cinq feux de forêt d'âges différents du District de Thunder Bay du MRN – des feux survenus il y a 12, 18, 24, 37 et 52 mois – ont été échantillonnés pour relever le niveau d'humidité et la valeur calorifique du bois. Cet échantillonnage a été réalisé pour quatre des plus prolifiques espèces d'arbres du nord-ouest de l'Ontario – le bouleau à papier, le peuplier faux-tremble, le sapin baumier et l'épinette noire. Le niveau moyen d'humidité (en fonction de la masse sèche) des cinq feux variait de 27,1% à 34,9% et la valeur calorifique moyenne allait de 19,0 MJ/kg à 21,1 MJ/kg. Des différences significatives de l'humidité du bois ont été relevées entre les espèces et l'âge des feux. Les espèces feuillues étaient significativement plus humides que les espèces résineuses. Les résultats démontrent que zones de feux de forêt non contrôlés pourraient fournir du combustible de bonne qualité pour la production de bioénergie dans le nord-ouest de l'Ontario.

Mots clés : biomasse, zones de feux de forêt non contrôlés, production de bioénergie, niveau d'humidité, valeur calorifique, nord de l'Ontario

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Introduction

The concept of large-scale bioenergy production from forest biomass is relatively new for Canada. The Nordic countries, however, have been producing bioenergy for heating and electricity from forest biomass for many years. A number of forest biomass-based bioenergy projects have been initiated in Canada in the last three decades in an attempt to look for alternatives to fossil fuels (Luxmore 2008). Under the current energy reforms, the Ontario government has also taken an initiative to phase out coal-fired power generating stations by 2014 (EPA 2007, Tang 2009). The creation of bioenergy is also seen as one of the important components for revival and transformation of Ontario's forest-based industry, which has lost its competitiveness in the last few decades. The bioenergy plants based on combined heat and power (CHP) cycle can further increase profits and lower costs of forest industries by simultaneously generating steam for heating purposes and power for plant operations (Uddin and Barreto 2007). In addition, developing the new bioenergy sector will lead to the creation of a number of jobs for the local communities. In Finland, it was estimated that 11 000 new jobs would be created by utilizing 10 million m³/ year of wood residue for bioenergy production (Kiukaanniemi 2003).

The rapid expansion of interest in the forest bioenergy sector, however, necessitates the need to look for a sustainable supply of biomass for the power generating plants. For example, at the Atikokan Generating Station in northwestern Ontario, approximately 526 000 bone dry tonnes (BDt) per year of biomass would be needed to produce 150 MW of power (OME 2006). Many sources of biomass are being considered to fill this demand including harvesting residues, unutilized wood supply, mill wood waste, dedicated energy crops, fuel-grade peat and wood pellets. As the need for biomass increases, these sources alone may no longer be able to satisfy the needs of power generation facilities and new sources may be sought after. A potential source of woody biomass in Ontario is from forest fires. On average, an area of 35 460 ha or 3 868 034 m³ of wood, which has the potential to be salvaged, is devastated by wildfire every year in the area of undertaking Ontario (OMNR 2008a). Although there have been concerns over the effects of salvage logging residues from the natural ecosystem (Nappi *et al.* 2004), the current forest management regime in Ontario has encouraged the utilization of fired killed and damaged trees (OMNR 2002). While temperature does affect the properties of wood (Kolin

and Danon 1998, Winandy and Rowell 2005), mild wildfires only affect the outer part of trees (Watson and Potter 2004). The insulating nature of the bark and wood as well as relatively short exposure to the fire limits the damage to the remaining wood (Zicherman and Williamson 1981, Bortolotto and Moreschi 2003). The salvage of fire-killed trees has been identified as a source of fibre for the pulp and paper industry as well as other forest sector industries in Canada (Watson and Potter 2004, Moya *et al.* 2008). However, these endeavours may not be the most profitable options in today's economic climate, when the traditional forest products industry is not able to compete in the global markets, using marginal raw materials. The use of salvage of fire-killed trees may be most appropriate in bioenergy power generating plants, if the biomass from these trees has proper fuel quality. Moisture content and calorific value are considered to be two important characteristics of fuel quality of forest biomass (Hakkila 1989, 2003; Nurmi 1999; Jirjis 2005). For example, fired killed ponderosa pine (*Pinus ponderosa* Dougl. Ex laws.) trees have been recognized as a high-quality source of biomass in Colorado for energy production due to its low moisture content and similar energy content to unburnt trees (Mackes and Jennings 2008).

The purpose of this study is to check the fuel quality of four fire-burnt boreal tree species: white birch (*Betula papyrifera* Marsh.), trembling aspen (*Populus tremuloides* Michx.), balsam fir (*Abies balsamea* [L.] Mill) and black spruce (*Picea mariana* [Mill.] BSP). These species composed 70% of the forested area in Ontario in 2004–2005, making their importance and abundance quite apparent (OMNR 2008b). The specific objectives of the study are to compare the changes in moisture content of different fire-burnt tree species over time in northwestern Ontario. This was tested by sampling four tree species in five different fire age classes and looking at both the differences and similarities between species and age since fire. Calorific value was also checked in each species over time to test if there is degradation in fire-burnt trees with age.

Methodology

Five forest fires with different times since burning were identified in the MNR Thunder Bay District in northwestern Ontario. The five fires were 12, 18, 24, 37, and 52 months old, and site locations in unsalvaged burnt stands are shown in Fig. 1. These five fires were selected from unsalvaged burnt

Fig. 1. Locations of five forest fire sample sites. Numbers at each fire site indicate months since fire.

SOURCE: NRVIS DATA – NATURAL RESOURCES AND VALUES INFORMATION SYSTEM (ONTARIO MINISTRY OF NATURAL RESOURCES)

stands due to their proximity to Thunder Bay as well as their representation of five different time periods, since timber was left standing after the occurrence of fire.

Each of the four tree species selected was sampled for calorific value and moisture content for each fire. In order to maintain uniform climate conditions, all sites were sampled in a three-week period between July 28 and August 18, 2008. The moisture content was sampled from seven randomly selected trees for each species and fire age in the field using a Protimeter Surveymaster SM (GE, Billerica MA, USA); however, only one tree per species per site was sampled for calorific value. All moisture content data are from the Protimeter Surveymaster SM, which provides moisture content readings on a dry weight basis (DB). This form of expressing moisture content is commonly used in sawmilling and lumber trade and is calculated using the following formula:

$$[1] \quad \text{Moisture Content} = \frac{\text{Water (g)}}{\text{Dry wood (g)}} \times 100\%$$

The calorific values were tested in the laboratory from collected samples to check if the energy content of the fire-killed trees from northwestern Ontario was different from unburnt trees as found by Mackes and Jennings (2008) for Ponderosa pine. The trees chosen at each of the fires followed the same sampling criteria. All sampled trees had minimal amounts of fire scarring, i.e., fire penetration no deeper than the bark. Every attempt was made to sample mature trees when present at the fire, although at the 12- and 18-month-old fire sites, there were very few mature trees from which to choose. The moisture content of the sampled trees was assessed by remov-

ing bark along with 1 cm of wood with an axe at 1.3 m height. The Protimeter Surveymaster SM was then used to obtain the moisture content of the tree and the value was recorded. The Protimeter Surveymaster SM was chosen to obtain moisture content of the standing trees due to the logistical concerns of transporting samples to the lab. The Protimeter Surveymaster SM is considered very accurate up to the fibre saturation point (25% to 30% moisture content) and anything above is considered an estimate (GE Protimeter 2006), which is sufficient from the point of view of this study. This protimeter has been tested for its accuracy (Wilson 1999), and has also been used in other studies to obtain the MC of wood (Venn *et al.* 2003, Leitch 2009). To ensure accuracy, the MC of one out of the seven samples was also tested using the oven dry method. The experiment was designed to test the hypotheses using an Analysis of Variance (ANOVA) that fire age and tree species affect moisture content. All ANOVA assumptions were tested and met prior to statistical analysis. Where significant differences were found, Duncan's post hoc test was used to explore similarities within treatments.

At each fire site, a sample bolt was collected from each of the four tree species to determine the calorific value of the trees. The bolt was collected from one of the seven sample trees chosen for moisture content determination. The bolt was cut from 1.3 m height, placed in a sample bag and transported back to the laboratory. All samples were dried, ground to 40 mesh size, and then dried again to oven dry moisture content in order to ensure complete combustion. These samples were then tested for calorific value using a Parr 6200 Oxygen Bomb Calorimeter following standard testing methods provided by the manufacturer (Parr Instrument Co.2007). Due to lack of repetition in the calorific values data, there are no statistical tests performed, and these data will only be used to ensure that there are no drastic changes in the calorific content of fire-burnt trees.

Results and Discussion

The moisture content data collected from the field using a Protimeter Surveymaster SM are summarized in Table 1. The results show overall average moisture content of 30.1% with a standard deviation of 14.7% for all tree species and fire ages. The 12-month-old fire in trembling aspen showed maximum moisture content of 53.7% and the 24-month-old fire in black

Table 1. Average Moisture Content (%) for four tree species and five fire ages

Months	Tree Species			
	Balsam fir	White birch	Trembling aspen	Black spruce
12	26.8 (5.9) ^a	45.6 (9.5)	53.7 (16.8)	22.5 (3.4)
18	22.9 (7.8)	43.7 (8.5)	34.2 (14.7)	21.8 (4.7)
24	17.7 (1.4)	40.9 (11.9)	49.2 (16.3)	16.8 (0.9)
37	18.7 (3.5)	39.0 (16.0)	26.3 (9.5)	17.2 (2.6)
52	22.6 (3.4)	37.6 (11.8)	39.7 (12.5)	23.0 (5.9)

^aNumbers in brackets are standard deviations

Table 2. The results of analysis of variance for moisture content for four fire-killed tree species and five fire ages

Source	Type III SS	df	Mean Square	F	Sig.
Species	14032.72	3	4677.57	48.92	0.000
Age	1964.99	4	491.25	5.14	0.001
Species*Age	2393.21	12	199.44	2.09	0.023
Error	11473.24	120	95.61		
Total	164247.57	139

Fig. 2. Moisture content of four fire-killed tree species at the five fire ages.

spruce had minimum moisture content value of 16.8%. However, species-wise comparison of moisture content showed that the highest average moisture content (41.3%) was found in white birch fire-killed trees and the lowest average moisture content (20.3%) was found in black spruce fire-killed trees.

The results of analysis of variance are presented in Table 2. The main effects of species (p -value = 0.000) and fire age (p -value = 0.001), as well as the interaction effect of species and fire age (p -value = 0.023) were found to be statistically significant. The results of Duncan's post hoc tests revealed the fire-killed tree species grouping within each fire age that were having statistically significant difference in moisture content compared to the rest. The results of interaction effects of fire-killed tree species and fire ages are presented in Fig. 2. Fig. 2 also shows a general trend of decrease in moisture content over time, although a gradual increase in moisture content was noticed in some of the old fires. These findings are consistent with those of Mackes and Jennings (2008), who found the moisture content in seven-year-old fire-killed trees of Ponderosa Pine was reduced to 9.4% compared to 77.8% in living trees.

Box plots in Fig. 3 provide a detailed picture of fire-killed tree species–fire age interaction based on moisture content. The results show that in general all softwoods were grouped together in one group, which has significantly lower moisture content as compared to the other group of hardwoods. The average moisture content (30%) of fire-killed trees reveals that these trees provide a feasible option as a source of biomass for bioenergy production. However, the most crucial piece of information discovered in this study was the inherent moisture content difference between the hardwood and softwood

Fig. 3. Box plots representing the moisture content for all combinations of fire-killed species–fire age interactions. Boxes represent 25th and 75th quartiles, the line within the box indicating the median, and the whiskers outside the box extending to the smallest and largest values within 1.5 times inter-quartile range. Similar letters mean no significant difference (Duncan's post hoc test).

species of fire-killed trees. Hardwood fire-killed tree species had average moisture content (41%), which was 20% higher than the average moisture content (21%) of softwood fire-killed tree species. It seems apparent that softwood trees dry quickly after fire and quickly approach the equilibrium moisture content in the range of approximately 14% (Simpson 1998). These two distinct groups will allow proper sorting and mixing of different tree species to control the desired moisture content of feedstock entering a boiler. The extreme variations found in many observations of moisture content of hardwood fire-killed tree species could partially be due to the limitations of the Protimeter Surveymaster SM, used to conduct field sampling. It is reported that the accuracy of the Protimeter Surveymaster SM decreases as the moisture content in the sample increases. The bark remaining on the trees following a fire may also be one of the major factors affecting moisture content as it has been found that logs without bark can dry up to three times quicker than logs with bark (Defo and Brunette 2006). Softwoods may quickly experience reduced moisture due to the observed splitting and shedding of bark, which exposes wood and increases drying. Hardwoods on the other hand, seem to slowly reduce their moisture content after a fire as bark remains on the trees for a long time as was noticed in some older fires.

The results of calorific value data collected from Parr 6200 Oxygen Bomb Calorimeter are shown in Table 3. The calorific value of lower bole wood of fire-burnt trees for white birch, trembling aspen, black spruce and balsam fir in this study was found to be higher than that reported by Singh and Kostecsky (1986) by 1.0, 0.6, 0.9, and 0.5 MJ/kg, respectively. However, a limitation of this study is that with no repetitions for calorific values at each of the fires, no statistical comparison could be preformed. Even without any rigorous statistical analysis, it is evident from the results that there are no drastic decreases in calorific value of fire-killed trees following a fire disturbance.

Timing a post-fire salvage cut may be the most difficult decision for forest managers, who want to collect biomass from fire-killed trees. The results do not provide very clear information about the decreasing trends in moisture content

Table 3. Average Calorific Value (MJ/kg) for four tree species and five fire ages

Months	Tree Species			
	Balsam fir	White birch	Trembling aspen	Black spruce
12	20.5	19.6	19.2	20.1
18	21.0	20.0	19.7	20.5
24	20.0	19.2	19.0	19.4
37	20.0	19.3	19.0	19.7
52	20.0	19.6	19.4	19.6

of different fire-burnt tree species with fire age. The grouping of different fire ages into subsets may also not be very useful for planning the timing of salvage harvest of fire-killed trees. However, most of the fire-killed tree species reach their optimum moisture content levels in 12 months, after which there is no substantial decrease in moisture content. Hardwood species are however, fairly erratic and do not seem to have a discernable pattern. Many boreal tree species depend heavily on forest fires to provide proper germination sites for seeds released after the fire and begin seeding in sites shortly after a fire takes place (OMNR 2002). The longer the period of time after the fire, the larger the seedling on site, which could be possibly damaged by the harvesting operations. To reduce the amount of seedling damage, salvage operations could be treated as a shelterwood cut. The timing of the salvage operations could be planned with specialized equipment in such a way that the harvest skidways cause minimum site damage and result in maximum profits (Hanell *et al.* 2000). Fire sites generally tend to have large amounts of fallen timber on the site in older fires. Although trees on the ground may be collected for biomass, it is unknown if these trees would have as low a moisture content as was found in the dead standing timber. Salvage logging of fire-killed areas can also be used as a site rehabilitation technique. An example of this is the 12-month-old fire, where the fire occurred mainly in young plantations of jack pine, which do not yet have many seeds in the canopy to be released after fire (Farrar 1999). With this site not having the ability to naturally regenerate itself, and with the difficulty to replant due to dead standing timber being an obstruction as well as a safety hazard to tree planters, early biomass harvesting is the most feasible solution. Therefore, removal of the dead standing timber at the 12-month-old burn immediately could be a profitable exercise and allow the re-establishment of the fire-killed plantations.

Conclusion

Fire-killed trees examined in this study had desirable moisture content and calorific value for the production of bioenergy. The policy in Ontario currently supports the salvage of these fire-killed forests, which can increase the potential biomass supply. The timing of salvage logging of fire-killed trees may be the most important decision for managers, as moisture content reaches fairly stable levels after 12 months but remains at that level for a long period of time. The knowledge of desirable fuel qualities such as calorific value and

moisture content in fire-burnt trees allows forest managers to implement site rehabilitation in a potentially profitable manner. The logistics and economics of salvaging fire-killed trees must be further studied in greater detail to ensure economic feasibility and efficiency of the salvage operations.

Acknowledgements

We thank AbitibiBowater Thunder Bay, especially Tom Lock, who helped with identifying sites and sampling trees, and Mike Kukko, who aided with the lab preparations and analysis. We also express our thanks to the editor and two reviewers for their useful comments.

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