STORAGE OF COMMINUTED AND UNCOMMINUTED FOREST BIOMASS AND ITS EFFECT ON FUEL QUALITY

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White birch was stored in the form of bundles, wood chips, and loose slash for a period of one year to examine the changes in biomass fuel properties. The samples were collected at regular quarterly intervals to measure moisture content, CNS content, ash content, and calorific value. Data loggers were also placed into the stored woody biomass to measure the temperature change inside the piles. After the first quarter of the storage period and continuing into the next three months of storage, the moisture content showed the most significant change. The moisture content of the biomass bundles increased from 29 % to above 80 % (db). The moisture content of the pile of wood chips covered with a tarp decreased from 51% to 26% and showed a continuous decline in moisture content to the end of storage period to an average range of 16.5% (db). However, the moisture content of uncovered wood chip pile was observed to continuously increase throughout the storage period, resulting in more than double in magnitude from 59% to 160% (db). The dry matter loss was higher in wood chip piles (8~27%) than in bundles (~3%). Among the other properties, there was slightly higher loss of calorific value in wood chips (~1.6%) as compared to bundles (~0.7%) at the end of one year.

Keywords: Biomass storage; Moisture content; Calorific value; Ash content; CNS composition; Dry matter loss

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INTRODUCTION

Forest biomass is a source of energy through the conversion of woody biomass into convenient fuels to provide energy for industrial, commercial, or domestic use. The immediate use of forest biomass residue is often unfeasible for various reasons, and biomass storage can play an important role in the forest industry. Better storage results in fuel of low moisture content and higher calorific value, which are the two important properties that determine the fuel price. The greater use of wood in chip or bundle form for energy purposes requires defined properties of the product. Consumers want to be supplied with wood chips or bundles of a high, constant, and uniform quality (Smith 1985; Lehtikangas and Jirjis 1998).

Forest harvest residue is either left in small piles after felling, chipped after some time, or compacted into bundles. Each method has its own advantages, but the chipping method is the most commonly used by the industry in North America. However, in Scandinavia the bundling method is also practiced for forest biomass storage. Right from the introduction of bundling technology, industry is trying to figure out which method is most suitable to maintain the quality of biomass fuel during storage.

Previous studies have shown that the storage of logging residue in bundles can increase the wood fuel quality, i.e., lower moisture content, higher heating value, and an acceptable level of ash contents (Lehtikangas and Jirjis 1998; Pettersson and Nordfjell 2007; Lehtikangas 2000, 2001). Amongst the fuel properties, the moisture content is the main property that drops over the time in uncomminuted residue, but it typically increases in comminuted residue, and it has also a significant effect on the net calorific value. This increase in moisture content in comminuted residue is attributed to the small particle size and higher degree of compaction that occurs in wood chip piles. Moreover, as a result of compaction in wood chip piles, less air movement takes place within the pile, resulting in higher internal heat and moisture content (Jirjis 1995, 2001). However, covering the residue piles could affect the moisture content. Coverage of piles can protect against rain and snow penetration into the stored material and thus decrease the moisture content; however, good airflow is necessary to disperse water vapour to minimize the chance of composting and mould formation (Nurmi and Hillebrand 2002). In addition, high stack heights should be avoided to prevent heat build up from composting and spontaneous combustion. During the storage, the top region of the pile becomes warmer, begins to steam, and becomes discoloured. The top region functions as a vent for dissipating moisture from the lower interior regions of piles. Self-heating of wood chips begins from the outer top of the pile, because this part of the pile has greatest exposure to solar radiation, and it therefore thaws first. Until self-heating begins, the pile remains in a general state of net heat gain; however, after heating begins, the pile experiences net heat loss. As compared to the wood chips, no particular energy changes take place if the forest biomass is stored in loose form (Jirjis 2005; White et al. 1983; Thornqvist 1985; Sampson and McBeath 1987).

The compression of uncomminuted wood, by tying it into bundles, can improve the handling efficiency and reduce transportation cost. Even though the material when formed into bundles can be stored and transported conveniently and the ease of air passage through a log pile allows drying, they may not always be in the most convenient form for automated handling and feeding. Also, the relatively small surface area to volume ratio is not ideal for efficient combustion or gasification. Wood chips can form a much more uniform fuel that can flow and be used to feed a boiler or other conversion system as a steady flow using a conveyor or other type of feeder. Wood chips have a large surface area to volume ratio, which allows them to be burned very efficiently. However, there is limited literature available for forest biomass storage, particularly in its uncomminuted form. Identifying a better storage method would help to improve forest harvest operations. Therefore, the objectives of this study are to examine the changes in biomass properties that take place in different forms of storage and to find out the best method to store woody biomass.

EXPERIMENTAL

Material and Experimental Piles

The brown biomass of White Birch (*Betula papyrifera*), the most commonly available species in Atlantic Canada, was used in this study. The biomass material was stored in the form of woodchips, bundles, and loose slash piles.

Fresh birch wood stems were comminuted into chips with nominal size between 2-25mm. Three cone-shaped piles of wood chips, each having 3m height, were constructed to represent different storage conditions. These piles were constructed in July 2007 at the facility in the University of New Brunswick (UNB). The first pile on the forest floor was covered with a breathable tarp to prevent rainwater from penetrating into it. The second pile was built on the forest floor, and it was uncovered for adequate air flow from all directions. The third pile was constructed on a plastic sheath underneath to prevent the moisture penetrating into the pile from the ground.

In the second form of storage, eight-months-old slash of birch was compacted into twelve bundles. Stems of birch were tied to form bundles, and bundles had an average weight of 50 kg, 3m average length, and 0.5 m average height. These bundles were placed 0.5m apart on the wooden beams to ensure maximum air flow from all directions. Three out of twelve had data loggers, which were placed at the top, centre, and bottom part of the bundle. Bundles with data loggers were opened at the end of the year and considered as controlled samples.

In the third form of storage, loose slash was stored and was not compacted for adequate natural airflow. A logger was also placed in the centre of this pile to measure the temperature and relative air humidity.

Sampling Technique

ASTM standard methods were used to measure the various biomass properties. Samples were taken for determination of moisture content, heating value, and ash content. The sampling interval of biomass stored under all treatments was three months. The moisture contents were determined by oven drying at 105 ^{o}C for 24 hours. The calorific values of the material were determined using a bomb calorimeter, and the ash content was determined by standard ignition method E 1534-93. Samples were taken for wood chips from the sampling zone, which was the mirror image of the location where the data loggers were placed in the pile (Fig.1). For the biomass bundles, three bundles were opened after every three months, leaving behind three bundles at the end of the year that had loggers in them (Fig. 2). Similarly, in the case of loose slash, samples were taken in three-month intervals, and from each form of storage the samples were taken from top, middle, and bottom part of the biomass pile. From each part around six samples were taken for the laboratory analysis and then the average value results were taken for analysis. Data loggers were removed after a year and the data downloaded into the computer for analysis.

The bundles were weighed every month to measure the dry matter loss. In case of wood chips, three net bags of 1 kg each were placed in each pile. These bags were weighed prior to placing them in the pile, and then the difference in dry weight of each bag at the end of the storage period represented the dry matter loss. One net bag of wood chips was taken out at every three months interval to measure the weight and dry matter loss, and this net bag was not placed back to its position. This way the remaining net bags were not disturbed and had no effect on the results of experiments.

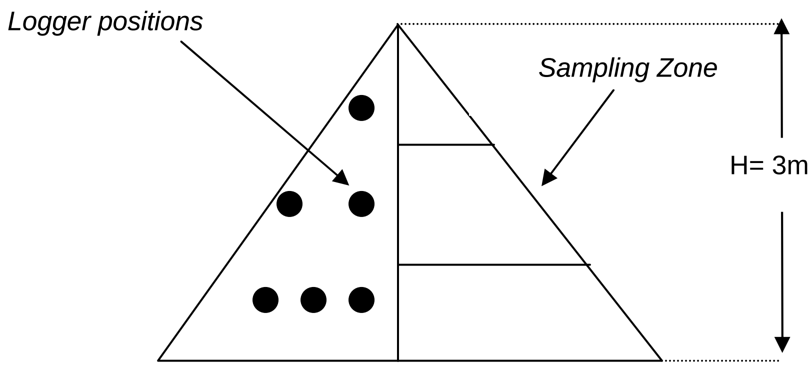

Fig. 1. Schematic diagram of woodchips pile profile showing sampling zone and logger positions

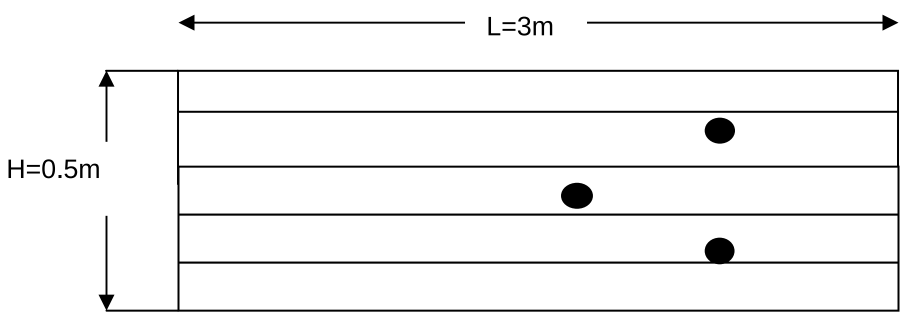

Fig. 2. Schematic diagram of biomass bundle showing the position of loggers

Weather Conditions

Ambient temperature and relative humidity were measured twice every day throughout the whole storage period, at 12.00 AM and 12.00 PM. The mean temperature at the time of constructing piles was higher i.e. at the beginning of July 2007 (21 ^{o}C), and then immediately it started to decrease until the 1st of December (Fig. 3). The temperature was constantly below 0 ^{o}C until the month of March, and then continued to rise towards the end of the storage trial, August 2008.

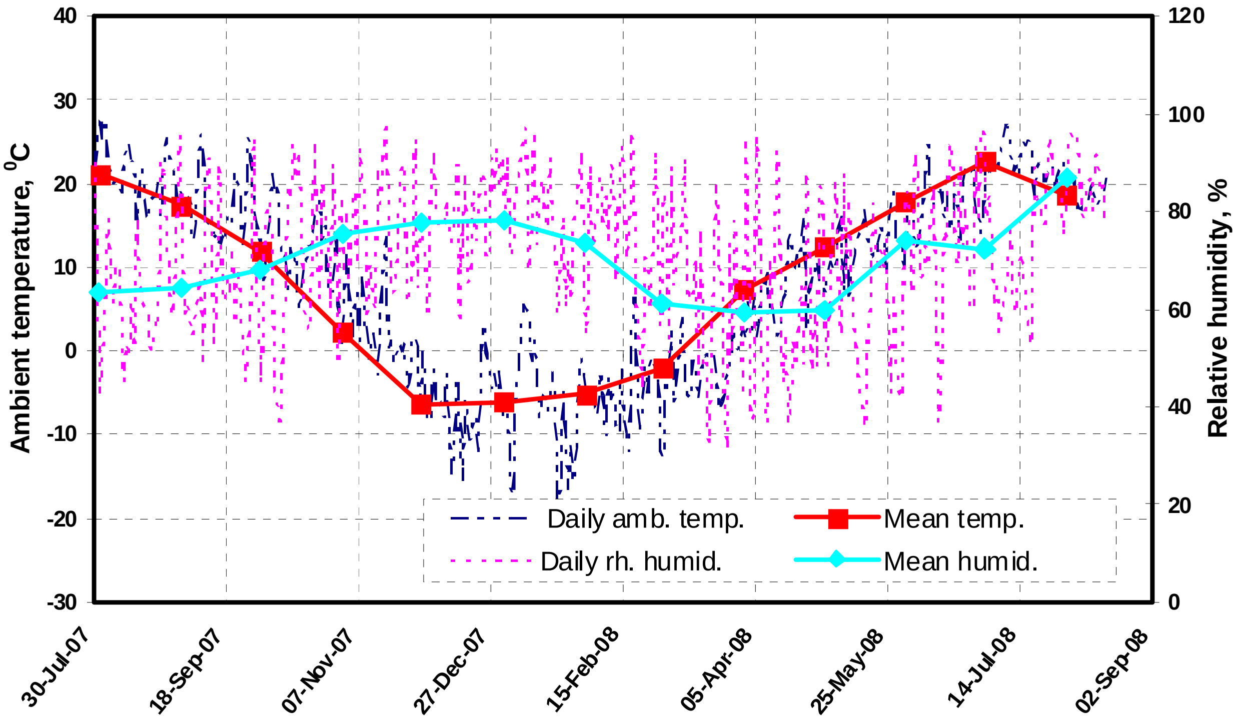

Fig. 3. Ambient temperature and relative humidity during the storage period

The mean relative humidity was higher from the beginning of December to March, started declining for a short period (for April), and then rose again due to rainfall at the end of the storage period.

RESULTS AND DISCUSSION

Changes in Moisture Content

The moisture content of biomass bundles and wood chips at the beginning of the experiment were averaging around 29.5 ± 2.84 % and 59.5 ± 1.60 % dry basis (db), respectively. The loose slash woody biomass was stored at the beginning of November 2007 and had an average moisture content of 45.5 ± 5.00 % (db).

The moisture content inside the bundles was varying significantly. During the first three months of storage period at the top and at the centre part were increased rapidly to 104% and 80% (db) respectively, due to the rainy season. Even though the bottom part showed increment in moisture content, the slope of the increment was not as big as the other parts of the bundle (Fig. 4).

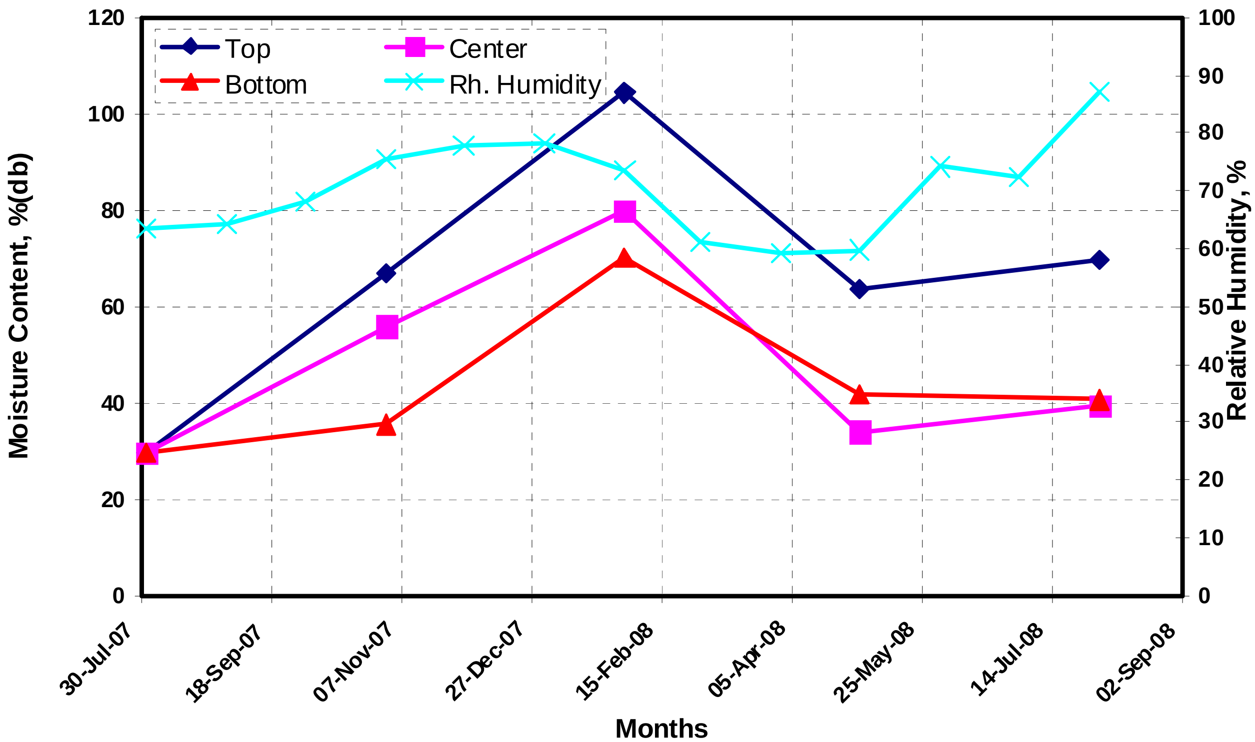

Fig. 4. Moisture content of bundle and relative humidity of the air during storage period

From January to mid-April, due to low rainfall the moisture content showed a decreasing pattern, and the lowest was observed in the middle part of the bundle, which was around 34 % (db). Then the moisture content had been increasing in the entire part of the bundles until the end of the storage period due to re-wetting, caused by higher relative humidity of the air and rainfall.

In the case of the covered wood chips pile the moisture content showed a decreasing trend throughout the storage period and also it was observed to have a uniform moisture distribution inside the pile (Fig. 5). During the first three month period of storage a fast decline in moisture content was observed because of a higher ambient temperature that allowed moisture in the wood chips to evaporate through the breathable covering tarp. Then in the next period the moisture decrease was slow due to lower ambient temperature. At the end of the storage period the moisture content had decreased to around 16.5, 19.87 and 13.13 % (db) in the top, centre and bottom part of the wood chips pile, respectively.

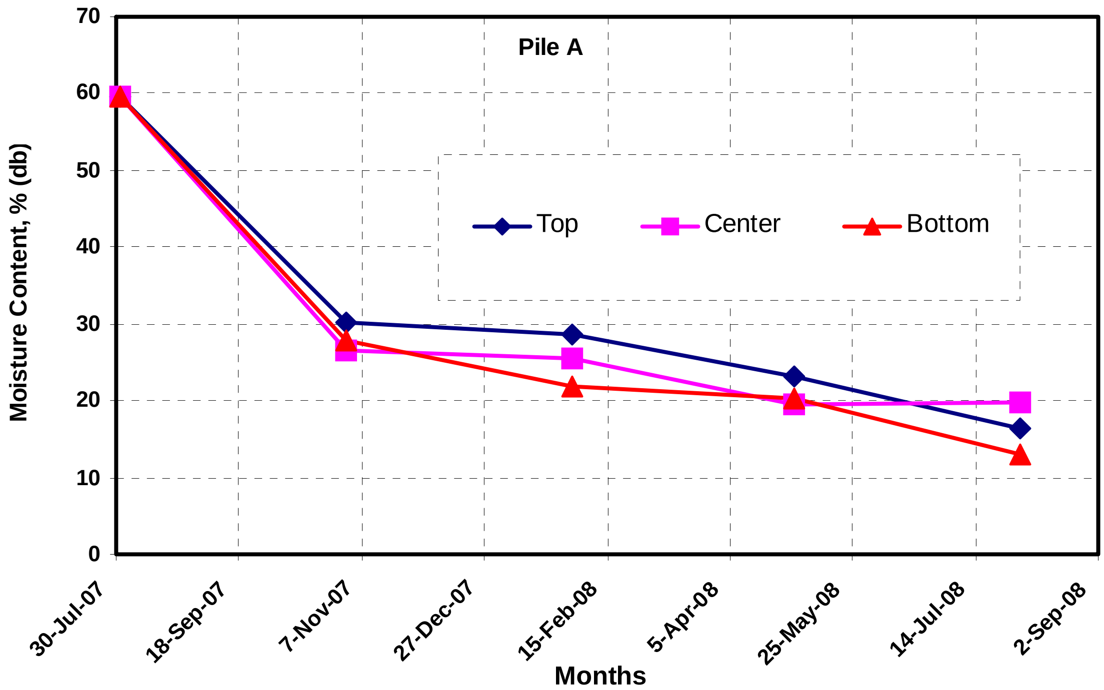

Fig. 5. Change in moisture content of wood chips pile covered with tarp

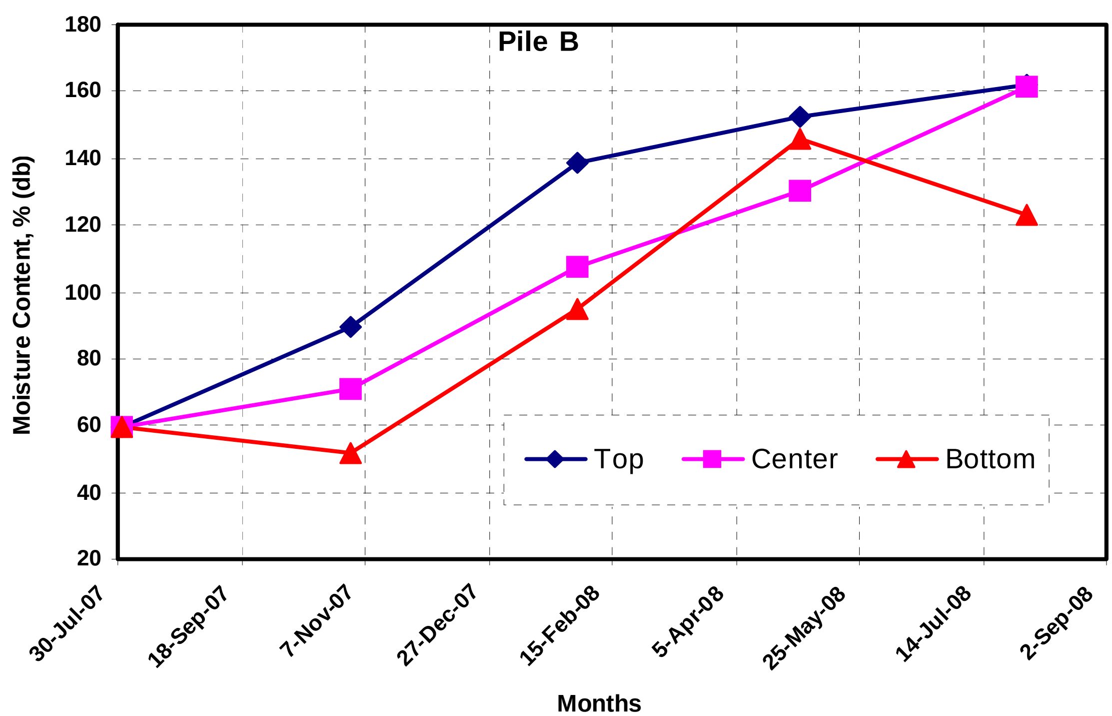

Fig. 6. Change in moisture content of wood chips pile with plastic sheath underneath

The moisture content of wood chip piles with a plastic sheath underneath showed an increasing trend with time (Fig. 6). The moisture content of the uncovered wood chips pile increased with time during the storage period. The top part of the pile showed the highest increase (162%) in moisture content, mainly due to the surface exposure to the atmosphere and high relative humidity of the air (Fig. 7). In comparison to this, the covered wood chip pile showed the lowest moisture content, which was below 20% (db) by the end of storage period.

The loose slash storage trial started at the beginning of Nov. 2007. It showed a non-uniform moisture content distribution in the pile (Fig. 8). The top part of the loose slash pile showed higher moisture content due to the surface exposure to the atmosphere. The initial average moisture content of the loose slash was around 45.5%. It showed an increasing trend with time of storage but fell in magnitude in May to an average of 56.5%, then rose again at the end of final storage period to an average value of 65.4%.

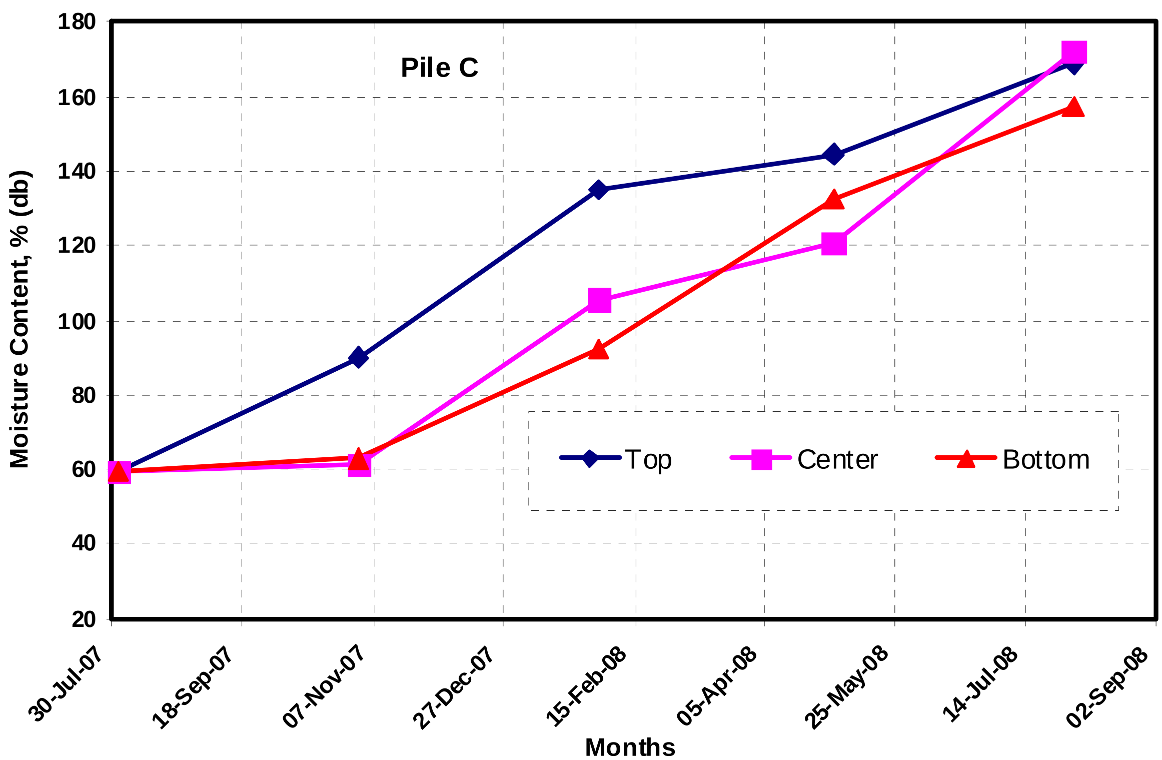

Fig. 7. Change in moisture content of uncovered wood chips pile

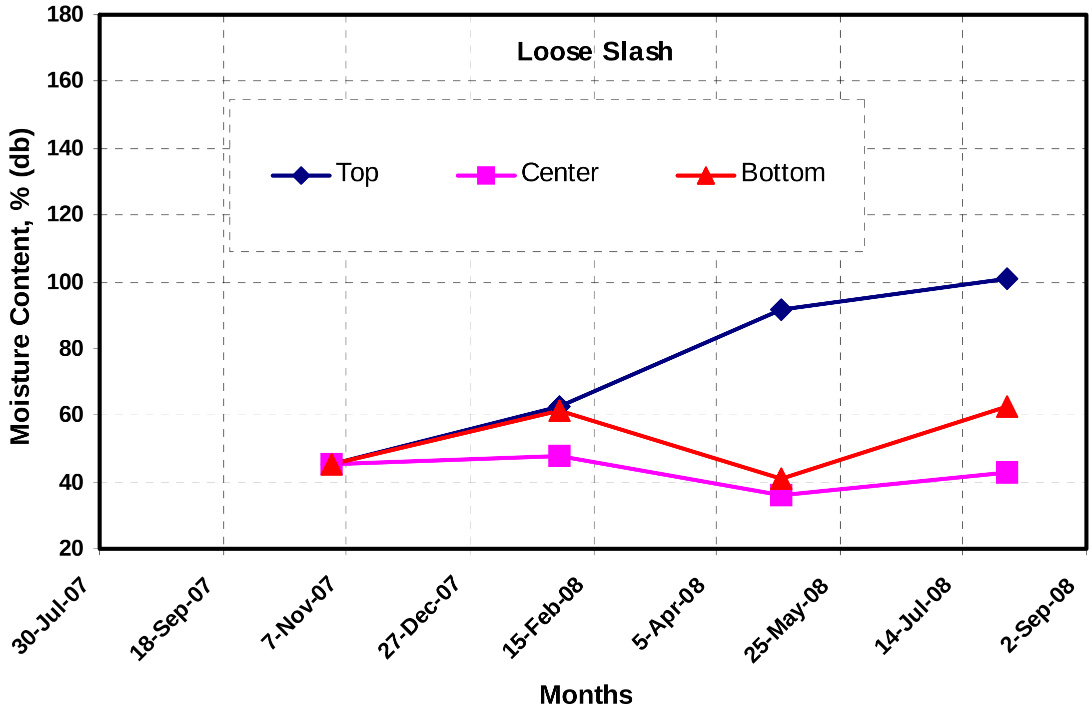

Fig. 8. Change in moisture content of loose slash during storage period

Changes in Energy Content

The change in the heating value was not significant in any of the forms of storage. The average calorific value of the bundles before storage was 18.84 ± 0.61 MJ/kg. After the storage period the average energy content declined to 18.71 ± 0.40 MJ/kg. Most of the changes took place in the top parts of the pile. In case of the wood chip piles, the average initial heating value was 19.60 ± 0.30 MJ/kg, but a decrease in calorific value was observed in all form of wood chips storage piles. By the end of the storage period the covered, underneath plastic sheath, and uncovered wood chip piles had calorific value of 19.56 ± 0.28, 19.44 ± 0.11 and 19.28 ± 0.38 MJ/Kg, respectively (Table 1).

Higher loss of calorific value was observed with a plastic sheath underneath and uncovered wood chip piles. However, in the case of loose slash storage form, the average calorific value showed an increasing trend during the storage period, and changed from the initial value of 18.83 ± 0.13 to 19.54 ± 0.22 MJ/kg. In general, relatively higher calorific value changes were observed in uncovered wood chip piles (1.6%) than in bundles (0.7%) and the loose slash forms of storage.

Changes in Ash Content

At the beginning of the storage period the average ash content of the bundles was 0.25 ± 0.04 % (db). The ash content was increased with time of storage, and after the first three month of storage, the average ash content was raised to 0.32% (Table 1).The ash content of the wood chips pile before storage was 0.43 ± 0.02 %, and increasing ash content with time of storage was observed in all wood chip piles form of storage. After the first three months of the storage period the ash content of covered, underneath plastic sheath, and uncovered wood chips biomass were 0.41, 0.60, and 0.51 %, respectively.

By the end of the storage period the covered, uncovered, and the underneath wood chip piles had an ash content of 1.06, 1.09, and 1.12%, respectively. The results shown in Table 1 indicate that the covered wood chip had relatively lower ash content at the end of the storage period. This may be due to environmental factors that influence the increase in ash contents, such as accumulation of dust particles coming with strong wind, affecting the uncovered woody biomass storage. Earlier studies (Jirgis 1995, 2005; Lehtikangas 2001) also reported that fungus activity in the bundle's storage was too small to cause any health hazard, and the ash content and the percentage of fines were considerably lower than in wood chips.

Table 1. The Average Calorific Value and Ash Content in Different Parts of Bundles, Wood Chips Piles and Loose Slash
(The standard deviation is shown in parentheses.)

	Calorific value (MJ/kg) (SD*)				Ash content (%) (SD*)			
	Nov-07	Feb.-08	May-08	Aug.-08	Nov-07	Feb.-08	May-08	Aug.-08
Bundles								
Top	18.97(0.16)	18.86(0.16)	18.51(0.17)	18.36(0.22)	0.33(011)	0.63(0.01)	0.96(0.01)	0.84(0.01)
Centre	18.76(0.60)	-----	19.07(0.49)	19.24(0.20)	0.31(0.02)	-----	0.82(0.01)	0.87(0.01)
Bottom	18.99(0.08)	-----	18.44(0.16)	18.53(0.41)	0.32(0.01)	-----	0.81(0.01)	0.89(0.01)
Average	18.91(0.13)	18.86(0.16)	18.76(0.34)	18.71(0.38)	0.32(0.01)	0.63(0.01)	0.86(0.01)	0.87(0.01)
Wood chips pile covered with tarp								
Top	18.97(0.12)	19.54(0.15)	19.11(0.03)	19.17(0.05)	0.42(0.01)	0.42(0.01)	0.80(0.01)	0.91(0.01)
Centre	18.37(0.15)	19.84(0.09)	19.74(0.08)	19.81(0.09)	0.39(0.02)	0.43(0.01)	0.85(0.02)	1.16(0.10)
Bottom	19.48(0.16)	20.00(0.07)	19.74(0.06)	19.69(0.14)	0.40(0.01)	0.45(0.01)	0.82(0.01)	1.12(0.09)
Average	18.94(0.45)	19.79(0.32)	19.53(0.30)	19.56(0.28)	0.41(0.01)	0.43(0.01)	0.82(0.02)	1.06(0.11)
Wood chips pile with plastic sheath underneath								
Top	18.77(0.19)	19.40(0.40)	19.23(0.05)	19.34(0.41)	0.60(0.02)	0.48(0.01)	0.96(0.01)	1.09(0.02)
Centre	19.15(0.35)	18.91(0.08)	19.33(0.07)	19.40(0.13)	0.57(0.04)	0.52(0.05)	1.00(0.01)	1.11(0.08)
Bottom	18.91(0.06)	18.69(0.09)	19.58(0.01)	19.59(0.12)	0.62(0.02)	0.46(0.01)	1.13(0.02)	1.08(0.05)
Average	18.94(0.16)	19.00(0.29)	19.38(0.15)	19.44(0.11)	0.60(0.02)	0.49(0.03)	1.03(0.07)	1.09(0.07)
Wood chips pile uncovered								
Top	20.03(0.43)	19.66(0.43)	19.19(0.03)	19.33(0.13)	0.51(0.01)	0.51(0.01)	0.73(0.01)	1.23(0.15)
Centre	19.62(0.16)	19.06(0.36)	19.13(0.04)	19.05(0.26)	0.48(0.01)	0.57(0.09)	1.11(0.03)	1.10(0.14)
Bottom	17.69(0.01)	18.61(0.20)	19.58(0.06)	19.46(0.39)	0.53(0.02)	0.48(0.02)	1.21(0.01)	1.02(0.24)
Average	19.40(0.39)	19.11(0.43)	19.30(0.27)	19.28(0.38)	0.51(0.02)	0.52(0.04)	1.02(0.21)	1.12(0.09)
Loose slash								
Top	-----	18.66(0.06)	19.23(0.08)	19.33(0.12)	-----	0.61(0.01)	0.69(0.01)	0.66(0.05)
Centre	-----	18.77(0.14)	19.26(0.05)	19.45(0.36)	-----	0.63(0.03)	0.78(0.01)	0.86(0.02)
Bottom	-----	19.06(0.30)	19.80(0.10)	19.84(0.18)	-----	0.73(0.03)	0.77(0.02)	1.07(0.04)
Average		18.83(0.17)	19.43(0.26)	19.54(0.22)		0.66(0.05)	0.74(0.04)	0.86(0.17)

*SD=Standard Deviation

The same trend was observed for the loose slash; the average ash contents were increased from 0.66% to 1.03% at the end of the storage period (Table 1).

Changes in Dry Matter Loss

The rate of dry matter loss was higher in wood chips than in the bundles form of storage after the end of the storage period (Table 2). Dry matter loss of bundles (3%) was also lower than wood chip piles (8~27%). Especially the underneath plastic sheath and uncovered wood chip piles had a higher dry matter loss than any other storage form of wood chip piles. This was probably due to the large surface area available for microbial growth so that it consumes the nutrients in the wood chips. Similarly, the storage of large particle size and logging residues had minimal dry matter loss than comparing to the small particle size (Jirjis 1995 and 2005; Lehtikangas and Jirjis 1998; Pettersson and Nordfjell 2007).

Table 2. Dry Matter Loss in Bundles and Wood Chip Piles

Form of storage	Dry matter before storage (kg)	Dry matter after storage (kg)	Dry matter loss (%)
Bundles	37.92	36.80	3
Covered wood chips	0.75	0.69	8
Wood chips pile with plastic sheath underneath	0.88	0.69	22
Wood chips pile uncovered	0.9	0.72	27

Changes in Carbon, Nitrogen, and Sulphur Content

The changes in the composition of the experimental biomass in all forms of its storage are presented in Table 3. All the measurements are expressed on a dry basis. The average initial carbon, nitrogen, and sulphur content of wood chip piles in the beginning of storage were 43.6 ± 2.2 %, 0.6 ± 0.12 %, and 0.0 %, respectively. The bundles initial carbon, nitrogen, and sulphur content were 43.8 ± 0.89 %, 0.1 ± 0.06 %, and 0.0% .The carbon content was increased in all forms of biomass storage, while the nitrogen content was decreased. The sulphur content in all form of storage was also increased at the end of the storage period. The increase in sulphur content can be attributed to contaminated air.

Temperature Changes Inside the Piles

The temperature was measured at different positions inside the piles throughout the year. During the whole storage period the temperature inside the pile had the same pattern with the ambient temperature. However, there was a slight difference in different forms of storage piles.

Table. 3. Carbon, Nitrogen and Sulphur Composition of Experimental Biomass
(The standard deviation is shown in parentheses.)

	Composition (%) (SD*)			
	Nov-07	Feb.-08	May-08	Aug.-08
Bundles				
Carbon	42.77(1.00)	-------	51.57(0.22)	51.43(0.30)
Nitrogen	0.18(0.08)	-------	0.02(0.01)	0.02(0.01)
Sulphur	0.00(------)	-------	0.13(0.16)	0.14(0.06)
Wood chips covered with tarp				
Carbon	43.78(1.96)	-------	52.49(0.45)	51.57(0.41)
Nitrogen	0.47(0.13)	-------	0.01(0.01)	0.01(0.01)
Sulphur	0.00(-----)	-------	0.17(0.01)	0.21(0.04)
Wood chips pile uncovered				
Carbon	42.76(1.79)	-------	52.65(0.20)	51.83(0.03)
Nitrogen	0.48(0.43)	0.01	0.01(0.01)	0.01(0.01)
Sulphur	0.00(-----)	0.49	0.23(0.02)	0.22(0.05)
Wood chips pile with plastic sheath underneath				
Carbon	44.15(1.63)	-------	52.52(0.57)	51.61(0.30)
Nitrogen	0.56(0.12)	0.01	0.01(0.01)	0.01(0.004)
Sulphur	0.00(-----)	0.52	0.23(0.04)	0.12(0.10)
Loose slash				
Carbon	47.8(1.10)	-------	53.00(0.43)	52.00(0.2)
Nitrogen	0.00(----)	0.01(0.01)	0.01(0.12)	0.01(0.03)
Sulphur	0.30(0.10)	0.30(0.1)	0.30(0.09)	0.30(0.11)

*SD=Standard Deviation

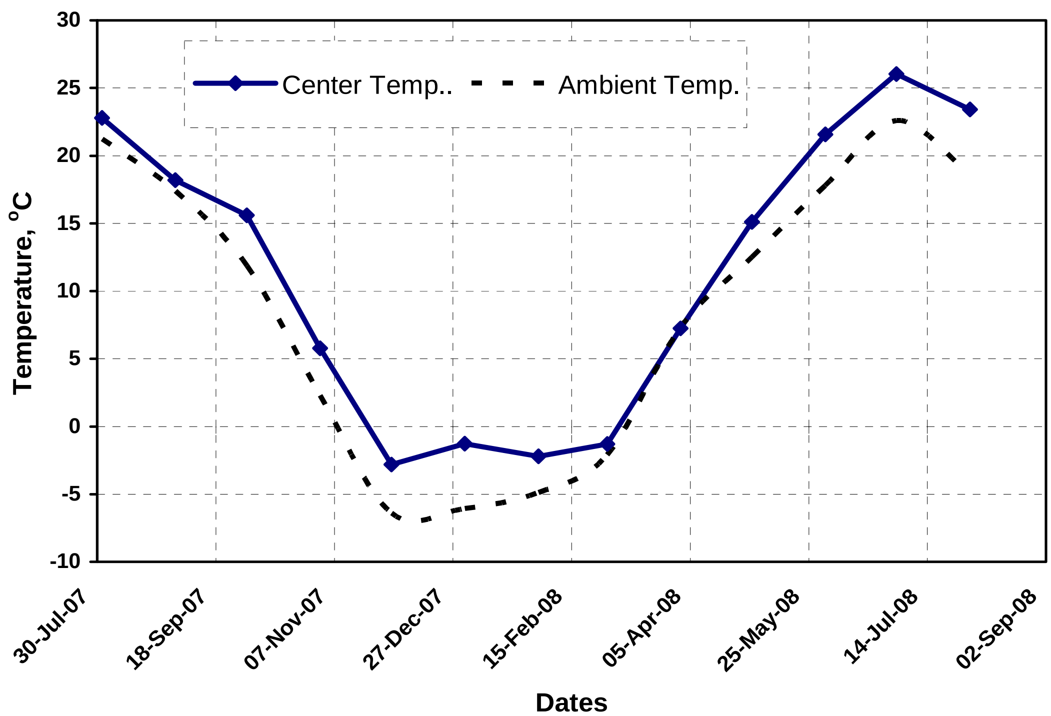

Fig. 9. Temperature changes inside the wood chips pile covered with tarp

Temperature in covered (Fig. 9) and underneath plastic sheath (Fig.10) wood chips piles was slightly higher than uncovered wood chips pile. As the result of good air flow conditions, no rise in temperature was measured in the uncovered woody chips piles, and the pile temperature approximated the ambient temperature (Fig. 11). There was no self-ignition observed in any pile during the storage period. However, another study (Jirjis 2005) showed a sudden rise in temperature inside the pile for the storage of willow shoots of 3m high and also as the height of the pile increased the heat development was rapid.

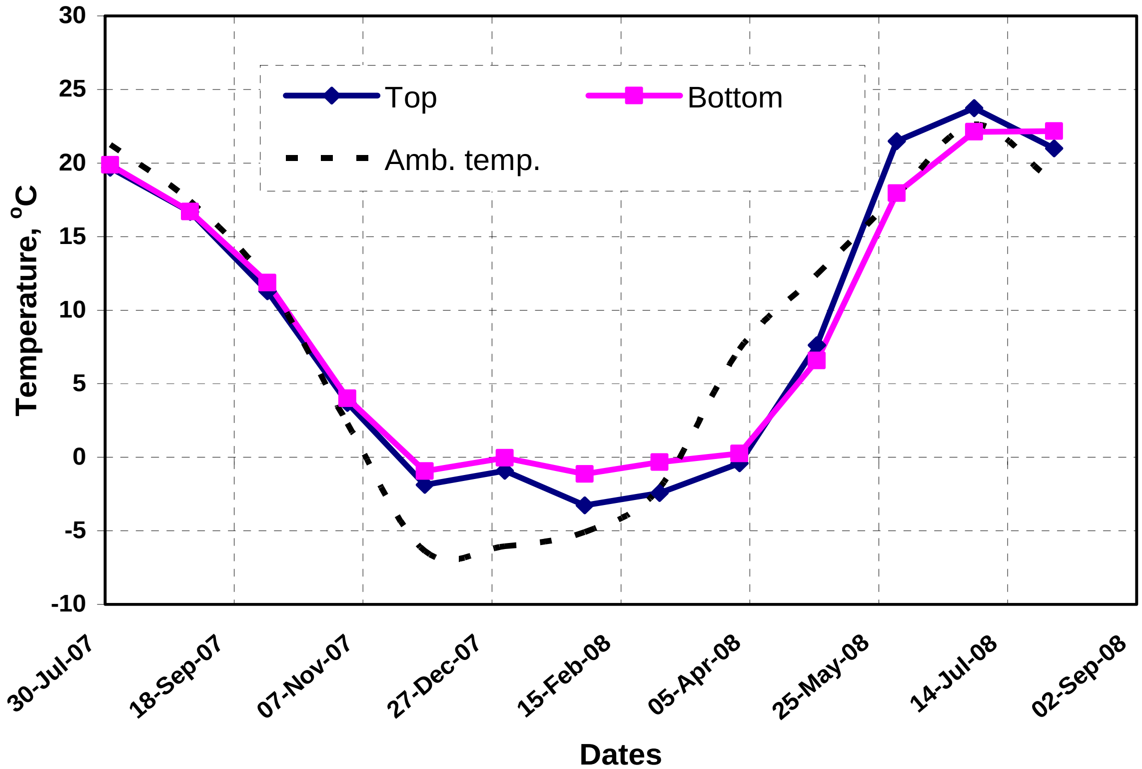

Fig. 10. Temperature changes inside the wood chips pile with plastic sheath underneath

The temperature in the wood chip piles was higher compared to the bundles for the same ambient air temperature due to slow heat transfer as a result of low thermal conductivity of wood chips, the heat produced inside the pile could not dissipate to the surroundings completely. During low ambient temperature the bottom part of the wood chip piles had a higher temperature value than the other part of the wood chip piles, and reversely when the ambient air temperature was high the top part would have a higher value of temperature. However, in case of bundle storage there was no significant temperature difference inside the pile at different ambient temperature, and no temperature development in the piles and more dependent on ambient conditions (Fig. 12).

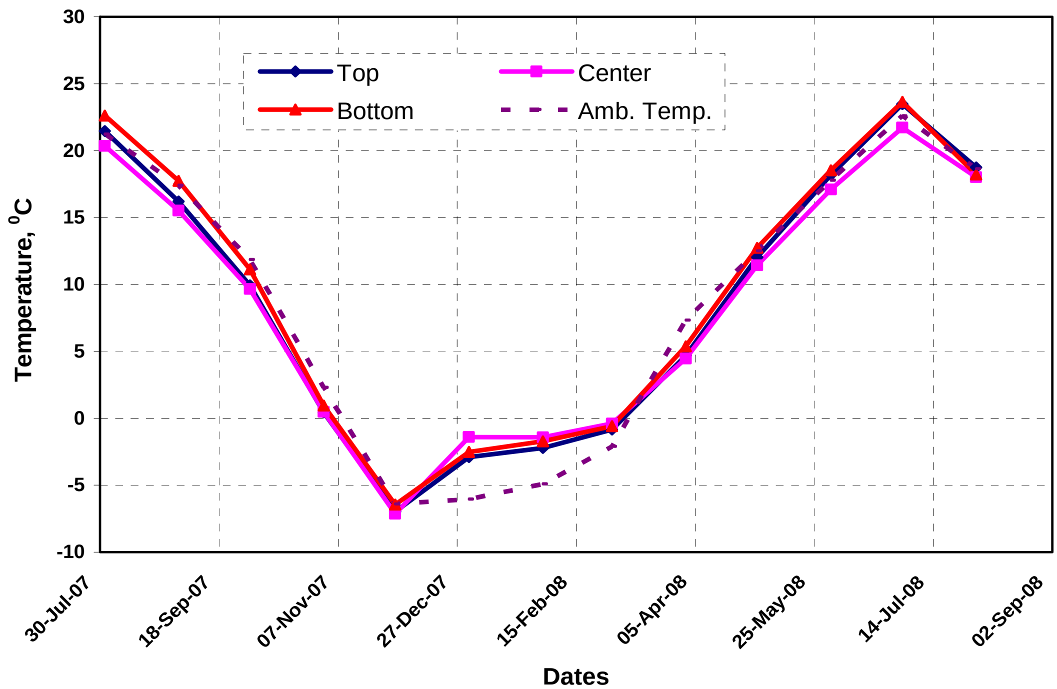

Fig. 12. Temperature changes inside the bundles

CONCLUSIONS

1. Changes of woody biomass properties with respect to moisture contents, calorific value, ash contents, and dry matter loss were observed during the storage period in the form of wood chips pile, bundle, and loose slash. Moisture content showed significant change during the one year storage period.
2. The rate of moisture content increment was lower in bundle form of storage than in an uncovered wood chips pile. However, covered wood chips pile showed decreasing moisture content through out the storage period and also had almost uniform moisture content distribution in the top, middle, and bottom part of the pile. The least moisture content drop of the biomass bundles was observed between February and April during the one year storage period.
3. Loss of calorific value and dry matter loss were higher in wood chip piles as compared to the bundles at the end of the storage period. Particularly, the maximum dry matter loss was observed in uncovered wood chip piles at the end of the storage period.
4. The change in carbon content was slightly higher in wood chips than in bundles and loose slash. Temperature development in piles of bundles was also lower and more dependent on ambient temperature.
5. In general this study signifies that the storage of biomass in bundles can reduce the moisture contents and loss of calorific value. However, the use of a breathable tarp reduces moisture content of wood chips and dry matter loss under Eastern Canadian weather conditions.

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