Examensarbete Master's Thesis

Forests as a Natural Resource

Effects of Storage and Geographical Location on Fuel Quality Of Norway Spruce Forest Residues

Effekter av Storage och geografiskt läge för bränslekvalitet gran Skogsavfall

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ABBERIVATIONS

MC	Moisture Content
CV	Calorific value
AC	Ash Content
$Q_{gr, v}$	Calorific value at constant volume (higher heating value)
$Q_{net, p.m}$	Net Calorific value at constant pressure (lower heating value)
TWh	Terawatt hours
ODTS	Organic Dust Toxic Syndrome
DML	Dry matter losses
g	gram
C	Carbon
H	Hydrogen
O	Oxygen

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Summary

Sweden is a forest rich country with a total land area of 40.8 million hectares of which 22.7 million hectares are categorized as productive forest land. More than 50% of this is owned by private owners. The total standing volume on the productive forest land is about 3400 million m^3. The dominant forest species are Scots pine and Norway spruce, which constituted about 38% and 27% respectively of the Swedish productive area (Swedish Forest Agency, 2010). This abundant availability of forest biomass plays a prominent role in the Swedish energy supply. According to Swedish Energy Agency (2008) renewable sources meet 43% of the total energy requirements in Sweden, out of which a considerable figure of 23% is fulfilled by wood fuels. Forest residues are a potential source, which can be utilized for bioenergy purpose, and the demand for it has increased in the wood fuel market in recent years (Björheden, 2006). In Sweden, the highest demand for forest residues occurs in the cold winter season since it is mostly used for heat production. Storage is therefore necessary to meet the demand.

Storage and handling of forest residues is a complex process. The forest residues which include needles and twigs are vulnerable for varying weather conditions i.e. temperature, wind, humidity, air and precipitation. Furthermore other factors including duration of storage, placement of windrows and the initial quality of the forest residues have an impact on the fuel quality. For all these reasons it becomes necessary to skilfully manage the storage of forest residues and thereby ensuring high fuel quality.

The aim of this thesis work was to evaluate and compare the effect of prior summer storage (brown storage) or direct windrows storage of freshly harvested biomass (green storage) on the fuel quality of Norway spruce forest residues at three different geographical locations in Sweden.

In this study Norway spruce forest residues were collected at three geographical locations in southern Sweden after storage. At each locality numbers of sites were chosen. Freshly harvested forest residues were then stored at each location by using two storage methods. The first storage method was referred to as brown storage (prior summer stored forest residues). In this method the forest residues were stored in small piles for at least 20 weeks at the clear cut after harvesting and then they were gathered into windrows at landing for further storage. The other method used was referred to green storage (freshly harvested and stored forest residues) where the biomass was gathered to windrows after a few weeks storage in small piles at the clear cut. The investigated fuel characteristics included; moisture content, ash content, calorific value and net calorific value.

Moisture content decreased significantly after storage in both green and brown stored forest residues. After one year storage the rate of moisture content was lower in brown stored forest residues as compared to green stored forest residues. Brown forest residues had lower ash content than green stored at the end of the storage period. This was probably due to the amount of needles which was larger in green stored material than in brown stored. After one year storage the calorific value and net calorific value had almost reached the same value irrespectively of storage method. Therefore from energy point of view, it can be concluded that there was no significant difference between green and brown storage methods. However, green storage method has an advantage such as shorter storage duration of forest residues before gathering into windrows than brown storage on the same site. Moreover, it is more time saving and economically profitable compared to brown storage.

Key Words: Ash content, Calorific value, Logging residues, Moisture content, Norway spruce, Storage, Wood fuel quality.

1. Introduction

During the past few years the demand of energy has continuously increased throughout the world. Fossil fuels are the major source of energy, but its high price, uncertain long-term availability and negative impact on the environment has created an urgent need to find suitable alternatives. Renewable sources such as biofuels, which constitutes a substantial energy potential, could be used as an alternative to fossil fuels. Bio-based fuels can be of various types but they come from the same driving source, the sun light, since plants produce biomass through photosynthesis. Biofuels can be categorized into wood fuel, straw fuel, reed fuel and recycle paper and black liquor (Andersson, 2002) Fig. 1. Biofuel derived from trees is called wood fuel and consists of wood, bark, needles and leaves. Mostly, wood fuel can be divided into three main categories, forest fuel, recycled wood fuel and short rotation forest (Lehtikangas, 1998).

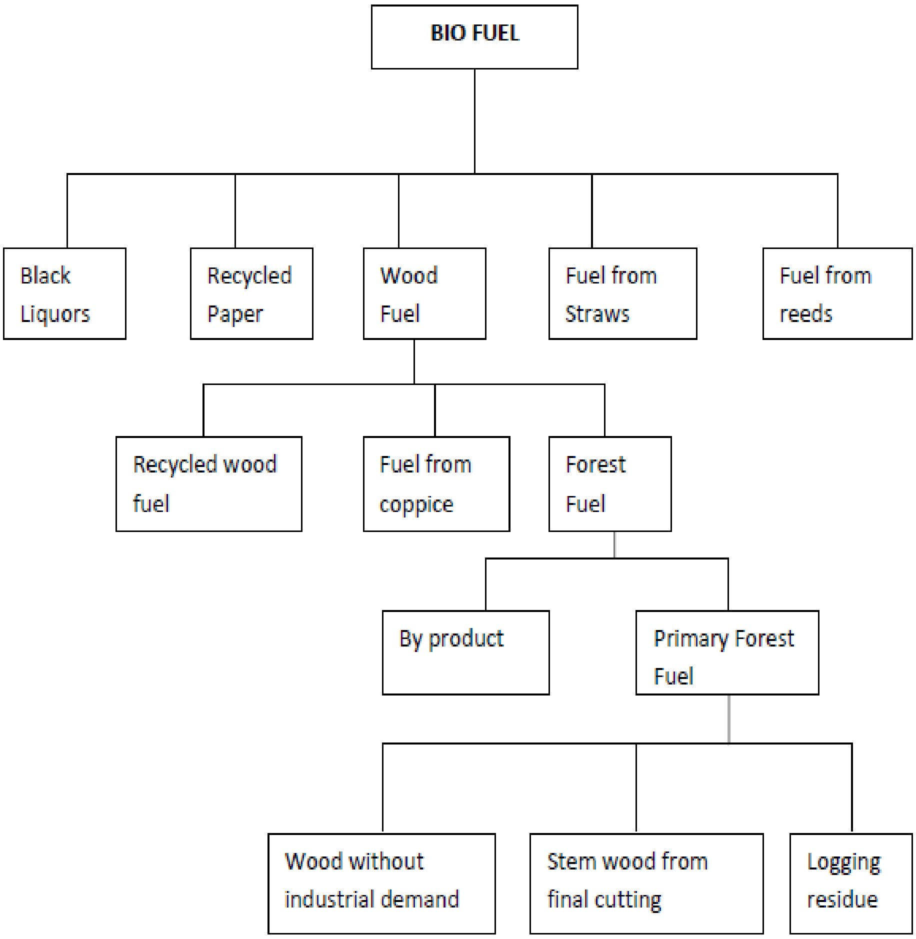

Figure 1. Biofuel and its subdivisions. (Andersson, 2002)

Forest fuel is a term generally used to describe the two assortments; primary forest fuel and by products from wood industry. Primary forest fuels comes from the forest in the form of fire wood, logging residues, stem wood from final cuttings and wood from non-industrial application (Ringman, 1996).
Forest residues include various varieties such as forest slash that is the upper portion of stem, i.e. branches and tops, defective parts of wood and pre-commercial thinning preformed for timber stand improvement.

1.1 Background

Biomass from forest residues i.e. top and branches, as a renewable source for energy, constitutes a large potential and the demand for it has increased on wood fuel market. In Sweden, forest residues play a prominent role in the energy supply and are mainly used for district heating system. In Sweden, the current supply after harvest has been approximately 7 TWH. However, according to Svensson (2008) there is a potential to generate 16-25 TWh/year from forest residues. Furthermore it is, according to Börjesson and Engström (2010), possible to increase the energy supply to 60 TWh by 2050 through better utilization of primary forest fuel. Although forest residues have the potential to be a high quality biomass as a fuel it can be affected during handling and storage before it reach the end user. There are various biomass characteristics, which we cannot control, such as chemical composition, natural ash content, heating value. Other quality parameters can be improved directly or indirectly by better storage and handling i.e. moisture content, homogeneity, composition of fuel (Jirjis *et al.*, 2011).

Usually, forest residues after harvesting are stored in small piles during some summer months before the biomass is gathered into windrows. Storage of forest residues in small piles at the clear cut can reduce the moisture content rapidly and mostly results in lower moisture content than in green stored forest residues. Furthermore storage at clear cut can result in higher defoliation of nutrient and energy rich needles than storage in windrows at landing (Nurmi, 1999). Higher amount of needles could increase the ash content in stored biomass, which later on can cause problems during combustion (Van Loo & Koppejan, 2008).

An alternative to the former storage method is to gather freshly harvested residues directly into windrows at landing. By covering such a windrow with paper, resistant for precipitation, could be a better alternative than prior storage in small piles in wet weather (Jirjis, 1995). Direct gathering of forest residues into windrows can speed up the forest re-generation on the harvested site. It is therefore likely that direct gathering of forest residues into windrows as compared to brown storage method save both money and time. (Hafmar & Eliasson, 2010). However, the risk of higher microbial activities in green stored forest residues is larger, since it may offer a more suitable and nutrition rich substrate than in brown storage.

1.2 Aim & Objectives

The aim of this thesis work was to evaluate and compare the effect of prior summer storage (brown storage) to direct windrows storage of freshly harvested biomass (green storage) on the fuel quality of Norway spruce forest residues at three different geographical locations in Sweden. The objective will be realized through the determination of quality parameters, e.g. moisture content, ash content, calorific value and net calorific values.

2. Theory

2.1 Properties of wood

Wood is one of the rich resources in the bio-based industry. The major components of woody biomass are cellulose, hemicelluloses, lignin, extractives and minerals. Cellulose, the most abundant organic material on earth, makes up nearly 50% of the dry weight of woody biomass. Hemicelluloses comprise 25 to 35% and lignin, which acts as the glue that holds the cellulose and hemicelluloses together constitutes between 15 and 25% of the dry weight (Saarman, 1992).

The energy content of different wood components varies and lignin and extractives comprise more energy contents than carbohydrates. For example, extractives and lignin have an energy value about 33-38 MJ/kg and 25-26 MJ/kg (dry basis) respectively, while cellulose and hemicelluloses have a value around 17-18 MJ/kg and 16-17 MJ/kg respectively (Lehtikangas, 1998).

Woody biomass consists of several elements, but the main constituents are carbon (C), hydrogen (H) and oxygen (O). These components comprise about 52%, 6% and 42% of the dry weight respectively on an ash free basis (Lehtikangas, 1998). During the process of combustion C and H are oxidized to form CO_2 and H_2O. While C and H contribute positively to the calorific value, oxygen has a negative impact. Woody biomass also contains minerals like chlorine (Cl), sulphur (S) and nitrogen (N). On dry basis the total mineral contents range from 0.6-0.8% in whole tree (Lehtikangas, 1998). These minerals do not contribute to energy during combustion, since they affect the energy content negatively. Mineral content in trees varies according to the type of species and site where it’s grown. For example soft wood species have lower concentrations of minerals than hardwoods (Anon, 2010). Minerals in the woody biomass have a significant role during the combustion process such as (Cl), which is an essential component of chlorophyll in trees. Chlorine has the ability to form alkali compounds with (Na) and (K), which may lead to oxidation and cause corrosion during combustion. Sulphur and Nitrogen are also essential elements of all fuel systems. Both of these elements converts into their oxides during combustion processes and conceive severe consequences on the ecosystem by acidifying the water and soil (Van Loo & Koppejan, 2008).

2.2 Quality parameters

2.2.1 Moisture content

Moisture content (MC) is referring to the ratio of water content to the total green weight. Changes in the moisture content after harvesting depends on the precipitation, temperature, rate of material decomposition and storage. High MC can cause favourable conditions for the microbial activities, which can lead to dry matter losses in the stored material. Wet fuels consume more energy to evaporate water before combustion process. MC is therefore the most important factor of fuel quality, since it affects the calorific value and storage properties (Pettersson & Nordfjell, 2007). There are two main factors that determine the fuel price; higher calorific value and low moisture content, which are obtained by appropriate storage of the forest residue (Lehtikanagas & Jirjis, 1998).

2.2.2 Ash content

The non-combustible material of woody biomass is referred to as ash. Ash can be divided into a natural part and a part generated from contaminants. Natural ash content for wood has been reported to be approximately 0.4% for stem, 4.5% for needles, 3% for bark (Thörnqvist, 1985). Percentage of natural AC varies between different species. Young trees comprise higher AC than mature trees while hard wood tend to have higher AC than soft wood. On average the AC in Scots pine and Norway spruce needles is about 2.6% and 5.1% respectively (Pettersson & Nordfjell, 2007). Difference in the properties of tree component and along with contaminates cause difference in AC. Contaminants such as dirt, sand and gravel result in a high AC, which thereby increases in the biomass. An increased AC in stored biomass results in a decrease in burnable mass.

2.2.3 Heating values

The gross calorific value at constant volume is by definition the number of heat units measured as being liberated when unit mass of solid fuel is burned in a bomb under standard conditions (Anon, 1990). Differences in the chemical composition of tree species and tree components cause differences in the calorific values, since cellulose, hemicelluloses, lignin and extractives differ in energy content. Soft wood has higher calorific value than the hard wood (Hakkila & Parikka, 2002).

The net calorific value at constant pressure is by definition the number of heat units which could be liberated in unit mass of the fuel was burned in oxygen under conditions of constant pressure (Anon, 1990). The net calorific value is calculated form calorific value by subtracting the energy used to vaporize the water. The correlation between moisture content and net calorific value clearly shows that higher moisture content in the material lower the net heating value, since a wetter biomass requires more energy for evaporation of water during the combustion process than a dry biomass (Fig. 2).

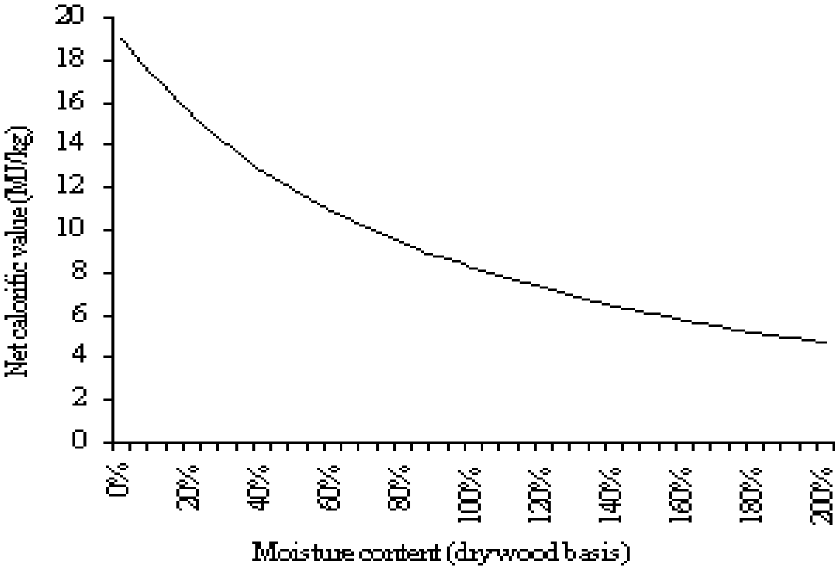

Figure 2: *The correlation between net calorific value and moisture content. (Fordyce &Ensor, 1982)*

2.3 Storage of wood fuel

In Sweden, the fuel demand is at its peak when the climatic conditions are towards colder side as mainly seen during autumn and winter months. The production of forest residues after logging takes place all year round. Storage of logging residues is therefore necessary in the summer and spring seasons to meet the irregular demand. The characteristics of a material that can affect storage outcome are decomposition rate, tree species and material composition. Variations in material properties result in variation in quality of characteristics like, moisture content and particle size distribution. Decomposition rate is different for different species of trees e.g. Birch, thick bark allows slow desiccation but fast degradation. On the other hand oak, aspen and alder show rapid drying process (Lehtikangas, 1999).

There are different methods to store woody biomass after harvesting and all methods have their own advantages and disadvantages. Type of storage mostly depends upon the type of material demanded by the end user. In some cases the woody biomass is harvested, processed, transported and utilized within a very short span. However, it is not always possible to utilize all biomass at once. In some countries, due to variable climatic conditions, there arises a need for storage. Otherwise the supply and demand becomes disproportionate. In this regard, we discuss the storage types of materials, namely unprocessed logging residues, processed material, composite residue logs or in other terms, chips and bundles. There are few methods to store woody biomass. Major methods are described below.

2.3.1 Storage of logging residues

Forest residues are sometimes stored in small piles at the clear cut area after harvesting. Storage of forest residues in small piles usually result in loss of needles due to defoliation which is better for nutrition recycle to forest as compared to storage at landing (Nurmi, 1999). Higher amount of needles could increase the ash content in the stored material (Lehtikangas, 1991). The drying of trees occurs through transpiration from leaves and other open wood surfaces. Thus we can achieve a drier material with a higher heating value. However, some disadvantages related to the logistics during handling result in high cost with this method. It is essential to cover the top surface of the windrows in areas with high precipitation so that melting snow and rain water can runoff (Lehtikanagas & Jirjis, 1995). The covering of windrows can improve the storage of biomass material. Jirjis *et al.* (1989) observed a more significant decline in MC of covered windrow than in uncovered ones. Forest residues of soft wood were stored in covered and uncovered windrows. There was 8 to 10% decline in MC observed during the period of Jan-March in covered windrows compared to uncovered windrows (42 and 50% respectively). At the end of storage period moisture content in covered windrows was decreased by 4% units from the initial value (36.1%), while uncovered windrows showed a rise in moisture content reaching up to 44%.

Figure 3 Forest residues storage in covered windrows with Kraft paper. Source (Kallio & Leinonen, 2005).

Jirjis and Lehtikangas (1993) observed in their study that MC in forest residues reduced from an initial value of 55% to 26 % after 7 months of storage in covered windrow and to 37 % in uncovered ones. However, after 11 months of storage the MC was risen slightly to 29% in covered windrows and to 51% in the uncovered. It is illustrated by Jirjis *et al.* (1989) that placement and positing of windrows could change the moisture content in the stored material, as reported in a study where windrows placed in the south-north direction showed lower moisture content due to the west wind effect. Amount of fine fraction in stored forest residues material can also affect the quality of fuel. A good correlation between the fine fraction and moisture content has been shown by Lehtikangas and Jirjis (1995), because fine particles in the windrows absorb more moisture than other part of the windrows under moist period. The reason for this is that fine particles in the stored material reduced the movement of air inside the windrows which led to slower drying process. It is mentioned by Jirjis (2005), that the young plant materials are more prone to microbial degradation and are liable to perish and can suffer lower fuel quality as the moisture content will become higher. Higher amount of fine fraction can increase the ash content in the material. It has been reported that it is possible to decrease the ash content in the stored material by reducing the amount of fine fraction which supports the correlation shown between fine fraction and ash content (Lehtikangas & Jirjis, 1995).

Heating value varies between different parts of the tree, and species (Thörnqvist, 1985). During storage of logging residues in windrows, variations in total energy change, related to dry matter losses, in different treatments were found (Jirjis & Lehtikangas, 1993). They reported that the total energy change was +4% in covered and -10% in uncovered windrows after 11 months of storage, while September samples of logging residues lost 14.5% after 7 months of storage in covered windrows (Jirjis & Lehtikangas, 1993).

2.3.2 Storage of Processed Wood fuel

Storage of processed material is another method where wood fuel chipped material or sawdust are stored on-site or at nearby facilities for a period. Woody biomass is reduced in size in the forest or at the mill, and then stored. Chipped materials are stored for a number of weeks outdoors in large piles and under cover in large silos or bins. Wood fuel Chips stored in bins are used within several hours or days, while silos are used for longer-term storage needs. The handling of the chipped material is easy but involves high risk of dry matter loss and self-ignition. Chips of excessive mould and other fungal growth can lead to health risks for workers who handle the fuel (Fuller, 1985).

Figure 4: Storage of forest residues chips at terminal. (Kallio & Leinonen, 2005).

Storage of forest residues in chipped form was tested for moisture content under the covering of roof. Thörnqvist (1985) quoted that chip piles covered with roofs, which allow air circulation, showed a reduction of MC from 55 to 20% but using a tarpaulin as a covering roof would increase the moisture content rather than decreasing it as it affects air circulation. By fan drying with cold air the moisture content could be reduced to 20% in fuel chip piles (Thörnqvist, 1983). The fan size determines the drying time. But an increase in the storage time would again increase the moisture content.

Brand *et al.* (2007) pointed out a significant increase in the ash content due to other effects of the season for those which have been harvested in October and it was at its low for those which have been harvested in august. There was also a significant effect on the net calorific value in stored bark material while it was positive for those which have been harvested in October (2003), and the ones harvested in August (2004) had low values (Brand *et al.*, 2007).

2.3.3 Storage of Composite Residue Logs

In order to avoid the disadvantages of chips storage such as dry matter loss, moisture retention, heat generation, and health hazards, woody biomass can be stored under cover in bundle form (Richardson et al., 2002). Logging residual material should be kept for drying during summer months (Fredholm, 1998). These methods ensure continuity of supply for a whole year. Shortening the storage time of chipped material will minimize the risk of chemical or microbial decomposition thus minimizing the risk of dry-matter loss, heat generation and health risks (Fredholm, 1998).

Figure 5: Bundling of forest residue and storage of composite residue logs. Source (www.svebio.se)

2.4 Problems related to storage

During storage and handling of forest residues a lot of problems are usually encountered. The main problem being drastic change in the properties of forest fuels.

2.4.1 Microbial Activities

Biological materials can be degraded by various microbes such as fungi and bacteria. The defence system in growing plants is so efficient that the microbes cannot destroy very deep and have less harmful effects. But when the tree is harvested or falls down, the conditions becomes highly favourable for microbial growth, since the plant defence system is no more effective. Therefore the dead tree composition becomes favourable substrate for microbial activity (Lehtikanagas, 1999).

Microbial growth can cause degradation of the wood material, which result in losses of biomass substance. Environmental conditions, such as an optimal temperature for growth which lies between 20 °C and 40 °C, are required for maximal microbial growth. Microbial activity is distorted beyond these optimal limits. The microorganisms need nutrients for their vital functions, which are usually present in abundance in wood. They also require moisture for their maximum growth. Throughout the metabolism CO_2 and water are produced, which increases the temperature inside windrows (Lehtikangas, 1999). Mould and blue stain fungi comparatively need fewer nutrients. Their ability to attack and utilize wood substances is slow and weak but in the decomposition of pine needles and leaves, they have a significant impact. Fungi and bacteria can cause substance loss, because they derive their nutrition from cellulose, hemicelluloses and lignin (Lehtikangas, 1999). Storage of organic materials can raise the temperature in it. The possible reasons could be the decomposition of fresh material and breakdown of starches and fats into carbon dioxide and water by the action of microbes generates heat. The respiration increases decomposition process as there is increased access to oxygen (Thörnqvist, 1984).

Factors which can affect the temperature development during storage of chipped material are moisture content at storage start, windrow size and degree of compaction. The compaction rate is dependent on the material composition, percentage of fine fraction and chip pile size (Thörnqvist, 1984). The wood contains different moisture levels and the material tends to dehydrate the moisture to become dry. This moisture exchange is a chemical process and the reaction produces heat (Thörnqvist, 1984). It ranges between 5 °C and 60 °C and the reaction gets faster with smaller particle size, i.e. the decomposition process occurs faster in comminuted wood than in uncomminuted forest fuels. At temperatures above 50 °C the chemical oxidation is of prime importance since the chemical processes can go on until the temperature reaches so high values that self-ignition occurs. There are many factors affecting the risk of spontaneous self-ignition, i.e. size of stored biomass material, moisture content and oxygen, which can act catalytically (Thörnqvist, 1984).

2.4.2 Dry Matter Losses

If wet woody biomass is not used immediately after harvesting, fungus would start to degrade it. The degradation of lignin, cellulose and hemicelluloses depend upon the moisture contents. Microbial activities in the stored material and spillage of material during handling and storage can cause dry matter losses (Thörnqvist *et al.,* 1990).Storage of forest residues in covered windrows can improve the fuel quality (Jirjis, 1995). Jirjis and Lehtikangas (1993) showed that dry matter losses were lower in Norway spruce forest residues stored in covered windrows than uncovered windrows. Dry matter losses in covered windrows were determined to 2.3% of dry weight and 10% in uncovered windrows. Dry matter losses in covered windrows of compacted logging residues 8.4% to 18.1% were found after 12 month of storage (Pettersson & Nordfjell, 2007). Fredholm and Jirjis, (1988) concluded that about 12 % of the dry matter was lost when green chipped biomass material stored in a large pile for seven months and 26% in case of bark pile for the same period while a 20% decrease in energy content was observed. During windrow storage of biomass dry matter losses occur due to the defoliation and decomposition of needles (Nurmi, 1999). Higher dry matter losses were observed in composite logging residues which were made from green residues than summer dried (Jirjis & Norden, 2005). Dry matter losses, due to loss of needles, was reported to be 21% in uncovered bundles and 12% in covered bundles in the month of May, since no dry matter found in August due to earlier loss of needles during summer season (Lehtikangas & Jirjis, 1993). Stockpiling of composite residues logs showed no dry matter losses and no health problem during the storage according to Jirjis and Nordén (2002).

2.4.3 Health Risks

Richardson *et al.,* (2002), mentioned that fungi and bacteria generally begin to colonize a biomass material after the construction of piles. Growth rate of microorganism in the stored material mostly depends upon internal factors (moisture content, composition and size of material) and external factors (size and form of pile and storage duration). The rate of fungal colonization could be reduced, if biomass material stored in uncomminuted form instead of chipped (Richardson *et al.,* 2002). They also reported that moulds and actinomycetes produce a large number of microspore during the handling of chips. López *et al*., (2009) illustrated in their study that exposure to these microspores, at a large scale, can cause a health hazard to humans and the two most common diseases resulting from inhalation of these microspores are organic dust toxic syndrome (ODTS) and allergic alveolitis.

2.4.4 Environmental Effects

Temperature, wind, suitable weather conditions and precipitations are the best examples of physical and chemical processes provided to us by nature. Fuel management system should be in collaboration with different seasonal conditions. It is recommended that uncomminuted fuel should be stored in an open area in contact with air. Places with annual rainfall up to 1400 mm (e.g. Western part of Sweden) cannot take advantage of this rule. For chipped material stack formation and height are the most important factors, so stack volume is inversely proportional to the exposed area of fuel. Hence there will be less affect by weather conditions but if the length of stack wood chips or bark is higher than 6 m then they remain unaffected by variation in weather conditions. It is the fact that final quality of the product is highly dependent on the input material and on its quality of course. Large stacks can be used to design fuel storage to avoid the heat generation in it as they are less exposed to the weather condition (Lehtikangas, 1999).

3. Material and Methods

Norway spruce forest residues were, after storage, collected at three geographical locations in southern Sweden (Fig. 6). For each locality a number of sites were chosen (Table 1). In this study the forest residues were stored at each locality by using two storage methods. The first storage method was referred to as brown storage. In this method the forest residues were prior summer stored in small piles for at least 20 weeks at the clear cut after harvesting and then they were gathered into windrows at landing for further storage. The other method used was referred to as green storage where the biomass was gathered to windrows after a few weeks of storage in small piles at the clear cut. The differences in harvesting period and storage time expressed for brown and green stored forest residues at the different sites are given below (Table 2).

Figure. 6. The three locations and the sites where the samples were collected. (www.eniro.se)

Table 1.Total harvested area and volume of stored Norway spruce forest residues.

Location	Site name	Harvested area (ha)	Total volume (m^3)
South	Torsäs	7	550
West	Kungsbacka	9.8	800
West	Ulricehamn	0.2	450
East	Nybro	3.2	600
East	Ödeshög	13	700
East	Mjölby	7	500

Table 2. Differences between the locations and storage methods, related to harvesting and storage time of forest residues.

Location	Site number	Storage type	Harvesting Time (year and weeks)	Storage time before gathered into windrow (weeks)	Storage time in windrows (weeks)
South	1	Green	0836	28	36
South	1	Brown	0836	46	18
West	1	Green	0906	5	40
West	1	Brown	0906	21	24
West	2	Green	0905	6	49
West	2	Brown	0905	22	33
East	1	Green	0907	7	30
East	1	Brown	0907	23	14
East	2	Green	0907	7	37
East	2	Brown	0907	23	21
East	3	Green	0902	11	37
East	3	Brown	0902	28	20

3.1 Sampling Procedure

Stored forest residues samples were, according to Hafmar and Eliasson (2010) collected from three different levels of the windrows (Fig.7). The biomass for each level was then chipped. Samples of the material were then taken out by using a 10 litres bucket. At total, were five samples taken from each level. The samples from each level were then mixed well and then spread into a 5 cm thick layer on a sheet. After that, were five samples of 2 litters collected from the mixed material.

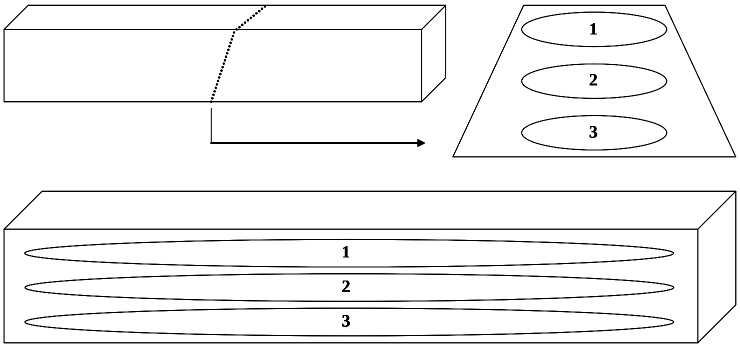

Figure 7. The three level of sampling in windrows. (Hafmar &Eliasson, 2010).

Figure. 8: Sampling from the stored material (Hafmar & Eliasson, 2010).

3.2 Sample preparation

The collected dry samples were grinded, for 20 minutes, into a 0.25 mm powder in a Retsch machine (model type SM2000), for further analyses for ash content (AC) and calorific vale ($Q_{gr,\ v}$). From the powder were samples also prepared to pellets with a weight of about one gram. From the green and brown material were totally 180 samples prepared for further analyses.

3.3 Laboratory analysis

3.1 Moisture content

All samples were weighed before drying and moisture content was determined according to the Swedish standard SS 187170 (1997). After the samples were dried to constant weight, equation no.1 used for determination of the MC.

$$MC = \frac{GW - DM}{GW} \times 100 \ \% \qquad (1)$$

MC = Moisture Content (%)

GW = Green Weight (kg)

DM = Dry Matter Weight (kg)

3.2 Ash content

The ash content was determined according to the Swedish standard SS 187171(1984). This method includes weighing of samples and then burning it in a muffle oven at 550 ˚C for 2 hours. After burning of the sample the remaining ash was weighted. Equation no.2 was then used to determine the ash content.

$$AC = \frac{AW}{DW} \times 100 \ (\%) \qquad (2)$$

AC = Ash content (%)

AW= Ash Weight (g)

DW= Dry weight of sample (g)

Ash contents were determined for totally 180 samples, five samples per level, for each material and site.

3.3 Heating values

From the grinded material the number of samples, 15 from each site and storage form, were reduced by mixing them into two separate samples. The calorific value ($Q_{gr,\,v}$) was measured by using a bomb calorimeter (Parr 6300) according to the Swedish standard SS 187182 (1990). This method includes burning a pellet during standardized and controlled conditions.

The net calorific value was then calculated from the $Q_{gr,v}$ by using equation (3).

$$Q_{net,p,m} = (Q_{gr,v} - 2.45 \times 9 \times [\frac{H_2}{100}]) - 2,45 * \frac{MC}{100-MC} \qquad (3)$$

$Q_{net,p,m}$ = Net calorific value at constant pressure (MJ/kg DM)

$Q_{gr,v}$ = Calorific value at constant volume (MJ/kg DM)

2.45 = Heat of evaporation for water at 20° C (MJ/kg)

9 = Number of created part of water from one unit hydrogen

H_2 = Percentage of hydrogen (wt %)

MC = Moisture content (%)

4. Results and discussions

4.1 Moisture content

In general the moisture content (MC) was lower in brown stored forest residues than in green stored, except in the south location (Fig. 9). However, the green forest residues in the south location were left at the clear cut area 28 weeks before gathering into windrow. Since the storage duration of the green forest residues at the clear cut area exceed a long period, it could be discussed if the material should be considered as green or brown. The MC varied between all three locations and the highest average value was found in location west. This was probably due to higher precipitation in this location than in the other two. Similar results for MC have been reported by Jirjis and Lehtikangas (1993). Furthermore, Nurmi (1999) has explained that difference in the rate of MC could be caused by differences at the storage site and geographical locations. The storage period before the residues were gathered into windrows also influence the MC of the stored biomass. There was no difference in MC in brown and green stored forest residues between the two sites of West location. In location east there was a significant difference in MC between all three sites. In site 1 the MC was lower than in site 2, since the forest residues at the latter site were collected during a wetter season. One reason that could explain the higher MC in site 3 compared to the other sites was the placement of the windrow at that site, which according to Hafmar and Eliasson (2010) could have affected the drying conditions. The placements of windrows at site 3 were in a slope and under the shade of trees.

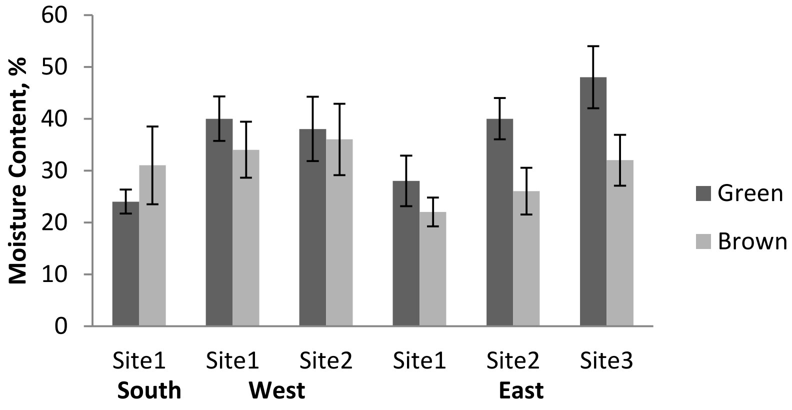

Figure 9. Average moisture content, %, for brown and green windrow stored forest residues at each site at the three geographical locations. Bar shows standard deviation.

In general the middle layers of green and brown stored forest residues were significantly dryer than the top and bottom layer (Table 3). There were significant differences in MC between the levels and the locations. In the South location the top level of the green stored forest residues was dryer than the middle and bottom layer, while in the brown stored forest residues the middle level was dryer than the top and bottom. In the east location, in which the average determined MC highest, was found at the bottom of the green stored windrow. This was probably due to high precipitation during the storage period.

Table.3 Average moisture content (%) in different levels of brown and green windrow stored forest residues.

Level	South	West		East			Number of sample at each site
	Site 1	Site 1	Site 2	Site 1	Site 2	Site 3	
Green							
Top	22	37	46	34	44	49	5
Middle	23	37	41	22	40	45	5
Bottom	26	46	38	27	36	55	5
Brown							
Top	39	40	44	25	23	33	5
Middle	22	34	39	19	22	26	5
Bottom	31	28	34	23	32	37	5

4.2 Ash content

The average AC was higher in green than brown stored forest residues, except at the two sites of location East (Fig. 10). The AC varied between all locations and the highest value was found in East location. The difference in AC in stored forest residues between the locations were probably due to the amount of sand and other inorganic compound from the soil. On the other hand it might be due the higher amount of needles in the stored material, since a higher AC has been observed in needles (Lehtikangas, 1991). There was no significant difference in AC in stored forest residues between sites in South and West locations while significant variation was observed between all sites in the East location. The higher AC at sites 2 and 3 compared to site 1 in the East location was probably caused by two reasons. Firstly the placement of windrow might be at a non-proper place and secondly the handling of the forest residues could have caused higher amount of contamination.

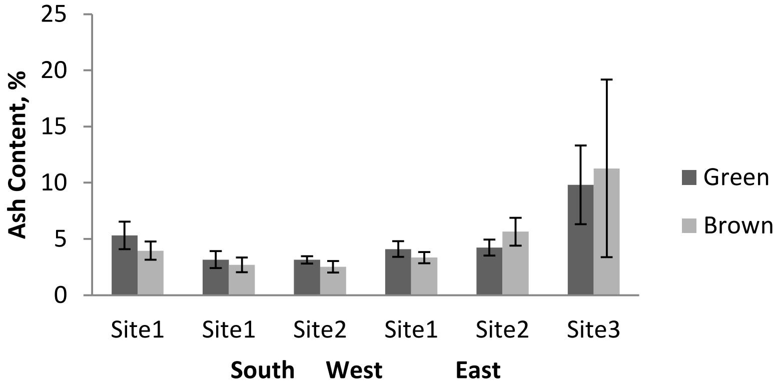

Figure. 10. Average ash content, % dry wt in brown and green windrow stored forest residues at each site at the three locations. Bar shows standard deviation.

The correlation between the moisture content and ash content cleared that higher moisture content can decrease the ash content in the stored material (Fig. 11). Dry sample could be explained by higher contamination level, since sand are dryer than wood.

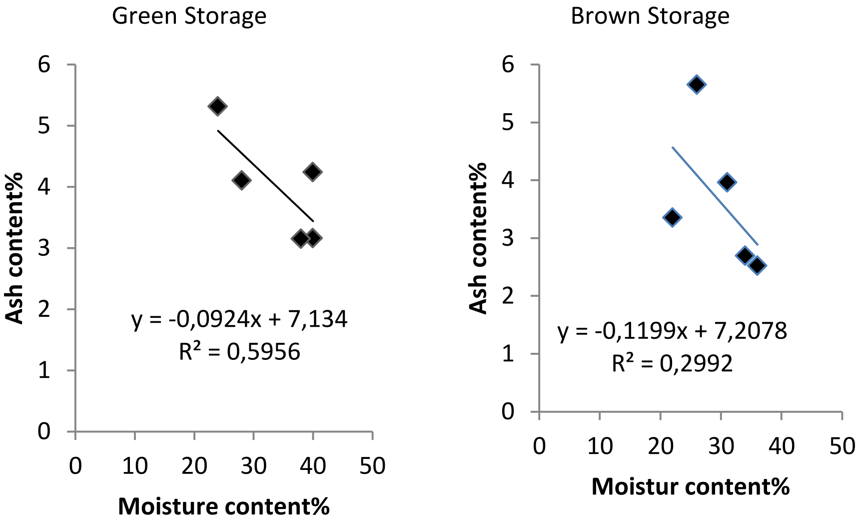

Figure 11: Correlation between MC and AC in green and brown stored forest residues

In general the AC in the material decreased by the distance from the forest floor, resulting in highest values at the bottom layer in the windrows. This could be explained by an increased amount of sand and other inorganic compound removed from the higher levels as well as a higher amount of needles in the windrow stored material. When the levels of all locations were compared in both green stored forest residues, the AC was highest at the third site of location east (Table 4).

Table4. Average ash content (%) in different levels of brown and green windrow stored forest residues.

Type of Storage	South	West		East			Number of samples at each site
	Site 1	Site 1	Site 2	Site 1	Site 2	Site 3	
Green							
Top	4.31	2.69	2.97	3.49	3.94	7.33	5
Middle	5.14	2.89	3.22	4.13	4.36	8.12	5
Bottom	6.49	3.90	3.27	4.68	4.42	15.03	5
Brown							
Top	3.16	2.11	2.18	3.21	5.29	5.32	5
Middle	4.28	3.69	2.65	3.40	5.71	6.52	5
Bottom	4.50	3.28	2.72	3.45	6.13	21.96	5

4.3 Calorific value

The Average Calorific value ($Q,_{gr,\ v}$) in both green and brown stored forest residues reached almost the same value (Fig. 12). The calorific value of green and brown stored forest residues varied significantly between the locations. In South and West locations the ($Q,_{gr,\ v}$) was higher in green and brown stored forest residues compared to the East location, since the AC was higher in the later location. These variation in ($Q,_{gr,\ v}$) among the locations followed the change in ash content.

When calorific values of green and brown stored forest residues were compared within the location, significant variation were found between the sites. In West region average ($Q,_{gr,\ v}$) of green stored forest residues was higher than brown stored forest residues at both sites, while in East region the average calorific value varied between the sites. Higher ($Q,_{gr,\ v}$) was found at site 1 in both green and brown stored forest residues compared to the other two sites. Same results of gross calorific values were also observed by Lehtikanagas and Jirjis, (1995). These variation in the ($Q,_{gr,\ v}$) between sites might be due to the higher amount of needles and ash contents in the stored material. It is clear from correlation between AC and ($Q,_{gr,\ v}$) that higher Ash content in stored material can reduce heating value (Fig. 13). Higher amount of ash in the biomass lower the melting point and can cause corrosion during combustion.

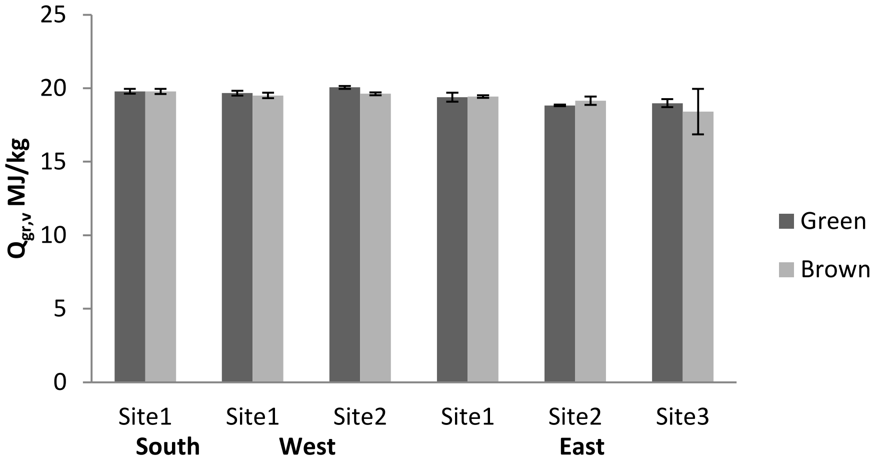

Figure 12. Average Calorific value (Q gr, v) in brown and green windrow stored forest residues at each site at the three locations. Bars shows standard deviation.

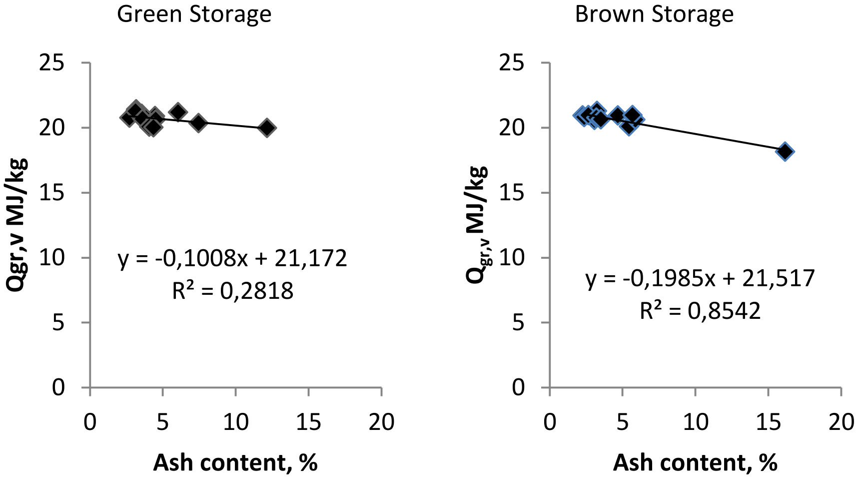

Figure 13. Correlation between ash content and Calorific value (Qgr,v)) in green and brown storage.

4.4 Net Calorific value

In general the net calorific value (Q_{net}) expressed on a dry basis and dry matter in both green and brown stored forest residues reached almost the same value (Fig. 14), except at site 3. At the East location where the net calorific values were lower in brown storage material than in green stored, which could be explained by loss of energy rich needles which has higher ash content.

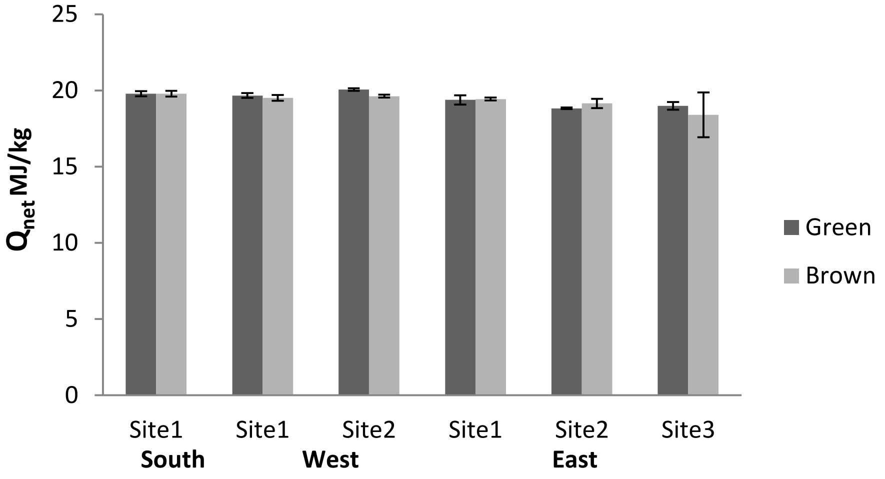

Figure 14. Average net Calorific value (Qnet) expressed on dry basis dry matter in green and brown windrow stored forest residues at each site at three locations. Bar shows standard deviation.

The net calorific value (express for wet basis and dry matter) in green and brown stored forest residues reached almost the same value (Fig. 15).

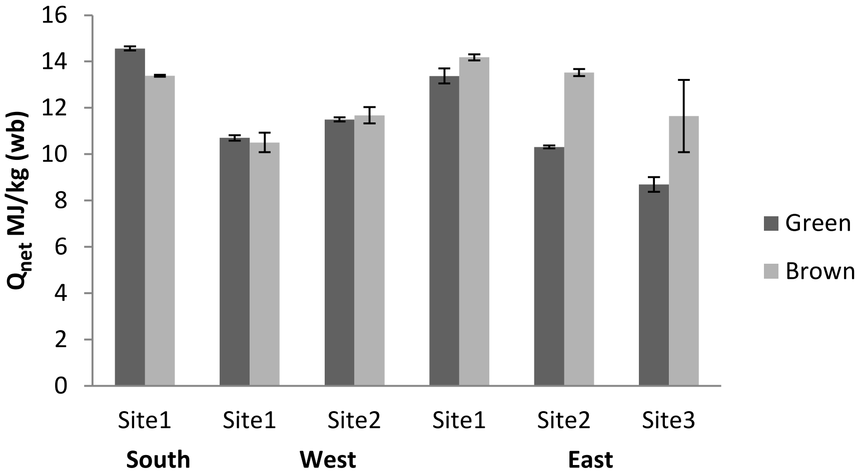

Figure 15. Average net calorific value expressed for wet basis and dry matter in (green and brown stored forest residues for each site at three different locations.

The net calorific value (expressed for wet basis and fresh weight) in brown stored was slightly higher than green stored forest residues. The average net calorific value after storage in green and brown stored forest residues was 11.5 and 12.4 MJ/kg at wet basis (Fig. 16). The difference in the energy content followed the MC and AC in green and brown stored forest residues.

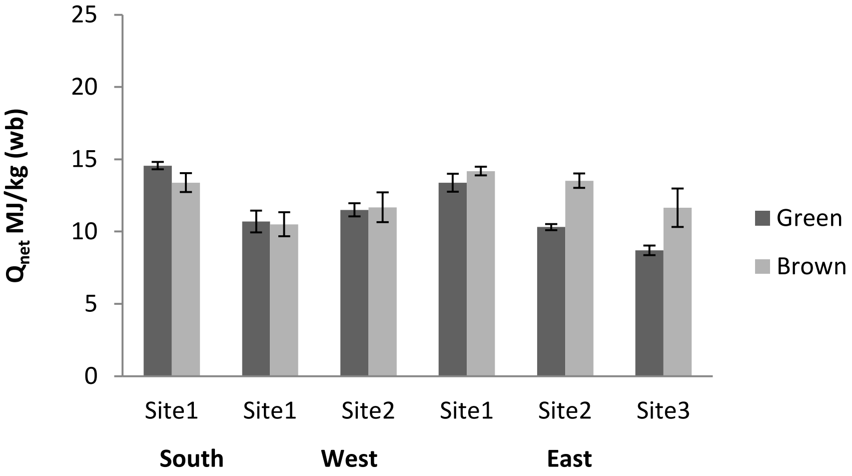

Figure 16. Average net calorific value expressed for wet basis and fresh weight in (green and brown stored forest residues for each site at three different locations.

The correlation between moisture content and net calorific value cleared that higher moisture content in the material lowers the net heating value (Fig. 16). Higher moisture in the biomass material consumes more energy to evaporate the water than the dry biomass material during the combustion process.

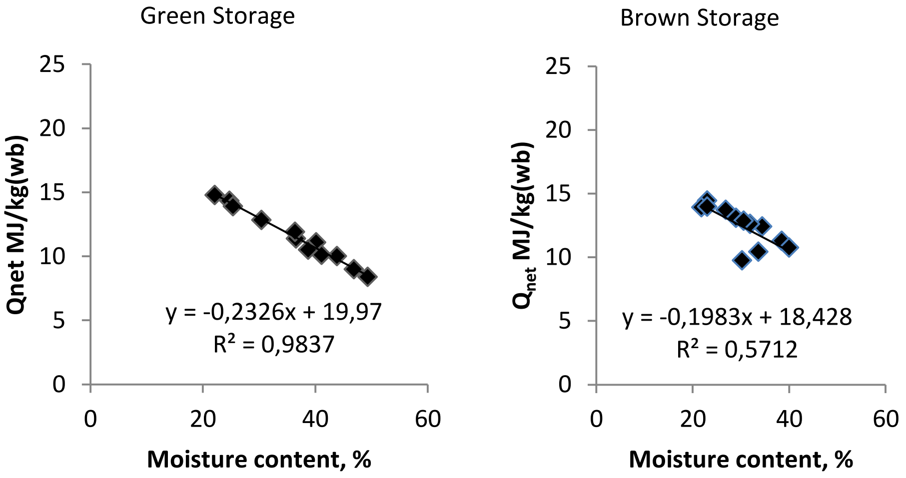

Figure 17. Correlation between moisture content and calorific value (Qnet) in green and brown storage.

5. Conclusion and recommendations

Changes in properties of forest residues biomass were observed with respect to moisture content, ash content and calorific value after one year storage in the form of green and brown storage.

Moisture content decreased significantly after storage in both green and brown stored forest residues. After one year storage the rate of moisture content was lower in brown stored forest residues as compared to green stored forest residues. Brown forest residues had lower ash content than green stored at the end of the storage period. This was probably due to the amount of needles which was larger in green stored material than in brown stored. After one year storage the calorific value and net calorific value had almost reached the same value irrespectively of storage method. Therefore from energy point of view, it can be concluded that there was no significant difference between green and brown storage methods. However, green storage method has an advantage such as shorter storage duration of forest residues before gathering into windrows than brown storage on the same site. Moreover, it is more time saving and economically profitable compared to brown storage**.**

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Appendix

Moisture content and Ash content in green storage at Location south site 1

Sample name	Storage type	Level	Moisture Content	Ash content
G.N1.1	Green	Top	23	4.6
G.N1.2	Green	Top	20	4.5
G.N1.3	Green	Top	21	4.5
G.N1.4	Green	Top	23	4.1
G.N1.5	Green	Top	22	4.0
G.N2.1	Green	Middle	22	5.4
G.N2.2	Green	Middle	24	4.4
G.N2.3	Green	Middle	22	5.6
G.N2.4	Green	Middle	23	4.9
G.N2.5	Green	Middle	22	5.5
G.N3.1	Green	Bottom	26	7.7
G.N3.2	Green	Bottom	25	8.2
G.N3.3	Green	Bottom	25	6.1
G.N3.4	Green	Bottom	28	5.3
G.N3.5	Green	Bottom	27	5.2

Moisture content and Ash content in green storage at Location west site 1

Sample name	Type of storage	Level	Moisture content	Ash content
LN.N1.1	Green	Top	36	3.6
LN.N1.2	Green	Top	38	2.4
LN.N1.3	Green	Top	36	2.9
LN.N1.4	Green	Top	36	2.7
LN.N1.5	Green	Top	37	2.1
LN.N2.1	Green	Middle	38	2.8
LN.N2.2	Green	Middle	35	2.8
LN.N2.3	Green	Middle	41	3.2
LN.N2.4	Green	Middle	40	2.8
LN.N2.5	Green	Middle	42	2.9
LN.N3.1	Green	Bottom	43	4.6
LN.N3.2	Green	Bottom	46	4.9
LN.N3.3	Green	Bottom	47	3.2
LN.N3.4	Green	Bottom	46	3.6
LN.N3.5	Green	Bottom	46	3.2

Moisture content and Ash content in green storage at Location west site 2

Sample name	Storage type	Level	Moisture content	Ash content
UV/N.G.N1.1	Green	Top	45	2.9
UV/N.G.N1.2	Green	Top	44	2.9
UV/N.G.N1.3	Green	Top	40	3.1
UV/N.G.N1.4	Green	Top	39	3.1
UV/N.G.N1.5	Green	Top	39	2.9
UV/N.G.N2.1	Green	Middle	35	3.6
UV/N.G.N2.2	Green	Middle	39	3.8
UV/N.G.N2.3	Green	Middle	32	3.4
UV/N.G.N2.4	Green	Middle	36	3.4
UV/N.G.N2.5	Green	Middle	34	1.9
UV/N.G.N3.1	Green	Bottom	21	3.0
UV/N.G.N3.2	Green	Bottom	45	3.4
UV/N.G.N3.3	Green	Bottom	43	3.8
UV/N.G.N3.4	Green	Bottom	41	2.8
UV/N.G.N3.5	Green	Bottom	39	3.4

Moisture content and Ash content in green storage at Location East site1

Sample name	Storage type	Level	Moisture content	Ash content
EE.N1.1	Green	Top	34	2.9
EE.N1.2	Green	Top	32	2.9
EE.N1.3	Green	Top	32	3.1
EE.N1.4	Green	Top	36	3.1
EE.N1.5	Green	Top	34	2.9
EE.N2.1	Green	Middle	23	3.6
EE.N2.2	Green	Middle	22	3.8
EE.N2.3	Green	Middle	22	3.4
EE.N2.4	Green	Middle	22	3.4
EE.N2.5	Green	Middle	22	1.9
EE.N3.1	Green	Bottom	27	3.0
EE.N3.2	Green	Bottom	28	3.4
EE.N3.3	Green	Bottom	27	3.8
EE.N3.4	Green	Bottom	27	2.8
EE.N3.5	Green	Bottom	28	3.4

Moisture content and Ash content in green storage at Location East site 2

Sample name	Storage type	Level	Moisture content	Ash content
FF.N1.1	Green	Top	47	4.3
FF.N1.2	Green	Top	43	4.2
FF.N1.3	Green	Top	41	2.6
FF.N1.4	Green	Top	43	4.3
FF.N1.5	Green	Top	46	4.4
FF.N2.1	Green	Middle	35	4.6
FF.N2.2	Green	Middle	33	4.3
FF.N2.3	Green	Middle	36	4.5
FF.N2.4	Green	Middle	38	4.0
FF.N2.5	Green	Middle	36	4.4
FF.N3.1	Green	Bottom	40	4.1
FF.N3.2	Green	Bottom	38	3.8
FF.N3.3	Green	Bottom	40	4.4
FF.N3.4	Green	Bottom	41	3.7
FF.N3.5	Green	Bottom	41	6.1

Moisture content and Ash content in green storage at Location East site3

Sample name	Storage type	Level	Moisture content	Ash content
GG.N1.1	Green	Top	50	7.8
GG.N1.2	Green	Top	52	7.1
GG.N1.3	Green	Top	42	7.3
GG.N1.4	Green	Top	51	7.3
GG.N1.5	Green	Top	51	7.2
GG.N2.1	Green	Middle	40	8.1
GG.N2.2	Green	Middle	42	7.6
GG.N2.3	Green	Middle	42	9.5
GG.N2.4	Green	Middle	43	8.1
GG.N2.5	Green	Middle	41	7.4
GG.N3.2	Green	Bottom	55	14.5
GG.N3.3	Green	Bottom	54	15.5
GG.N3.4	Green	Bottom	55	13.8
GG.N3.5	Green	Bottom	55	16.4

Moisture content and Ash content in brown storage at south location site 1

Sample name	Storage type	level	Moisture Content	Ash content
GB.N1.1	Brown	Top	36	3.3

GB.N1.2	Brown	Top	39	3.0
GB.N1.3	Brown	Top	37	3.2
GB.N1.4	Brown	Top	41	3.3
GB.N1.5	Brown	Top	41	3.1
GB.N2.1	Brown	Middle	24	4.0
GB.N2.2	Brown	Middle	23	3.0
GB.N2.3	Brown	Middle	20	5.3
GB.N2.4	Brown	Middle	22	4.9
GB.N3.1	Brown	Bottom	32	4.2
GB.N3.2	Brown	Bottom	29	4.6
GB.N3.3	Brown	Bottom	28	4.5
GB.N3.4	Brown	Bottom	34	4.6

Moisture content and Ash content in brown storage at Location west site 1

Sample name	Storage type	Level	Moisture content	Ash content
LB.N1.1	Brown	Top	42	2.3
LB.N1.2	Brown	Top	39	1.7
LB.N1.3	Brown	Top	39	1.6
LB.N1.4	Brown	Top	41	2.8
LB.N1.5	Brown	Top	39	2.2
LB.N2.1	Brown	Middle	33	2.8
LB.N2.2	Brown	Middle	36	2.5
LB.N2.3	Brown	Middle	32	2.1
LB.N2.4	Brown	Middle	38	3.1
LB.N2.5	Brown	Middle	32	3.1
LB.N3.1	Brown	Bottom	29	2.7
LB.N3.2	Brown	Bottom	28	3.5
LB.N3.3	Brown	Bottom	26	2.9
LB.N3.4	Brown	Bottom	28	3.9
LB.N3.5	Brown	Bottom	29	3.5

Moisture content and Ash content in brown storage at Location west site2

Sample name	Storage type	Level	Moisture content	Ash content
UV/N.B.N1.1	Brown	Top	49	1.7
UV/N.B.N1.2	Brown	Top	47	2.5
UV/N.B.N1.3	Brown	Top	41	2.8
UV/N.B.N1.4	Brown	Top	44	2.4
UV/N.B.N1.5	Brown	Top	39	1.7
UV/N.B.N2.1	Brown	Middle	29	2.8
UV/N.B.N2.2	Brown	Middle	31	2.9
UV/N.B.N2.3	Brown	Middle	30	2.4
UV/N.B.N2.4	Brown	Middle	29	2.6
UV/N.B.N2.5	Brown	Middle	28	2.7
UV/N.B.N3.1	Brown	Bottom	30	3.1
UV/N.B.N3.2	Brown	Bottom	34	2.2
UV/N.B.N3.3	Brown	Bottom	36	2.7
UV/N.B.N3.4	Brown	Bottom	36	3.6
UV/N.B.N3.5	Brown	Bottom	32	2.1

Moisture content and Ash content in brown storage at Location east site 1

Sample name	Storage type	level	Moisture content	Ash content
EEB.N1.1	Brown	Top	25	3.2
EEB.N1.3	Brown	Top	24	2.8
EEB.N1.4	Brown	Top	27	2.8
EEB.N1.5	Brown	Top	24	4.1
EEB.N2.1	Brown	Middle	19	3.5
EEB.N2.2	Brown	Middle	19	2.9
EEB.N2.3	Brown	Middle	19	3.5

EEB.N2.4	Brown	Middle	19	3.7
EEB.N3.1	Brown	Bottom	24	2.6
EEB.N3.2	Brown	Bottom	23	3.7
EEB.N3.4	Brown	Bottom	22	3.5
EEB.N3.5	Brown	Bottom	24	4.1

Moisture content and Ash content in brown storage at Location east site 2

Sample name	Storage type	level	Moisture content	Ash content
FFB.N1.1	Brown	Top	24	4.9
FFB.N1.2	Brown	Top	22	6.5
FFB.N1.3	Brown	Top	24	4.9
FFB.N1.4	Brown	Top	23	4.6
FFB.N1.5	Brown	Top	23	5.7
FFB.N2.1	Brown	Middle	22	6.9
FFB.N2.3	Brown	Middle	22	6.4
FFB.N2.5	Brown	Middle	23	6.4
FFB.N3.1	Brown	Bottom	30	7.7
FFB.N3.3	Brown	Bottom	32	7.0
FFB.N3.5	Brown	Bottom	32	3.7

Moisture content and Ash content in brown storage at Location east site 3

Sample name	Storage type	Level	Moisture content	Ash content
GGB.N1.1	Brown	Top	34	5.6
GGB.N1.2	Brown	Top	34	4.2
GGB.N1.3	Brown	Top	33	6.0
GGB.N1.4	Brown	Top	33	5.3
GGB.N1.5	Brown	Top	33	5.6
GGB.N2.1	Brown	Middle	24	6.3
GGB.N2.2	Brown	Middle	23	7.0
GGB.N2.3	Brown	Middle	30	6.4
GGB.N2.4	Brown	Middle	31	7.1
GGB.N2.5	Brown	Middle	24	6.0
GGB.N3.1	Brown	Bottom	37	21.1
GGB.N3.2	Brown	Bottom	36	20.6
GGB.N3.3	Brown	Bottom	36	21.0
GGB.N3.4	Brown	Bottom	38	23.6
GGB.N3.5	Brown	Bottom	37	23.6

Gross calorific value (Q,$_{gr,v}$) in green and brown storage at each location

Location	Site	Storage type	Sample name mixture	Gross calorific value(Q,$_{gr,v}$)
South	1	Green	G.N1.1-G.N2.2	20.9
South	1	Green	G.N2.3-G.N3.5	21.2
South	1	Green	LN.N1.1-LN.N2.2	20.8
South	1	Green	LN.N2.3-LN.N3.5	21.0
West	1	Green	UV/N.G.N1.1-UV/N.G.N2.2	21.4
West	1	Green	UV/N.G.N2.3-UV/N.G.N3.5	21.3
West	1	Green	EE.N1.1-EE.N2.2	20.7
West	1	Green	EE.N2.2-EE.N3.5	20.6
West	2	Green	FF.N1.1-FF.N2.2	20.1
West	2	Green	FF.N2.3-FF.N3.5	20.0
West	2	Green	GG.N1.1-GG.N2.2	20.3
West	2	Green	GG.N2.3-GG.N3.5	20.0
East	1	Brown	G.B.N1.1-G.B.N2.2	21.3
East	1	Brown	G.B.N2.3-G.B.N3.5	20.9
East	1	Brown	LN.B.N1.1-LN.B.N2.2	20.9
East	1	Brown	LN.B.N2.3-LN.B.N3.5	20.6
East	2	Brown	UV/N.B.N1.1-UV/N.B.N2.2	20.8
East	2	Brown	UV/N.B.N2.3-UV/N.B.N3.5	21.0
East	2	Brown	EEB.N1.1-EEB.N2.2	20.8

East	2	Brown	EEB.N2.2-EEB.N3.5	20.6
East	3	Brown	FFB.N1.1-FFB.N2.2	20.1
East	3	Brown	FFB.N2.3-FFB.N3.5	20.6
East	3	Brown	GGB.N1.1-GGB.N2.2	21.0
East	3	Brown	GGB.N2.3-GGB.N3.5	18.1

Net calorific value (db) dry matter in green and brown storage at each location

Location	Site	Storage type	Sample name mixture	Net calorific value (Q$_{\text{net, p.m}}$)
South	1	Green	G.N1.1-G.N2.2	19.0
South	1	Green	G.N2.3-G.N3.5	19.1
South	1	Green	LN.N1.1-LN.N2.2	18.1
South	1	Green	LN.N2.3-LN.N3.5	17.9
West	1	Green	UV/N.G.N1.1-UV/N.G.N2.2	18.5
West	1	Green	UV/N.G.N2.3-UV/N.G.N3.5	18.6
West	1	Green	EE.N1.1-EE.N2.2	18.4
West	1	Green	EE.N2.2-EE.N3.5	18.5
West	2	Green	FF.N1.1-FF.N2.2	17.1
West	2	Green	FF.N2.3-FF.N3.5	17.2
West	2	Green	GG.N1.1-GG.N2.2	17.0
West	2	Green	GG.N2.3-GG.N3.5	16.5
East	1	Brown	G.B.N1.1-G.B.N2.2	18.8
East	1	Brown	G.B.N2.3-G.B.N3.5	18.8
East	1	Brown	LN.B.N1.1-LN.B.N2.2	18.2
East	1	Brown	LN.B.N2.3-LN.B.N3.5	17.4
East	2	Brown	UV/N.B.N1.1-UV/N.B.N2.2	17.9
East	2	Brown	UV/N.B.N2.3-UV/N.B.N3.5	18.6
East	2	Brown	EEB.N1.1-EEB.N2.2	18.8
East	2	Brown	EEB.N2.2-EEB.N3.5	18.6
East	3	Brown	FFB.N1.1-FFB.N2.2	18.1
East	3	Brown	FFB.N2.3-FFB.N3.5	18.4
East	3	Brown	GGB.N1.1-GGB.N2.2	18.6
East	3	Brown	GGB.N2.3-GGB.N3.5	15.8

Net calorific value (wb) dry matter in green and brown storage at each location

Location	Site	Storage type	Sample name mixture	Net calorific value (Q$_{\text{net, p.m}}$)
South	1	Green	G.N1.1-G.N2.2	14.8
South	1	Green	G.N2.3-G.N3.5	14.3
South	1	Green	LN.N1.1-LN.N2.2	11.4
South	1	Green	LN.N2.3-LN.N3.5	10.0
West	1	Green	UV/N.G.N1.1-UV/N.G.N2.2	11.1
West	1	Green	UV/N.G.N2.3-UV/N.G.N3.5	11.9
West	1	Green	EE.N1.1-EE.N2.2	12.8
West	1	Green	EE.N2.2-EE.N3.5	13.9
West	2	Green	FF.N1.1-FF.N2.2	10.1
West	2	Green	FF.N2.3-FF.N3.5	10.5
West	2	Green	GG.N1.1-GG.N2.2	9.0
West	2	Green	GG.N2.3-GG.N3.5	8.4
East	1	Brown	G.B.N1.1-G.B.N2.2	12.4
East	1	Brown	G.B.N2.3-G.B.N3.5	13.7
East	1	Brown	LN.B.N1.1-LN.B.N2.2	11.3
East	1	Brown	LN.B.N2.3-LN.B.N3.5	9.7
East	2	Brown	UV/N.B.N1.1-UV/N.B.N2.2	10.7
East	2	Brown	UV/N.B.N2.3-UV/N.B.N3.5	12.6
East	2	Brown	EEB.N1.1-EEB.N2.2	14.5
East	2	Brown	EEB.N2.2-EEB.N3.5	13.9
East	3	Brown	FFB.N1.1-FFB.N2.2	14.0
East	3	Brown	FFB.N2.3-FFB.N3.5	13.1
East	3	Brown	GGB.N1.1-GGB.N2.2	12.9

East	3	Brown	GGB.N2.3-GGB.N3.5	10.4

Green and brown

One way ANOVA: Moisture content [%] m/m versus locations

Source	DF	SS	MS	F	P
Location	2	1504.6	752.3	10.80	0.000
Error	170	11840.2	69.6		
Total	172	13344.8			
S = 8.346		R-Sq= 11.27%		R-Sq (adj) = 10.23%	

Location	N	Mean	StDev
1	29	26.966	6.445
2	68	35.309	7.624
3	76	34.263	9.510

Green and brown

One way ANOVA: Moisture content [%] m/m versus sites

Source	DF	SS	MS	F	P
Site	5	4968.6	99.7	19.81	0.000
Error	167	8376.2	50.2		
Total	172	13344.8			
S = 7.082		R-Sq= 37.23%		R-Sq (adj) = 35.35%	

Site	N	Mean	StDev
1	29	26.966	6.445
2	30	37.267	5.777
3	30	36.900	6.541
4	27	25.370	4.853
5	28	33.536	8.071
6	29	39. 862	9.698

Green and brown

One way ANOVA: Ash content [%] versus locations

Source	DF	SS	MS	F	P
Location	2	546.6	273.3	25.33	0.000
Error	170	1834,3	10.8		
Total	172	2381.0			
S = 3.285		R-Sq= 22.96%		R-Sq (adj) = 22.05%	

Location	N	Mean	StDev
1	29	4.659	1.236
2	68	2.931	0.654
3	76	6.824	4.848

Green and brown

One way ANOVA: Ash content [%] versus sites

Source	DF	SS	MS	F	P
Site	5	1211.12	242.22	34.58	0.000

Error	167	1169.85	7.01		
Total	172	2380.97			
S = 2.647		R-Sq= 50.87%		R-Sq (adj) = 49.40%	

Site	N	Mean	StDev
1	29	4.659	1.236
2	30	2.927	0.738
3	30	2.835	0.583
4	27	3.769	0.715
5	28	4.893	1.206
6	29	10.564	6.120

Green and brown

One way ANOVA: Calorific value [MJ/kg] d.b versus locations

Source	DF	SS	MS	F	P
Location	2	3.554	1.777	5.70	0.011
Error	21	6.551	0.312		
Total	23	10.105			
S = 0.5585		R-Sq= 35.17%		R-Sq (adj) = 29.00%	

Location	N	Mean	StDev
1	4	21.065	0.191
2	8	20.965	0.262
3	12	20.232	0.736

Green and brown

One way ANOVA: Calorific value [MJ/kg] d.b versus sites

Source	DF	SS	MS	F	P
Site	5	.,032	1.006	3.57	0.020
Error	18	5.073	0.282		
Total	23	10.105			
S = 0,5309		R-Sq= 49.80%		R-Sq (adj) = 35.85%	

Site	N	Mean	StDev
1	4	21.065	0.191
2	4	20.830	00.196
3	4	21.101	0.270
4	4	20.658	0.070
5	4	20.191	1.280
6	4	19.846	1.208

Green Storage

One way ANOVA: Moisture content [%] m/m versus location

Source	DF	SS	MS	F	P
Location	2	2896.6	1448.3	25.04	0.000
Error	86	4973.9	57.8		
Total	88	7870.5			
S = 7.605		R-Sq=36.80 %		R-Sq (adj) =35.33 %	

Location	N	Mean	StDev
1	15	23.533	2.264
2	30	39.300	5.344

3	44	38.341	9.734

Green Storage

One way ANOVA: Moisture content [%] m/m versus sites

Source	DF	SS	MS	F	P
Site	5	5985.7	1197.1	52.72	0.000
Error	83	1884.8	22.7		
Total	88	7870.5			
S = 4.765		R-Sq=76.05 %		R-Sq (adj) =74.61 %	

Site	N	Mean	StDev
1	15	23.533	2.262
2	15	40.467	4.291
3	15	38.133	6.151
4	15	27.733	4.920
5	15	39.867	3.962
6	14	48.071	5.993

Green Storage

One way ANOVA: Ash content [%] versus locations

Source	DF	SS	MS	F	P
Location	2	14.62	71.81	12.10	0.000
Error	86	510.44	5.94		
Total	88	654.06			
S = 2.436		R-Sq= 21.96%		R-Sq (adj) =20.14 %	

Location	N	Mean	StDev
1	15	5.313	1.220
2	30	3.157	0.628
3	44	5.965	3.335

Green Storage

One way ANOVA: Ash content [%] versus sites

Source	DF	SS	MS	F	P
Site	5	447.48	89.50	35.96	0.000
Error	83	206.58	2.49		
Total	88	654.06			
S = 1.578		R-Sq= 68.42%		R-Sq (adj) = 66.51%	

Site	N	Mean	StDev
1	15	5.313	1.220
2	15	3.160	0.765
3	15	3.153	0.481
4	15	4.100	0.695
5	15	4.240	0.707
6	14	9.811	3.514

Brown Storage

One way ANOVA: Moisture content [%] m/m versus locations

Source	DF	SS	MS	F	P
Location	2	213.1	106.5	2.21	0.116
Error	81	3907.5	48.2		
Total	83	4120.6			

S = 6.946	R-Sq=5.17 %	R-Sq (adj) = 2.83%

Location	N	Mean	StDev
1	14	30.643	7.469
2	38	32.158	7.730
3	32	28.656	5.597

Brown Storage

One way ANOVA: Moisture content [%] m/m versus sites

Source	DF	SS	MS	F	P
Site	5	1655.5	331.1	10.48	0.000
Error	78	2465.1	31.6		
Total	83	4120.6			
S = 5.622		R-Sq= 40.18%		R-Sq (adj) =36.34 %	

Site	N	Mean	StDev
1	14	30.643	7.469
2	15	34.067	5.365
3	15	35.667	6.894
4	12	22.417	2.778
5	13	26.231	4.512
6	15	32.200	4.945

Brown Storage

One way ANOVA: Ash content [%] versus locations

Source	DF	SS	MS	F	P
Location	2	496.2	248.1	16.33	0.000
Error	81	1230.6	15.2		
Total	83	1726.8			
S = 3.898		R-Sq= 28.73%		R-Sq (adj) =26.97 %	

Location	N	Mean	StDev
1	14	3.957	0.813
2	38	2.753	0.626
3	32	8.006	6.241

Brown Storage

One way ANOVA: Ash content [%] versus sites

Source	DF	SS	MS	F	P
Site	5	814.4	162.9	13.92	0.000
Error	78	912.4	11.7		
Total	83	1726,8			
S = 3.420		R-Sq= 47.16%		R-Sq (adj) = 43.77%	

Site	N	Mean	StDev
1	14	3.957	0.813
2	15	2.693	0.654
3	15	2.517	0.506
4	12	3.354	0.505

5	13	5.646	1.242
6	15	11.267	7.896

Green versus Brown

One way ANOVA: Moisture content [%] m/m versus Sortiment

Source	DF	SS	MS	F	P
Sortiment	1	1353.8	1353.8	19.31	0.0000
Error	171	11991.0	70,1		
Total	172	13344.8			
S = 8.374		R-Sq=10.14 %		R-Sq (adj) = 9.62%	

Source	N	Mean	StDev
Brown	84	30.571	7.046
Green	89	36.169	9.457

Green versus Brown

One way ANOVA: Ash content [%] versus Sortiment

Source	DF	SS	MS	F	P
Sortiment	1	0.1	0.1	0.1	0.935
Error	171	2380.9	13.9		
Total	172	2381.0			
S = 3.731		R-Sq=0.00%		R-Sq (adj) =0.00 %	

Source	N	Mean	StDev
Brown	84	4.955	4.561
Green	89	4.908	2.726

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