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Moisture Content of Norway Spruce Stump Wood at Clear Cutting Areas and Roadside Storage Sites

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Norway spruce (*Picea abies* (L.) Karst.) stump wood is a potential source of bioenergy in Finland. The heating value of stump wood depends on, among other things, the moisture, carbon and ash content of the wood. In this study the moisture content of Norway spruce stump wood was examined immediately after harvesting at the clear cutting area and after different drying times at the roadside storage sites. Immediately after stump harvesting the average moisture content (wet basis) was 53%. The stump wood dried fairly fast during spring and summer. One month after stump harvesting, the average moisture content was about 31%. If the stump wood had dried well once, water absorption became very weak and the moisture content increased only slightly in the late autumn. Each spring and summer the moisture content of the stumps was lower than during the previous year. Annually the lowest moisture content was observed at the beginning of July and the highest at both the beginning and the end of the year. The moisture content of stump wood followed an upwards opening parabola over a one year period and was repeated each year. Three years after harvesting the heating value of the stump wood was still 5.241 MWh/ton. Overall, when harvesting took place in the spring or early summer, the stump wood was combustible after a one month drying period immediately after harvesting.

Keywords bioenergy, harvesting, moisture content, *Picea abies*, stump wood
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1 Introduction

The use of wood as fuel has a long tradition in Finland where forest energy is the most important source of bioenergy. In 2007 the final energy consumption of renewable energy in Finland was 28.5% of the total energy usage. The aim of the European Union Commission is to increase renewable energy usage in Finland to 38% by the year 2020 and the Finnish Government has promised to abide by that target. (Government Programme… 2007, Energy.eu. 2010). Renewable energy has an essential part to play in preventing climate change. It is necessary to increase the use of forest energy substantially so that the goal of the European Union can be met. However, the above-mentioned target is very challenging for the technology of today and new innovations and bioenergy sources are needed.

Norway spruce (*Picea abies* (L.) Karst.) stump wood harvesting has increased in Finnish forest energy production recently. In 2005 the use of stump wood for energy generation purposes was 0.4 million m^3 solid (Laitila et al. 2007). The total techno-economic potential of stump wood energy is 2 million m^3 solid per year in Finland (Hakkila 2004).

Norway spruce is loosely anchored in the ground and therefore it is easier to harvest than pine. (Hakkila 1972, Laitila et al. 2008). Stump harvesting can result in a reduction of the infection rate of root rot fungus and is also a substitute for traditional soil preparation when reforesting. Therefore it also decreases the costs of reforestation (Procurement of forest… 2003, Saarinen 2006). Moreover, stump harvesting may reduce the damage of pine weevils. Impurities in the harvested stumps are a quality problem, as usually the stumps and roots include some rocks and soil. However, stumps are a suitable raw material for large power plants where small impurities do not cause problems (Hakkila and Aarniala 2004, Backlund 2009).

Stumps have a high energy content. The average energy content of stump wood is about 130 MWh/ha and can even be as high as 250 MWh/ha (Hakkila 2004, Näslund Eriksson and Gustavsson 2008). The heating value of the different parts of Norway spruce does not vary much. The average heating value of spruce stems, branches, stumps and roots is about 19.3 MJ/kg = 5.4 kWh/kg of dry mass (Nurmi 2000). The heating value of wood depends largely upon its moisture content. When moisture content of spruce wood increases by one percentage point the heating value of the wood decreases by 0.0594 MWh/ton; this change being linear. Thus, the heating value of spruce stump wood at different moisture contents can be calculated using the formula: $Q_{net,ar} = 5.3 - 0.0594 \times MC$, where $Q_{net,ar}$ is the net calorific heating value as received (MWh/ton) and MC is the moisture content (wet basis) (Alakangas 2000, Nurmi 2000, Kärkkäinen 2007). The moisture content of harvested stump root systems depends on many different factors, for example: the weather, the splitting methods used, storage conditions, drying time, season etc (Hakkila 1989, Laitila et al. 2008).

About half of the biomass of a living tree consists of water. From the point of view of energy production this water is unwelcome. Also transportation of this water is irrational and it decreases the heating value of the wood (Hakkila 1989, Nurmi 2000). It is therefore economically reasonable to dry energy wood at the storage site using natural forces such as solar and wind energy. However, the weather limits the drying of energy wood outdoors.

The first aim of this study was to research the moisture content of Norway spruce stump wood at the clear cutting areas immediately after stump harvesting and at roadside storage sites after different drying times. The second aim was to clarify the correlation between moisture content and other factors such as drying time and air humidity. The third aim was to examine the heating value of stump wood after three years of storage. Both moisture content and heating value are important factors from the point of view of heat energy production. The results can be used for cost-effective procurement and utilisation of stump wood for heat energy.

Table 1. The location, area, sampling time and amount of samples taken for the four different stump harvesting sites.

Site	Latitude	Area, ha	Sampling time (calendar week number) 2006	2007	2008	2009	Samples
Jurva 1	62°37´N	9.7	27,33,43,50	17,46	24,34,42	4, –, –	80
Jurva 2	62°36´N	5.9	28,33,43,50	17,46	24,34,42	4,19,22	96
Jurva 3	62°37´N	3.9	29,33,43,50	17,46	24,34,42	4,19, –	87
Ähtäri	62°35´N	0.4	23,34,47,51	17,46	24,34,42	–, –, –	70
Total		19.9					333

2 Material and Methods

2.1 Study Sites

The material was collected from four stump harvesting sites in western Finland between June 2006 and May 2009. There were only a few stump harvesting sites in this region in 2006. This study was requested by forest energy organisations who co-operated by providing the study sites. In general, worksites represented typical stump harvesting sites in Finland. Three of the sites were located in Jurva (latitude 62º37'N) and one site was in Ähtäri (latitude 62º35'N). All of the areas were clear cut 1–6 months prior to stump harvesting. The Ähtäri site was clear cut in November 2005, Jurva 1 in May 2006 and Jurva 2–3 in June 2006. Stump harvesting took place in June 2006 in Ähtäri and in July 2006 in Jurva. The soil types were; fertile or semi fertile mineral soil in Jurva and fertile peat soil in Ähtäri. The total stump harvesting area was 19.9 hectares (Table 1).

2.2 Harvesting, Storage and Sampling

The stumps were harvested by excavators which split the stumps and made small stump piles on the clear cut areas. The size of each pile at the clear cutting areas was equal to about one or two big forwarder loads (20–50 m^3 loose). After some weeks the stumps were moved from the clear cut areas to the roadside storage sites. The roadside storages were about 20–100 meters long and 8 meters wide. The samples for the moisture content analysis were collected from the clear cut areas and also from the roadside storage sites randomly. The first samples from every site were taken immediately after stump harvesting and the other samples were collected, after different drying times (3–30 weeks), from the top surface layer of the piles from either the clear cut areas or the roadside storage sites.

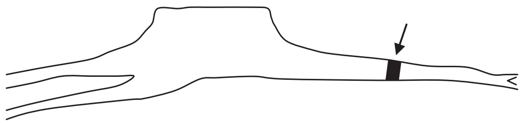

Fig. 1. The sampling point.

The samples were taken midway between the stump and the end of the root (Fig. 1). Only one sample was taken from any individual stump root system. The average diameter of the stumps was about 30 cm and samples were taken 70–110 cm from the center of the stump. At every storage site four samples were taken from the north–west and four from the south–east side of the pile during each sampling time. At the Ähtäri storage site there was a shading forest wall near to the pile, whereas the storage sites in Jurva were located in clear open areas. The shape of the sample was a circular slice of the stump wood excluding the first sampling time in Ähtäri when the samples consisted of stump wood chips. The average diameter of the slices was 7 cm and varied between 4–11 cm, the thickness being about 5 cm. Eight slices per site were collected at each collection time. The total amount of samples collected was 333.

2.3 Moisture Content Analysis

The samples were put into airproof plastic bags in the forest immediately after sampling. In the laboratory the samples were stored in a freezer before the moisture content analysis, or analyzed immediately. The moisture content analysis was based on international Standard ISO 589 "Hard coal – Determination of total moisture". The drying temperature was 105ºC, and a drying time of 24 h was used. The moisture content (wet basis) of the stump wood was calculated using the equation:

$$MC = \frac{(m_g - m_0)}{m_g} \times 100\% \quad (1)$$

where:
MC = moisture content (wet basis)
m_g = the mass of the sample before drying
m_0 = the mass of the sample after drying

2.4 Weather Data, Heating Value and Data Analysis

Weather data (temperature, air humidity and precipitation) was obtained from the nearest Finnish Meteorological Institute weather station to Jurva (2009). The station was situated in Kauhajoki (62°24´N, 22°11´E, 93 m) at a site called Kuja-Kokko. The annual air humidity curve was calculated from the Kuja-Kokko data. The evaporation data was received from Finland's environmental administration station (2009) at Ylistaro, Pelmaa (62°56´ N, 22°29´ E, 26 m). Samples for heating value analysis were taken at the end of the storage period immediately after stump crushing by a mobile crusher. The samples were collected randomly from different parts of the lorry's container. Finally two samples of about three litres each were combined for analyses. The determination of the heating value was made by Vaskiluodon voima Oy laboratory and was based on standard: CEN/TS 14918:2005 Solid Biofuels – Method for the determination of calorific value (CEN/TS 14918:2005). The data analysis was made using SPSS Statistics and MS Excel software.

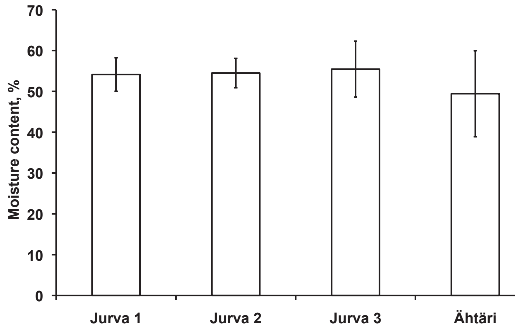

Fig. 2. Moisture content immediately after stump harvesting at four sites.

3 Results

3.1 Moisture Content Immediately after Stump Harvesting

The average moisture content of the stumps was 53% immediately after harvesting with a standard deviation of 6% (Fig. 2). At the Ähtäri work site the average moisture content was 49% after stump harvesting. It had clearly lower moisture content than the other sites, but the standard of deviation of moisture content was higher. However, at all three sites in Jurva the moisture content of the stumps were very close to one another.

3.2 Moisture Content after Different Drying Times

After stump harvesting the moisture content decreased rapidly (Figs. 3 and 4). The average moisture content was 31% one month after stump harvesting. Then moisture content increased during the autumn of 2006 and decreased again during the spring of 2007. The same trend was observed each year during this study. Also when the air humidity was low the moisture content of the stumps was low and vice versa.

The variation in moisture content between the different work sites was very small during the observation period. The highest standard deviation was 10% which occurred at the second sampling time in 2006. In all the other cases the standard

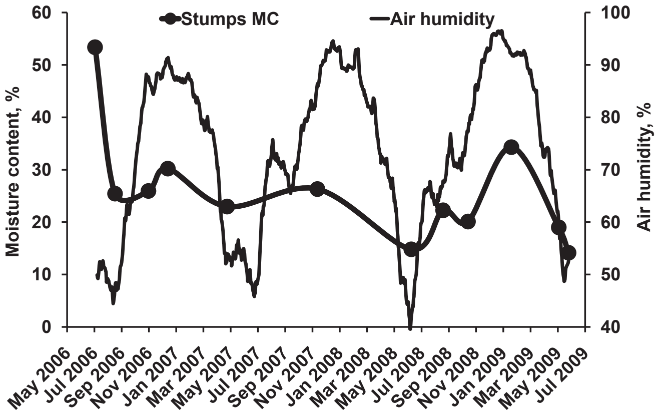

Fig. 3. Average moisture content of stump wood and air humidity as a function of time.

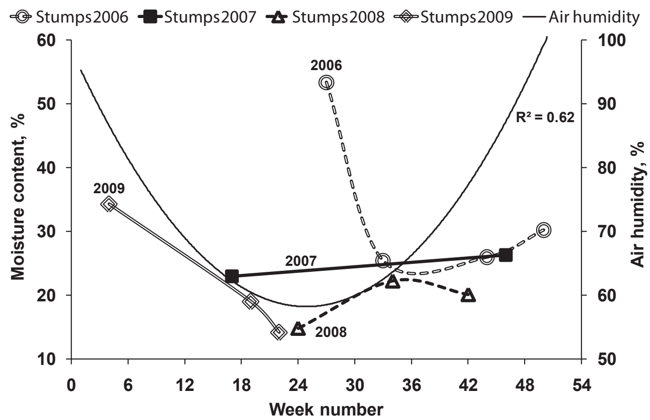

Fig. 4. Function of average moisture content of stumps during four years against calendar week number.

deviation was only 1–3% for the different study sites. In 2009 no more observations were made at the Ähtäri site.

3.3 Correlations between Moisture Content and Other Factors

The annual air humidity curve followed an upwards opening parabola $y = 0.065x^2 - 3.239x + 98.490$ with the coefficient of determination being 0.62. There was a weak non-linear correlation ($R^2 = 0.31$) between stump moisture content and air humidity (weekly average), if the first results of the moisture content immediately after harvesting in 2006 were ignored. The first sampling was ignored because moisture content immediately after stump harvesting was always about 49–55% despite air humidity. Between the stump moisture content and the temperature (weekly average) a non-linear correlation was observed with $R^2 = 0.44$.

Also, there was a non-linear correlation ($R^2 = 0.51$) between the moisture content of the stumps and time (Fig. 5) based on the four year average excluding the first moisture content results immediately after harvesting in 2006. The correlations were higher if the moisture content was examined year by year. The average annual moisture content of the stumps from four weeks after harvesting

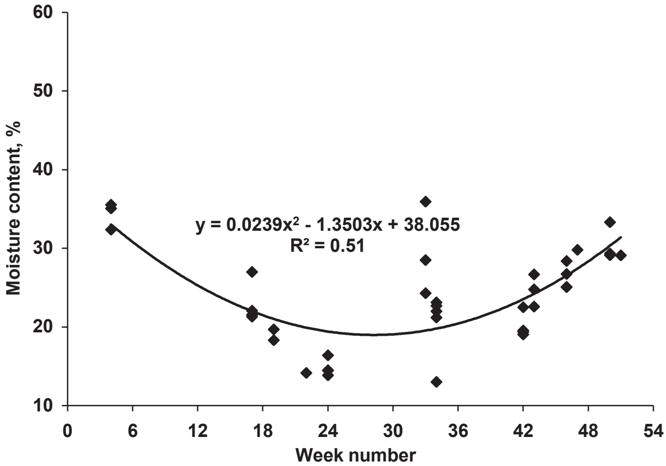

Fig. 5. The function between stump moisture content and time (calendar week number) based on the four year average.

in 2006 to the end of the storage period in 2009 follows an upward opening parabola $y = 0.0239x^2 - 1.350x + 38.055$. The highest moisture content occurred at both the beginning and the end of the year, being about 37%. The average moisture content was at its lowest in the beginning of July being about 19%.

The highest R^2 (0.63) in this study was received using model (Eq. 2) with four variables: calendar week number (t_{wn}), air humidity (AH_a), temperature (T_a) and drying time (t_d). Air humidity and temperature in the equation were weekly averages. Drying time means time from harvesting until sampling time and analyses. There was no correlation between moisture content and diameter of sample ($R^2 = 0.044$). Also, correlation between moisture content and precipitation in the long term was not detected ($R^2 = 0.106$).

$$\begin{aligned} MC &= 0.0189t_{wn}^2 - 1.0694t_{wn} \\ &- 0.0021AH_a^2 + 0.2499AH_a \\ &+ 0.0375T_a^2 - 0.7260T_a - 0.0340t_d + 32.747 \end{aligned} \tag{2}$$

where:
MC = moisture content (wet basis)
t_{wn} = calendar week number
AH_a = air humidity (weekly average)
T_a = temperature (weekly average)
t_d = drying time in weeks

3.4 Heating Values

The average heating value (Q_{net}) of the stump wood at the end of the storage period (three years after harvesting) was 5.241 MWh/ton and ($Q_{net,ar}$) was 3.808 MWh/ton with the moisture content (wet basis) being 24.2% . The average ash content of the stump wood was 1.7%.

4 Discussion

The material was collected between June 2006 and May 2009 and it was based on four different stump harvesting sites in the South-Ostrobothnia region in western Finland. The moisture content of the stumps was 53% immediately after harvesting. At the Ähtäri site the moisture content (49%) was a little lower than at the other sites. This may be due to the different sampling method used in Ähtäri when taking samples for the first time.

At the second sampling time at two sites in Jurva there was a quite high standard deviation of moisture content. This might have been due to the forest haulage that took place between the first and second sampling times. During forest haulage the stumps were mixed, and some stumps with higher moisture content from the bottom of the pile came to the top surface layer. In each case the samples were collected from the top surface layer of the piles at the clear cutting area or at the roadside storage sites. Inside the stump piles the moisture content of wood might have been different than on the surface of the pile. The variation might be either positive or negative depending on for example the weather conditions and the season.

The most favourable point in time for stump harvesting is in the spring and early summer. In the dry summer (the summer of 2006 was extremely dry) immediately after stump harvesting the moisture content decreases relatively rapidly, and about one month after harvesting the average moisture content was only about 31%. According to Backlund (2009) the moisture content of stump wood is between 20–40% after one summer season's drying period.

During the late autumn the moisture content increased, but not considerably. If stumps were dried well in the summer the water absorption was very slow in the autumn which maybe due to pit aspiration. The spruce bordered pits aspirate below the fibre saturation point FSP (29%) and after that it is almost impossible for water to penetrate anymore (Koponen 1985). Every spring and summer the moisture content was at a lower level compared to the previous year. This is remarkable information from the viewpoint of energy wood drying.

The ash content of wood is generally about 0.5% (Hakkila 1989, Haygreen and Bowyer 1996). According to Alakangas (2000) ash content of stump wood can be 3.8–13.0%, if it includes soil remnants. However, in this study ash content was lower being 1.7%. This may be due to the long storage time of about three years. During the storage period rain and frost cleaned the stumps. The heating value (5.24 MWh/ton of dry mass) was almost the same after the three year storage period than that of fresh wood 5.37 MWh/ton of dry mass (Nurmi 2000). In other words, the energy content of dry mass of stump wood was almost the same after three years than immediately after harvesting. Thus, the loss of energy in storage was very small. In addition, the moisture content of stump wood in the storage was under 35% during the entire study period excluding the first one month period after harvesting. Therefore the stumps at the forest roadside storage sites were combustible at any point during the three year period, providing that the stumps dried well at the beginning.

There are many factors which affect the moisture content of stump wood. Probably the weather is the most important factor, but conditions can vary between storage sites and good topography is essential. Storage at different forest roadside sites (e.g. ditches, hillocks, pit sites) can result in different moisture contents. Moreover, the structure of the storage causes variations in the stump wood moisture content. Dense stump wood storages can dry slower than coarse storages, because they include less airspace. Also, the stump splitting methods used can affect the moisture content. However, these factors could not be analyzed in this study.

The most important independent variable in this study was the calendar week number, if it was not taken into account during the one month period immediately after stump harvesting. Also, there was a correlation between temperature and moisture content as well as air humidity. However, the basic calendar week number may also include other unaccounted for seasonal factors (e.g. wind and solar radiation) that affected the data. It is well known that for example air humidity is at its lowest point in the summer months in Finland. The moisture content model (Eq. 2) is significant (p-value < 0.001), but the model still has some residual values. Therefore more data is needed to construct a more reliable model. For example it would be reasonable to take samples more frequently and also from the inner layers of the pile.

Moisture content is one of the most important factors in stump wood procurement. It directly affects the transportation costs and heating value of the stump wood. The results of this study can be used as basic knowledge for the calculation of cost-effective stump wood procurement and also for production planning and utilization of stump wood. However, further studies about stump wood moisture content in the different parts of a storage site and different kinds of storage sites are needed.

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