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Sampling procedure in a willow plantation for estimation of moisture content

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ABSTRACT

Heating value and fuel quality of wood is closely connected to moisture content. In this work the variation of moisture content (MC) of short rotation coppice (SRC) willow shoots is described for five clones during one harvesting season. Subsequently an appropriate sampling procedure minimising labour costs and sampling uncertainty is proposed, where the MC of a single stem section with the length of 10–50 cm corresponds to the mean shoot moisture content (MSMC) with a bias of maximum 11 g kg^{-1}. This bias can be reduced by selecting the stem section according to the particular clone. The average difference in MSMC between the largest and smallest shoot in a stump was 31 g kg^{-1}. This variation is only marginally smaller than the variation found in MC between stumps. The MC of individual stem sections may vary as much as 190 g kg^{-1} in one shoot. Variation in whole shoot moisture content was primarily influenced by the shoot diameter, but in addition significant effects of clone and shoot age were found.

1. Introduction

Biomass yield is estimated from the fresh weight of material, after deduction of the water content so that the value is dry matter production, per unit area. This is natural since the value as fuel is closely connected to the dry matter, DM even though the water content plays a major role for storage and usage of biomass. A measurement of the mass fraction of water is therefore needed, and from this mass fraction supplemented either with independent measurements of dry higher heating value by bomb calorimetry e.g. EN 14918:2009 [1], or calculation of the higher heating value from the derived molecular formula, the lower heating value can then be used in determining the value and sales price of the biomass feedstock. An increase in moisture content of 20 g kg^{-1} (2.0 percentage points) from e.g. 530 to 550 g kg^{-1} fresh harvested willow in the present study is equivalent to a decrease of 5.7% in lower heating value on wet basis calculated according to EN 14918:2009 [1]. Moisture content, MC in the present article is calculated as the mass fraction of moisture evaporated when willow was oven-dried to constant weight at 105 °C divided by total weight of fresh willow (water and dry weight of wood).

Usually estimation of MC has to be based on sampling as it is impractical to dry complete crop yields. Sampling has to be planned carefully since MC varies in a stand between plants, shoots and even for different heights of a single shoot. Hytönen [2] discovered up to 6% differences in MC between shoots in willow plots of *Salix* 'Aquatica' in the same field and that shoots with smaller fresh weight had higher moisture

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content. Telenius [3] did a comprehensive evaluation of distribution in moisture content in willow and poplar grown in the region of Uppsala, Sweden. He concluded that thinner willow shoots had higher MC than that of thicker shoots, and branches had 18 g kg^{-1} higher MC than stems. This is partly explained by Adler et al. [4], who found an increasing bark proportion by height and constant bark proportion of 20% for shoots above 20 mm in diameter at 55 cm above ground. Adler et al. [4] measured that willow bark normally contained 48–52 % MC compared to 36–48 % in willow wood.

The variation in MC has led to several different methods for estimation of the mean MC of a short rotation coppice, SRC stand. One way is to chip single plants or complete plots and take representative samples [5,6]. A less time-consuming method for SRC is sampling from single shoots for estimation of MC and other characteristics. The height for these samples varies. Subsamples of the shoots are often sections taken around breast height, ca. 1.3 m above ground [7,8], or around the balancing centre for a harvested complete shoot when placed horizontally [3,9,10]. Laureysensa et al. [11] collected one subsample of the lower half of the shoots in poplar and [2] took six complete shoots of unequal size. Others selected several stem discs or stem sections from various heights [12–15].

Only few of the studies have tested the reliability of different subsampling procedures for determination of mean shoot MC in SRC.

In willow, Telenius [3] showed that a small stem section from the horizontal balancing centre of complete shoots led to an estimation of the moisture content, which in average varied 7 g kg^{-1} from the mean MC of the complete shoot. Sampling the complete lower half of a stem or a section from 20 to 50 % of the total shoot height led to the same difference or bias. Telenius [3] concluded that a bias of 10–20 g kg^{-1} should be expected in any within-stem sampling procedure. Telenius [3] did most of his evaluation by dividing single shoots into 10 sections, each 10% of the total height, i.e. it is necessary to measure the total height.

The aim of the present study is to describe the variation of MC in willow and subsequently propose an appropriate sampling procedure minimising sampling uncertainty.

2. Materials and methods

2.1. Site description

The study was carried out in a willow (*Salix*) plantation with an initial planting density of 16,700 cuttings ha^{-1} grown on sandy soil in Grimstad (58°35′ N, 8°58′ E) close to the southern coast of Norway. The plantation area of 1500 m^2 was established in 2002/2005 with five different willow clones and divided into two- or three-year rotation strategies (Table 1). Fertilization (nitrogen, N) was 75 kg ha^{-1} $year^{-1}$ and the DM yield level of the plots at final harvest ranged from 6.3 to 19.7 Mg ha^{-1} $year^{-1}$.

Weather data (precipitation, temperature, wind speed, humidity, and leaf surface wetness) was collected from the Norwegian Institute for Agricultural and Environmental Research, Landvik, four km from the plantation. The weather data was used to calculate the following climate variables: Number of minutes with surface wetness registered last 24, 48, 72 h and 1 week before harvest (WaterFilm24 h, WaterFilm48 h, etc.); Crop water balance as the difference in mm between precipitation and calculated evapotranspiration based on wind speed and vapour pressure registered last 24, 48, 72 h and 1 week before harvest (Wbalance24 h, Wbalance48 h, etc.).

2.2. Sampling

Willow shoots were harvested manually with a lopper 10 cm above soil. In total 78 shoots for sampling were selected on 13 occasions from 21 November 2011 to 23 March 2012 (Table 1). On harvesting dates, generally six living shoots were harvested from two clone plots. From one clone plot, three shoots were harvested from one stump or alternatively three different sized shoots were collected from randomly chosen stumps. On 12 December 2011, all 15 shoots from six subsequent stumps in a row were sampled in Tordis for a more extensive examination of the MC variation along a row. Shoots were always selected from rows with minimum two border rows of the same clone.

In the field the length of the main stem and the distance from the stump to the horizontal balancing centre of the complete shoot incl. branches were measured. The balancing centre or the position of a shoot's geometric centroid was determined by balancing the harvested complete shoot horizontally on one finger. Stem diameters (SD) were measured at harvesting height 10 cm (SD10 cm), at 100 cm (SD100 cm) and breast height 130 cm (SD130 cm) above ground and balancing centre (SDBC). Then all branches were collected in a separate sample, which was divided into branch parts below and above 10 mm diameter. Occasionally, dead shoots from the actual stumps were collected in a separate sample. Finally, the main stem (shoot without branches) was cut into sections, as shown in Table 2, and put into paper bags. Later the same day in the laboratory all sections were cut into pieces of maximum 10 cm length in order to shorten the drying time. Immediately after samples were weighed and then dried in paper bags at 105 °C to constant weight for determination of MC.

2.3. Data analysis

2.3.1. Effects on mean shoot moisture content (MSMC)

The data were statistically analysed by a linear mixed model [16,17] using SAS 9.2 [18]. The effects of clone (C), shoot diameter (SD), shoot age (SA), harvest date (HD), climate (P) and some of their interactions on the mean shoot moisture content (MSMC) of the willow shoots were evaluated by model (1). The random effect of stump (St) is written in italics. The residual (e) is equivalent to variation among individual shoots. C and SA were treated as factors whereas SD, HD and P were treated as continuous variables. The random variables *St* and *e* were assumed to be normally distributed with mean zero and constant variances.

$$MSMC = C + SD + SA + HD + C * SD + SD^2 + C * HD + P + HD * P + St + e \quad (1)$$