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Research paper

Validation of prediction models for estimating the moisture content of logging residues during storage

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ABSTRACT

Increased use of forest biomass for energy and rising transportation costs are forcing biomass suppliers towards better moisture content management in the supply chain. Natural drying is used to decrease moisture content of energy wood. Drying is dependent on wood characteristics and weather conditions. Weather-dependent drying models for estimating the optimal storage time based on average moisture changes in fuel wood stacks stored outdoors have been developed for different stem wood and logging residues. Models are an easy option for estimating the moisture content of energy wood piles compared to sampling and measuring the moisture of samples. In this study, stand and roadside storage models for logging residues were validated against data from field studies and forest companies. Over 200 reference piles for the stand model, 23 piles for the roadside model and 10 piles for the combined model were studied. Results of the validation are promising. The difference between measured and modelled moisture was on average only 0.35%. The presented models can be implemented anywhere in Finland, because the Finnish Meteorological Institute has a weather observation service offering weather history data for every location in Finland. For international use, parameters need to be estimated on a case by case basis, but it should be possible to implement the approach also elsewhere.

1. Introduction

Increased use of forest biomass for energy and rising transportation costs are forcing biomass suppliers towards better moisture content (MC) management in the supply chain. Biomass fuel quality is often defined by its calorific value and from that point of view, the lower the moisture content the better [1,2]. Natural drying is used to decrease the moisture content of energy wood. Usually logging residues are left in the cutting area and spread out to dry. After a drying period the logging residues are forwarded and stored beside the road. Roadside storing time varies according to fuel needs. Energy wood supply operates year round, but the demand is notably higher from October to March [3]. In Finnish energy wood procurement, harvesting of logging residues is very important. In 2014, logging residues comprised 34% (2.6 Mm^3) of the consumption of forest wood chips in Finland [4]. Logging residues are mainly collected from stands dominated by Norway spruce (*Picea abies* L). In Finland, most of the logging residues are comminuted at the roadside using, for the most part, truck-mounted chippers [5]. The timing of the forwarding of residues is not straightforward. In early-phase forwarding, green residues may heat up, especially in large piles and the dry matter losses are potentially remarkable. Green needles also contain nutrients that are important to the future development of a forest stand. On the other hand, keeping residues on the site postpones site preparation for regeneration in late-phase forwarding. The needles represent approximately 15% of the logging residues from Norway spruce [6]. Nurmi and Hillebrandt [7] reported a reduction in needle content from 19.1 to 4% during one month of spring storage.

After tree cutting, wood starts to interact with the surrounding microclimate [8]. In Nordic conditions, the moisture content of wood drops rapidly in the spring because of the low relative humidity of air. In late August and September, evaporation rate usually decreases and the moisture content of the wood increases, in some cases even above the “original” moisture content after cutting. Maximizing natural drying and minimizing re-moistening are key

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elements in the quality assessment of energy wood [9]. The timing of the operations in relation to seasons is crucial in order to maximize the quality and monetary value of the energy wood.

The latest methodology for monitoring moisture change has been constant weighing of piles in racks built on load cells [10,11]. This methodology allows moisture changes to be monitored in much more detail than with previous sampling methods. The method also gives the moisture value of the whole pile, which is challenging to determine using sampling methods [12]. Weight can be recorded automatically and as often as needed, which enables exact investigation of the effect of weather on energy wood storage and its moisture content.

Constant weight monitoring shows the drying and moistening of the biomass, but the monitoring can be disturbed by dry matter losses. The weight change is the sum of the water to be added or removed and the dry matter (mainly) removed from the pile by microbiological processes [8]. Dry matter losses can be caused either by microbial activity, most commonly fungal attacks (biological), or spillage of material during handling and storage (technical) [13].

The first ideas about using models to predict moisture content of wood were presented in the 1980's. Stokes et al. [2] published their models for soft and hardwoods in southeastern USA. Liang et al. [14], Gigler et al. [15], Filbakk et al. [16] Murphy et al. [17], Erber et al. [10], Dong-Wook and Murphy [18] and Routa et al. [19] have developed different drying models for different species. All approaches in fuel wood moisture content modeling have one common target variable: moisture content, or rather the moisture content alteration during a specified period. The alteration can be explained by a large variety of explanatory variables, like meteorological variables, parameters of storing, material type and duration of storage.

The objective of this study was to develop a model to estimate the moisture content of logging residues during storage. The prediction models are necessary to support operational planning in energy wood supply. Changes of moisture content in response to weather conditions were connected. The requirements of the model were: easy application to the operational planning systems, simple and quick to calculate. The developed models were validated against data from other studies and forest companies.

2. Material and methods

2.1. Experimental design

At the Mekrijärvi Research Station of the University of Eastern Finland (62°46′N, 30°59′E), eight drying racks with continuous measuring systems were built to study roadside storage (Fig. 1). The purpose of the racks is to simulate energy wood storage beside the road in the forest after cutting. The drying racks are metal frames measuring 2.5 m in width by 2.8 m in height and 2.6 m in length. The racks are similar to those used on timber trucks to carry logs. In the system, four load cells in each corner of the rack continuously measure the weight of one pile (Fig. 2). These four cells are connected to a junction box, which is connected onwards to a weighing transmitter. The system enables continuous monitoring of pile weight. Weight data is stored in a file and changes in weight can be followed via the Internet. The moisture content is determined based on weight changes in the energy wood storage pile. When the weight of the pile decreases, the moisture content of the material decreases, and when there is more weight, the material has higher moisture content. The material in the rack was piled by a machine. As the piles in the racks are quite small compared with actual storage in the field, there are cover papers on the bottom and sides of the racks. The paper decreases the edge effect of the pile, preventing too fast drying. The piles are designed to replicate parts of larger roadside piles created during real harvesting operations.

Fig. 1. One of the drying racks at the University of Eastern Finland's Mekrijärvi Research Station.

In addition, two special drying platforms were built in 2013 (Fig. 3) for emulating drying in a small logging residue pile in stand conditions. The data for the stand model for logging residues was collected from platforms in summer and autumn 2013, 2014 and 2015, and from a field experiment 2012.

At the Mekrijärvi Research Station, there is a well-equipped meteorological station operated by the Finnish Meteorological Institute (FMI), which provides data on relative air humidity (%), air temperature (°C), wind speed (m s^{-1}), wind direction (°), solar radiation (W m^{-2}) and rainfall (mm), air pressure (hPa), ground temperature (°C), rainfall intensity (mm h^{-1}), visible distance (m), height of clouds (m) and snow depth (cm). The meteorological data is collected by a data logger. The weather data can also be obtained from grid data. The FMI provides gridded weather data for all of Finland. This data set consists of weather observations (e.g. temperature, humidity, precipitation), which have been interpolated to a 10 km × 10 km grid using the Kriging interpolation method [20].

The storage area at the Research Station is an open area, next to a lake and its elevation is 155 m above sea level. Mean annual precipitation in this area is 668 mm and mean annual temperature 2.1 °C. The mean temperature for the drying season is 9.8 °C [21]. The long-term average of precipitation for the drying period is 439 mm. The long-term averages (1971–2000) were taken from the nearby station, Ilomantsi Kirkonkylä, because there was no data from the Mekrijärvi station, as it was founded in 1999. The Ilomantsi Kirkonkylä station is located 11.6 km from Mekrijärvi and therefore represents the same climate conditions. The mean snow depth in the Mekrijärvi area is approx. 45–65 cm in the winter months.

As shown in Table 1, the first drying season (2012) was not optimal for wood drying. The mean temperature was slightly lower than the long-term average mean temperature and the precipitation sum was almost 50% more than the long-term average [21]. The best drying season was in 2013 when the mean temperature was highest and the precipitation sum was smallest. In 2014 and 2015 conditions were similar to the long-term average.