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Research paper

The effect of output unit choice on detection of feedstock effects on chipper productivity and fuel consumption

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ABSTRACT

Currently different trade units are used throughout the forest energy supply chain in Sweden: chipping contractors are paid per m^3 chipped volume, dry metric tonnes or MWh, hauliers per raw tonnes or m^3 chipped volume and the company supplying the chips to the heating plant most often per delivered MWh. This introduces business risks for all market players, and affects studies of chipping equipment. Lately, Skogforsk has used oven dry tonnes, but stakeholders that measure chips in other units want results to be presented in these units as well. To raise awareness about output unit selection and its effect on productivity and fuel consumption studies, Bruks 806 chippers were studied when chipping spruce and beech residues. Results show that the selection of output unit affects the capacity of detecting treatment differences and the direction of such differences. Chipping productivity based on effective chipping time was higher for spruce residues when calculated using chipped volume, and for beech when calculated using raw weight. Similar trends were found for fuel consumption per product unit. As both feedstock characteristics and output measurement unit selection affects study results, a proper experimental design to control these effects is important. In many cases it is a matter of keeping feedstock constant during comparisons of machines/treatments. Care is needed when using chipped volume, as chipper settings may influence chip bulk density and thus chip volume. The use of different units throughout the supply chain reduces transparency and increases the risk for sub-optimal decisions.

1. Introduction

Productivity and fuel consumption in comminution studies, as in all other studies are a measure of the output in relation to the input. The output in studies of comminution equipment has traditionally been measured in cubic metres of chips, raw tonnes i.e. Mg, or dry tonnes. In Sweden, Skogforsks studies of comminution equipment, chippers and grinders has reported productivities in oven dry tonnes (odt) i.e. oven dry Mg, per effective work time and fuel consumption in litres per odt since 2010. However, forest companies and contractors that measure chips in m^3 chipped volume (i.e. loose volume) have asked that study results should be presented in chipped volume, or at least that both ways to measure output should be used. The customers, i.e. heating and combined heat and power plants, are used to present costs and fuel consumptions per energy unit produced and they are interested in costs expressed in SEK per MWh or J. In the current study of the effects of feedstock on productivity and fuel consumption for Bruks 806 chippers, this issue has been brought to the foreground since the contractors studied were paid based on different units.

To complicate matters' further it is not uncommon that different market players in the same area use different units, or even that the same market player uses different units to pay the landowner for the biomass and the contractors for the works performed. The current situation in Sweden is that different trade units are used in the supply chain: chipping contractors can be paid for their work in m^3 chipped volume, dry tonnes or MWh, while hauliers are paid by raw tonnes or m^3 chipped volume and the company supplying the chips to the heating plant is most often paid by the MWh. The use of different units throughout the supply chain introduces business risks for all the market players, and might introduce incentives for individual players to act in a way that is not contributing to a maximised net value of the delivered fuel.

While raw weight is easy to measure accurately, it is not a good measure of either the amount of biomass or the energy content as long as the moisture content is unknown. Furthermore, the raw weight will change during storage of the material, fresh material will have a moisture content of about 50% (wet base), but properly stored material may have a moisture content as low as 25% in the end of the summer

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[1–4]. Measurement of the volume often has a subjective component, since the person who does the measurements needs to compensate for the unevenness of the chip surface in the pile or truck. On the other hand, it's a fair measure of the amount of biomass, although not as good as the dry weight. To be able to calculate dry weight, the moisture content of the chips needs to be known. Moisture content is most commonly obtained by sampling the chips and drying the sample until a constant weight is reached [5], although faster and easier to use methods are being evaluated [6–8]. Energy content is estimated on the basis of raw weight, moisture content and ash content. However, energy content can be calculated differently, depending on whether the energy absorbed for evaporating the water mass fraction is discounted from the total energy content of the dry wood or not. Either solution is justified, depending on whether the plant has a vapour condensation system or not.

Unfortunately, this heterogeneity also affects the scientific community. Measurement of time inputs has been harmonised by e.g. the IUFRO Forest work study nomenclature [9] and the COST guidelines for biomass production studies [10,11]. This is not the case with the measurement of the output, where there are no standardised units and methods to measure output. It is easy to realise why different units are used: field studies often have a primary utilitarian goal and are geared to provide specific answers to specific stakeholders. As a result, most studies adopt the trade units that are used in the area where they are conducted.

The many methods used to measure output make individual biomass production studies difficult to compare, which is further complicated by the fact that machine design might influence the measurement of the output [12]. The produced amount of chips or hog fuel has been measured in m^3 chipped volume [13–18], raw tonnes [19–24], dry tonnes [16,20,21,25–29] or as energy in J or MWh [30,31]. To further confuse things, some studies measure the amount of chips in solid m^3 of wood that has been chipped [31,32]. Studies have shown that the produced volume of chips can be influenced by the target chip size and the way the chips are evacuated from the chipper, e.g. if a fan or a conveyor is used, i.e. the machine set up influences the bulk density of the chips [12,33]. All this contributes to make fair comparisons of the result from different studies of comminution machinery difficult, especially if not enough information is provided to convert the units used in the compared studies to one common reference unit. Furthermore, one may wonder if output unit selection may affect the results of a study, that is: if using different units in a comparison of machines may change the outcome of the comparative study at hand.

The aims of this study were to raise awareness about the issue of product unit selection and its effect on study results, and to exemplify this by evaluating the effects of two feedstock types on chipper productivity and fuel consumption using different output units.

2. Material and methods

During 2013 and 2014 performance studies of the then new Bruks 806STC chipper were made to describe the time consumption and productivity, fuel consumption, and chip quality when chipping different type of logging residues with the machine. Chip size distribution was used as a measure of chip quality. The 806STC chipper is powered by a 368 kW Scania engine.

Chipping of Norway spruce (Picea Abies L. H. Karst.) residues was studied outside Djurås in central Sweden in May 2013 and chipping of beech (Fagus sylvatica L.) residues was studied outside Hässleholm in southern Sweden in April 2014. Average temperature was 18 °C in Djurås and 8 °C in Hässleholm. In both cases, stacked residues were chipped on the landing and transported to the closest suitable reloading position, in Djurås 50–100 m and in Hässleholm 50–250 m. The longer and more variable distance in Hässleholm was caused by a narrow road with less space where the truck could place the chip containers. The chipping operation in Djurås was performed by a contractor using a

Table 1
Feedstock properties for the studied beech and spruce residues.

Feedstock	Spruce	Beech
Moisture content	22.3%	39.3%
Bulk density (kg m^{-3} loose chips)	235	372
Dry bulk density (kg m^{-3} loose chips)	182	226
Energy content (h_{net}) (MWh odt^{-1})	5.53	5.35

Rottne F15c forwarder (184 kW) as carrier for the chipper, and the operation in Hässleholm was performed by another contractor using a Ecolog 574C (204 kW) forwarder as carrier. Both forwarders were equipped with booms with 10 m reach and the Rottne had a 0.30 m^2 grapple and the Ecolog a 0.28 m^2 grapple. These studies were deemed suitable to use for a comparison of how study results are affected by the choice of unit in which the produce is measured, due to large differences in feedstock properties (Table 1).

The time study of the chipping work was done as a comparative time study with snap back timing [34]. Time recording was made with Allegro hand-held computers equipped with Skogforsk SDI software. Chipping work was split into 8 elements (Table 2). All measured times for each load have been summarized per work element and divided by the amount of produced chips to get times in s per unit of produce. In the current analyses of the effect of different units of produce the elements *Boom out*, *Grip*, *Boom in & feeding*, *Adjustment*, and *Chipping*, have been summarized in the main work element *Effective chipping time*, likewise the elements *Move with load*, *Unloading*, *Move empty*, and *Landing work* have been summarized in the main work element *Complementary time*. The sum of *Effective chipping time* and *Complementary time* was defined as *Productive work time*. Only effective times have been included in the analyses. Delays that were not caused by the study are presented in Table 3 and Fig. 1.

The fuel consumption of the engine that powered the chipper and the engine powering the carrier including the hydraulic loader were measured by topping up their respective fuel tanks after each load using an accurate fuel gauge. To compensate for differences between trailer loads, fuel consumption per produced amount of chips were used in the analyses. Diesel fuel volume was converted to input energy in J by its energy content (9800 kWh per m^3 according to the supplier (https://www.okq8.se/foretag/drivmedel/) x 3600 = 35.68 GJ m^{-3}).

Chip mass (M) was measured using the certified scales at the heating plants in Borlänge and Hässleholm, where also the volumes were measured by the wood measurement associations. Chip mass per bin on the chipper was scaled using the scales of the machine in Djurås and thereafter corrected using the total weight according to the scales at the heating plant (Eq. (1)). The moisture content (M) of the chips was sampled in each chip bin of the machine in Djurås and per container in Hässleholm. Dry mass (Eq. (2)) and energy content as received (h_{net}, Eq. (3), according to the wood measurement association instructions) were thereafter calculated per bin in Djurås and per truck load in Hässleholm.

$$M_{corr} = M_{chipper} \times \frac{\sum M_{Certified}}{\sum M_{chipper}} \quad (1)$$

$$M_{dry} = M \times \left(1 - \frac{MC}{100}\right) \quad (2)$$

$$h_{net} = h_{eff} \times \left(1 - \frac{A}{100}\right) \times \left(1 - \frac{MC}{100}\right) - 0.678 \times \frac{MC}{100} \quad (3)$$

Where h_{eff} = 5.69 MWh/odt for spruce residues and 5.47 MWh/odt for beech residues, and ash content A = 2%.

The study was designed as a simple comparison of the two feedstocks and all analyses of productivity and fuel consumption were made using t-tests.

Chip size distribution was analysed using a general linear model