Journal of Cleaner Production 197 (2018) 208–217

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

# Modifying the settings of CTL timber harvesting machines to reduce fuel consumption and $CO_2$ emissions

Robert Prinz [a,*], Raffaele Spinelli [b], Natascia Magagnotti [b], Johanna Routa [a], Antti Asikainen [a]

[a] Natural Resources Institute Finland (Luke), Yliopistokatu 6, 80100, Joensuu, Finland
[b] CNR IVALSA, Via Madonna del Piano 10, Sesto Fiorentino, FI, Italy

ARTICLE INFO

*Article history:*
Received 2 March 2018
Received in revised form
23 April 2018
Accepted 18 June 2018
Available online 19 June 2018

*Keywords:*
Harvesting
Fuel consumption
$CO_2$ emissions
Productivity
Settings
CTL

ABSTRACT

The objectives of this study were to examine the possibility of reducing the fuel consumption and $CO_2$ emissions of harvesters during cut-to-length operations by applying various technical settings to the machine through the machine's own software package. The adjustment of machine settings had an effect on the fuel consumption per unit product (l $m^{-3}$) and can reduce the fuel consumption and $CO_2$ emissions in cut-to-length harvesting operations. The main factor significantly affecting both fuel consumption and productivity was stem size. The study involved three cut-to-length machines operating in thinning with comparable stand environment and silvicultural prescriptions.

The novelty of this work is in exploring the fuel saving potential of simple adjustments of machine settings in cut-to-length harvesting machines. Such adjustments have an impact on fuel efficiency and may reduce fuel consumption and $CO_2$ emissions in cut-to-length harvesting operations. This work may result in a reduction of energy consumption and environmental pollution, thereby contributing to cleaner production. This study bridges the gaps between research, development and implementation: it offers practical solutions that may affect manufacturers as well as practitioners and entrepreneurs in the field. The outcome of this study may result in innovative technology development with less impact on the environment.



## 1. Introduction

The global production of roundwood amounts to approximately 3.7 billion $m^3$ per year (FAO, 2016), of which over 1 billion originates from industrialized regions such as Europe, North America and Russia (Eurostat, 2016). In these countries, an increasing proportion of all harvesting work is mechanized, with shares that reach almost 100% in Atlantic, Baltic and Nordic Europe (Asikainen et al., 2009). Mechanized forestry equipment reaches high productivity but incurs high fuel consumption as well. Felling and processing alone require over 1.1 l diesel per $m^3$ of roundwood (Athanassiadis, 2000), and when this amount is multiplied for the volume harvested in industrialized countries, consumption soars to over 1 billion litres of diesel per year. That emphasizes the interest in increasing the efficiency of wood harvesting equipment and the reduction of pollutants emitted by diesel engines which affect human health and the environment (Petranović et al., 2015). Much work is being devoted to introducing new high-efficiency hybrid power solutions such as a hybrid-electric harvester (Johnsen, 2017) and/or to favour a switch towards biofuel blends (Mwangi et al., 2015) or mixing suitable additives to diesel (Fattah et al., 2014). These are likely to be the mainstream solutions of the near future, as older machines are being replaced with new and more modern ones. In the immediate future, however, large-scale changes can only occur through the adaptation of the existing fleet through retrofitting or suitable adjustments, as has been done in other fields, i.e. the achievement of reduced energy consumption in retrofitting of buildings (Zhou et al., 2016). Machine setting adjustment is probably the easiest solution: most tree harvesting machines can run in several modes, including a fuel saving mode like any other piece of equipment, i.e. engine operation modes in hybrid electric vehicles to reduce fuel consumption (Solouk et al., 2018). Also, mechanized harvesting machines collect a vast

* Corresponding author.
*E-mail addresses:* robert.prinz@luke.fi (R. Prinz), spinelli@ivalsa.cnr.it (R. Spinelli), magagnotti@ivalsa.cnr.it (N. Magagnotti), johanna.routa@luke.fi (J. Routa), antti.asikainen@luke.fi (A. Asikainen).

https://doi.org/10.1016/j.jclepro.2018.06.210
0959-6526/

amount of data during their operation. Big data can be utilized for improvements through data mining and development of methods and models similar to those developed to solve regional energy efficiency problems (Liu et al., 2018) or using in machining optimisation within the manufacturing sector, where a 40% energy saving and 30% productivity improvement can be achieved (Liang et al., 2018).

The demand for forestry equipment, including both purpose-built machines and converted machinery, is increasing on a global scale – the demand for forestry equipment in the world was forecast to grow annually by 4.5 per cent and reach 9.3 billion US dollars in 2019 (Freedonia, 2015). The demand for machines is highest on the North-American market with an estimated need of 14 000 to 35 000 harvesting machine chains (Asikainen et al., 2009). In 2014, the US and Canadian markets accounted for a third of global product demand, followed by Western Europe as the second largest market with a share of 22% of the total equipment sales (Freedonia, 2015). Asikainen et al. (2011) estimated the need for machines in the EU in 2010–2030 for the supply of biomass potential at 18 600 harvesters and 21 600 forwarders. Consequently, if successful, modifying and adjusting work settings to reduce fuel consumption and $CO_2$ emissions in CTL timber harvesting could affect a large number of machines.

As a matter of fact, energy saving, reduction of greenhouse gas (GHG) emissions and machine efficiency are some of the most important key performance indicators of forest harvesting operations, regardless of the final product: timber or fuelwood. Several recent studies have analysed the efficiency of harvesting operations, their carbon footprint and the fuel consumption and emissions of all machines deployed for the task (Erber and Kühmaier, 2017; Obi and Visser, 2017; Cosola et al., 2016; Spinelli et al., 2018). While efficiency has increased through mechanization (Berg and Karjalainen, 2003), forest operations still account for the majority of emissions along the wood value chain: in that regard, harvesting is the most critical phase, due to its large consumption of fossil fuel (Dias and Arroja, 2012; Morales et al., 2015).

Within mechanized wood harvesting systems, fuel consumption is the main energy input and may account for 82% of the total (Klvac et al., 2003). For harvesting operations, productivity, fuel use and fuel type have a strong effect on energy consumption and GHG emissions, as shown by Zhang et al. (2016) in their study about the environmental impact of harvesting. Fuel consumption during harvesting operation plays an important role in the overall timber extraction process: Lijewski et al. (2017) report that the fuel consumption of CTL harvesters represents 38% of the total fuel used along the technological cycle, which is higher than that consumed during forwarding (35%) and transportation (27%).

The technical efficiency of the harvesting operation is influenced by factors such as the size of operation, forest terrain, number of log assortments and piece size (Obi and Visser, 2017), whereas the fuel consumption of timber harvesting machines depends largely on work type, the mechanical condition of the equipment and the driving style adopted by the operator (Ackerman et al., 2014). Fuel consumption varies also between harvesting systems (Spinelli et al., 2014) and depends on the harvesting machinery used. In that regard, Magagnotti et al. (2017) reported a 2.4 times greater fuel consumption per unit product for excavator-based units compared to purpose-built machines. These same findings have been confirmed by previous studies relating fuel consumption and emissions to machine characteristics, operator, machine operating time, work productivity and stand management options (Athanassiadis et al., 1999; Berg and Karjalainen, 2003; Cosola et al., 2016).

In general, cutting performance is affected by a complex combination of different factors (Nurminen et al., 2006). For $CO_2$ emissions, the most important factors are: species distribution, forest management method, terrain conditions, machine choice and operator competence (Cosola et al., 2016).

Of course, a key parameter is the productivity of machines: if productivity increases more than fuel consumption, then emission per product unit is likely to decrease. Hiesl and Benjamin (2013) mentioned in their literature review that machine productivity is most affected by stand and site conditions, equipment configurations, management objectives, and operator experience. Earlier on, Lageson (1997) mentioned that thinning intensity has a strong effect on machine productivity deployed in tending operations. Like for any other work process, the productivity of mechanized harvesting (i.e. felling, delimbing and bucking) is significantly affected by the volume of the work object – in this case the harvested tree – according to a relatively complex function (Visser and Spinelli, 2012).

Increasing resource efficiency is a key element of cleaner production and one measure is to reduce fuel input when producing the same product output (Spinelli et al., 2018). Thus, the question arose if a reduction of diesel fuel consumption in harvesting operation through the modification of work settings of CTL harvesters can be achieved. The aim of this study was to investigate the possibility to reduce the fuel consumption and $CO_2$ emissions of timber harvesters during CTL operation under real working conditions by modifying the technical settings of the machine through the machine's own software package. The study focussed on the determination of the effects of selected setting treatments in single-grip harvesters on the diesel fuel consumption and $CO_2$ emissions per unit product, as well as on relative productivity.

## 2. Materials and methods

The study was carried out in Central Finland north of Jyväskylä, at three sites near Konttimäki (62° 36′ N 25° 7′ E), Kyyjärvi (63° 0′ N 24° 51′ E) and Saarijärvi (62° 38′ N 25° 32′ E) from 21st to 25th August 2017.

Three Ponsse single-grip harvesters were studied under real working conditions during cut-to-length operation (Table 1). The machines were prepared with pre-selected settings defined individually for each machine (see appendices A to C); the settings compared were defined as follows:

- BAU (business as usual): the setting which the contractor and/or operator would normally use; it is adjusted carefully by the operators for the given machine and conditions and typically optimized for operator skills and preferences to obtain highest productivity
- ECO (economy mode): setting aiming at the lowest fuel consumption in litres per harvested cubic metre; implementation of various fuel saving features
- POWER (production mode): setting aiming at the highest productivity; implementation of various features to increase productivity

### 2.1. Experimental design

Each of the three machines was operated under each of the three settings (BAU, ECO and POWER) for 5 work bouts, each lasting approximately one hour and representing a repetition. Therefore, the experimental design included 45 repetitions (3 machines × 3 settings × 5 replications). The setting sequence for each machine was randomized, in order to dampen background noise.