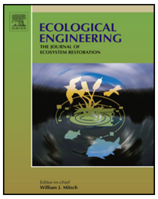
Ecological Engineering 61 (2013) 216–223

Contents lists available at ScienceDirect

Ecological Engineering

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



Skidding operations in thinning and shelterwood cut of mixed stands – Work productivity, energy inputs and emissions

Dinko Vusić[a], Marijan Šušnjar[a], Enrico Marchi[b,*], Raffaello Spina[c], Željko Zečić[a], Rodolfo Picchio[c]

[a] University of Zagreb, Faculty of Forestry, Department of Forest Engineering, Svetošimunska 25, HR-10002 Zagreb, Croatia
[b] University of Florence, Department of Agricultural, Food and Forest Systems Management, Via S. Bonaventura 13, 50145 Firenze, Italy
[c] University of Tuscia, Department of Science and Technology for Agriculture, Forests, Nature and Energy (DAFNE), Via San Camillo de Lellis, 01100 Viterbo, Italy

ARTICLE INFO

Article history:
Received 14 May 2013
Received in revised form 8 July 2013
Accepted 20 September 2013
Available online 26 October 2013

Keywords:
Skidding
Extraction
Emissions
Energy expenditure
Logging operations

ABSTRACT

The present study was conducted on the slopes of the Bilogora mountain in the central region of Croatia. Logging operations were performed at two felling sites with two different silvicultural treatments: thinning was performed at worksite A, and a regeneration cut was performed at worksite B. A half-length harvesting method and the skidding of half-processed wood assortments were used in the study areas. At both sites, the timber extraction was performed by a rubber-tired mini-skidder (Ecotrac 55V, Hittner tractors, Bjelovar – Croatia). The main aims of the present study were to provide limited but significant data regarding the experiences related to working times, productivity, energy inputs, and greenhouse gasses (GHG) emissions for timber extraction using a skidder. This skidder was an average, compact and highly specialised machine, and, as shown by previous studies, this mini-skidder can effectively replace forestry-fitted crawler tractors, common agricultural tractors and cable yarders under particular conditions. In the context of small-scale forestry this mini-skidder as when compared with common agricultural tractor or forestry-fitted tractors, is more environmentally friendly in terms of energy inputs and GHG emissions during the wood extraction operation. In addition, the most important parameters that affect the use of a similar machine during wood extraction were evaluated in the present work. The average extraction net (PSH_0) productivities ($m^3\,h^{-1}$) were $3.20\,m^3\,h^{-1}$ for worksite A and $4.95\,m^3\,h^{-1}$ for worksite B. The energy consumptions were $113.4\,MJ\,m^{-3}$ for worksite A and $56.1\,MJ\,m^{-3}$ for worksite B. Lower pollutant emission values were calculated for worksite B. At worksite B, the minimum value of CO_2 emissions on the environment caused by the skidding operation was determined.

1. Introduction

The mechanisation of timber harvesting depends on forest types, wood species, management methods and the terrain and climatic conditions. In several countries of south-Europe, motor-manual felling and processing are still very common (Brachetti Montorselli et al., 2010; Çalişkan, 2012; Picchio et al., 2009). After felling, processed or half-processed wood assortments are usually forwarded or skidded to the landing. Despite recent advances in dedicated harvesting technology, forestry-fitted farm tractors are still the backbone of the logging fleet in Mediterranean countries (Spinelli and Magagnotti, 2011), especially for the majority of forest owners and for a portion of the non-industrial private forestry population. Farm tractors are used for a variety of forest harvesting tasks, especially extraction (Picchio et al., 2009; Šušnjar et al., 2008), but their design and features are not developed for forest logging requirements. Rubber-tired mini-skidders can effectively replace forestry-adapted farm tractors under certain conditions, as outlined in previous studies (Savelli et al., 2010; Spinelli et al., 2012). Replacement is desirable in terms of environmental protection and labour safety and offers a substantial economic benefit (Spinelli et al., 2012, 2013).

In most Mediterranean countries, such as Croatia, Italy and Slovenia, the evolution of small-scale mechanisation is very important for forestry owners. Currently, the main method for wood extraction is winching-skidding, which is labour-intensive but still very popular among small scale operators (Picchio et al., 2012a). Methods should be identified to make wood extraction more

---

* Corresponding author. Tel.: +39 0553288609; fax: +39 055319179.
E-mail address: enrico.marchi@unifi.it (E. Marchi).

0925-8574/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.ecoleng.2013.09.052

effective, safe and comfortable. In addition, the growing need to implement sustainable forest management schemes often results in a massive shift towards continuous cover forestry (CCF) and reduced impact logging (RIL) (Picchio et al., 2012b); this shift has resulted in a real need for specialised and technologically advanced machines that are suitable for forestry.

Both industrial and non-industrial forestry are still under-investigated in terms of energy input and Greenhouse Gas (GHG) emissions (Heinimann, 2012). In forest harvesting, as in other productive sectors, each product, process or activity requires an energy input; forestry uses primary fossil resources and, hence, contributes GHG emissions into the environment. The impact of any technology (system) or product on the environment can be assessed by LCA methodology, which can identify inputs and outputs, including the environmental impact (ISO 14040-2 standards, revised in 14044) (Heinimann, 2012; Koponen et al., 2013; Maesano et al., 2013).

Studies regarding the performance, energetic inputs, and greenhouse gasses (GHG) emissions of timber extraction by skidding and that examine the opportunities for improvement remain limited (Picchio et al., 2009). Additional information on this topic is required, especially in terms of the energetic analysis and GHG emissions. Comparing these results to those obtained from earlier studies may help to evaluate the progress of technological development in the field.

The term "energetic analysis" refers to the study of the implied energy use in the production of a service or a product (Balimunsi et al., 2012; Picchio et al., 2009; Picchio et al., 2012c). This energy includes both the energy directly used during the production process (direct) and the energy stored in the materials used for the production (indirect). The direct and indirect consumption of fossil energy is just one aspect of the environmental impact of human activities, and its use as the main evaluation parameter may appear to be restrictive. Nevertheless, the use of fossil energy remains a good indicator of system sustainability (Magagnotti and Spinelli, 2011; Pervanchon et al., 2002; Picchio et al., 2012d; Maesano et al., 2013) and may partly reflect its other dimensions as well. Furthermore, fossil energy use has been adopted by other studies conducted on forest harvesting and may provide a good indicator for the comparison of results (Magagnotti and Spinelli, 2011).

Greenhouse gases essentially affect the climate, and a reduction of their emissions into the environment is one of the primary objectives of the current EU environmental policy (Viana et al., 2010). For this goal, it is absolutely necessary to increase the share of energy from renewable sources, where a zero balance of CO_2 originating from fossil resources can be expected. However, a zero balance of CO_2 is impossible in this case, as in many other systems of renewable energy production because of fossil fuel consumption during the production of renewable energy sources (Gustavsson et al., 2011; Klvac et al., 2012). In the case of forest harvesting, these emissions are mainly due to the use of tractors and mechanical equipment with internal combustion engines. The expected CO_2 emissions can be determined on the basis of the molecular formula, carbon–hydrogen ratio (C:H), energy content, and other factors associated with the fossil fuel source used (Calais and Sims, 2006). However, the simple calculation of CO_2 emissions based on the C:H ratio on a stoichiometric basis is rather naive because the emissions and their composition are also affected by other factors. Emissions generated during combustion can be related to the engine output power, where they depend on thermal efficiency, i.e., on the capacity of transforming fuel energy to engine efficiency. The emission factors of compression-ignition engines during combustion for harvester technologies were studied by (Athanassiadis, 2000; Klvac et al., 2012). The emissions generated by combustion, however, do

Table 1
Description of the worksites and stand characteristics.

Worksite	A (Forest office Kloštar Podravski)						B (Forest office Bjelovar)					
Location	45° 54′ 24″ N; 17° 06′ 06″ E						46° 02′ 19″ N; 16° 50′ 31″ E					
Area [ha]	13.56						40.14					
Age [years]	60						100					
Slope [%]	17 (extraction uphill)						0					
Altitude [m] a.s.l.	190–245						180–215					
Tree species	*Quercus petraea* (Matt.) Liebl.	*Fagus sylvatica* L.	*Carpinus betulus* L.	*Tilia* sp.	Other hard broadleaves	$\sum$	*Quercus petraea* (Matt.) Liebl.	*Fagus sylvatica* L.	*Carpinus betulus* L.	*Robinia pseudacacia* L.	Other hard broadleaves	$\sum$
Number of trees [N ha^{-1}]	30	340	67	14	45	496	11	133	34	8	2	188
Basal area [m^2 ha^{-1}]	1.52	13.87	2.05	0.77	3.29	21.5	1.82	27.6	2.39	0.24	0.11	32.16
Growing stock [m^3 ha^{-1}]	15.41	129.65	16.59	7.37	34.14	203.17	32.24	508.32	37.77	2.07	1.67	582.06
Average DBH [cm]	25	23	20	27	30	23.46	46	51	30	19	30	45.32
Average height [m]	20	19	17	21	22	–	33	35	29	20	29	–
Marked volume [m^3 ha^{-1}]	2.21	15.71	4.20	1.40	9.66	33.19	15.52	103.69	5.86	–	0.40	125.47