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Short communication

Productivity and energy consumption in logging operation in a Cameroonian tropical forest

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ABSTRACT

The logging activities influences the forests conservation and their management in the Congo Basin, for these raisons must be supported by an energetic assessment, and must be compatible with a sustainable forest management. This study aims to provide experimental data on working time, productivities, energy input of logging in tropical forests. The forestry company is aligned with the FSC forest certification scheme. The sites showed a good level of internal organization, but require more planning framework that allows higher interaction between management plans and harvesting. The mechanization level was high and valid for most of the contexts and the skidder use was preferable in order to maximize productivity and to reduce environmental impacts. The staff had already a good level of training. Ergonomics reached a good level even if the staff was stressed out by the environmental conditions. Energy inputs was mainly direct (felling and first processing operations, 57.37 MJ m^{-3}; processing 62.10 MJ m^{-3}; Logs loading 72.26 MJ m^{-3}). Bunching and extraction performed by skidder was the best logging yard in terms of direct energy input (90.7 MJ m^{-3}), productivity (10.187 m^3 h^{-1} $worker^{-1}$) and significant environmental protection.

1. Introduction

The extraction of wood for commercial purposes influences the forest conservation and management in the Congo Basin. Congo basin forests cover 227 million hectares; about 60% of these are classified for productive or commercial use. Thus, the forest sector offers an important opportunity for economic development in the Basin countries. Although the influence of wood logging on tropical forests has been an argument of extreme ecological interest in recent years, the international scientific papers have not dealt extensively with studies regarding forest harvesting, ergonomics, training, productivity, safety, energy consumption and working times developed in African forests and there are only few papers on these topics (Balimunsi et al., 2011, 2012; Biggs et al., 2011; Christie, 2008; Eggers et al., 2010; Silayo et al., 2010).

Worldwide forestry studies on logging play an important role in the rationalization of wood production and in the improvement of logging organization. Moreover, the use of forest products must be supported by an energy assessment and it must be compatible with sustainable forest management (Picchio et al., 2009, 2012a). In Africa, there is a lack of information regarding the energy analysis of forest logging and these are an important Operational Performance Indicator (OPI) which is a main purpose of many studies on environmental sustainability as Life Cycle Assessment (LCA) (Heinimann., 2012). 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 in this study may seem restrictive. Nevertheless, the use of fossil energy remains a good indicator of system sustainability (Magagnotti and Spinelli, 2011; Picchio et al., 2012b) and may partly reflect its other dimensions as well. Forest operations are impacted by different variables such as

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Table 1
Characteristics of the machines.

Machine	Chainsaw	Machine	Tractor	Skidder	Machine	Loader
Model	Stihl MS 880	Model	Caterpillar D7G	Caterpillar 535 C	Model	Caterpillar 966H
Displacement [cm^3]	122	Displacement [cm^3]	9,300	7,200	Displacement [cm^3]	11,100
Engine power [kW]	6.4	Engine power [kW]	188	162	Engine power [kW]	211
Mass [kg]	11	Mass [kg]	25,000	18,000	Mass [kg]	24,000
Guide bar length [cm]	120	Winch max pull [kN]	300	200	Power lift [kN]	161

the characteristics of the woods, the trees or the terrain. Therefore, studies on productivity are often carried out in order to understand the impact that these variables have and, on the basis of these results, to create empirical models. In recent years, productivity is considered to be the key to the reading of the economic and social development of a country. The productivity measurements are also of great importance for the forest technicians and the logging companies (Korkmaz, 2011; Savelli et al., 2010; Picchio et al., 2011b).

This study aims to provide experimental data on working time analysis, productivities, and energy input of logging operations in tropical forests managed by selective harvesting, as well as a comparison of two skidding systems. These studies are important for the improvement of the work planning level, ensuring not only the greatest economic and social benefits, but also reducing the environmental impacts of these forestry activities. The comparison of two skidding systems is one of the topics especially relevant to ecological engineering, in order to devise engineering solutions to improve the ecological performance of human-natural ecosystem interaction. Touching both environmental and technical performance, the problem is well within the scope of ecological engineering (Mitsch and Jørgensen, 2003).

2. Materials and methods

The area of interest (coordinate 2°54' North latitude and 16°03′ East longitude) is a concession to a private company, SEFAC. At present, SEFAC manages in the southeast of Cameroon a total concession area of 411,872 ha, all with an approved management plan. The area is slightly rough, with an elevation between 375 m and 650 m a.s.l. The pedology is characterized by red, ochre or yellow Latosol soil types, with a high content of clay, aluminium oxide and iron oxide, typical of humid tropical regions. The average annual rainfall is 1,500 mm, the average annual temperature is 24.5 °C and the average annual humidity is variable (between 60 and 90%).

The analysis of the management plan of the felling area showed that 61 main woody species, suitable for harvesting, were inventoried for a gross volume of about 17,100,000 m^3 with a 36 trees ha^{-1} potential, of which 61% is made up by 10 species: sapelli, fraké, ayous, emiem, red padouk, bété, eyong, tali, assaméla and kotibé. The felling rate used for all species is 1% and the rotation period is 30 years (SEFAC, 2005). Logging operations were made from March to May 2010 on a total area of 75 ha. All operations were carried out from SEFAC operators. The main operations were:

- tree felling and first processing, performed by a team of three workers, a logistics coordinator, a cutter and a helper. The trees marked on the map, once identified, are measured and evaluated. These trees are felled if they are suitable in terms of quality and, additionally, if they satisfy the legislative requirements regarding minimum utilization diameter. The felled tree is processed up until the branching off of the first large limb (as required by law);
- log bunching and extraction, performed by a team of three workers, a logistics coordinator who marks the logs and directs the tractor driver, a tractor driver, and a wincher to hook and unhook the logs. The D7G, a crawler tractor, was used in yard B, and the 535 C the forestry version of an articulated wheeled tractor (skidder) was used in yard A. These two tractors have similar features but different propulsion systems;
- log processing at the landing site, performed by a team of six workers, a landing coordinator, two chainsaw workers for processing, three workers for measurements and log marking for traceability;
- log loading, performed by a team of three workers, a tractor driver, an assistant, a load supervisor to choose the logs to be loaded. The loading phases were organized by a coordinator. The load is categorized by species and by the size of the logs. The loaded volume is generally about 30–40 m^3 per truck.

This research for the operations of felling and first processing, processing and log loading it was conducted like an observational study. The specific study of the bunching extraction operation was conducted like a proper experiment. In this case the experimental design has contemplated two treatments (skidder in yard A and crawler in yard B) with two replications for treatment characterized by two different drivers. The mechanization used is described in Table 1; in order to carry out a comparison between two tractors for this study in particular, the utilization area was split in two parts, but with similar characteristics. A skidder was used in yard A for the extraction, while in the yard B a crawler tractor was used. The main log and tree parameters (diameter and length) were measured in 2 subplots per each yard. In total these parameters were measured only for the 50% of the felled trees, by tape measure.

The cycle times of the machines were divided into time elements (process steps) which were considered typical of this type of work. Work time was recorded for every single phase (Harstela, 1991; Savelli et al., 2010). In order to calculate outputs in different plots, effective times and delays in the work routine up to 15 min (CWT, complementary work time and DT, delays) (Magagnotti, Spinelli 2012; Picchio et al., 2009) were recorded.

Based on work time and volume, the productivity per worker for the different operations was calculated as: average gross productivity (PHS_{15}), measured on the basis of time consumption, inclusive of all delays up to the maximum event duration of 15 minutes; average net productivity (PHS_0), computed with the exclusion of delays.

The energy consumption analysis of machineries and tools and the human energy input were defined as reported by Picchio et al. (2009 and 2012a), according to the Gross Energy Requirements (GER) method only for the machineries. The change proposed provides the assessment of human energy input. This aspect is important in many production activities, where the manual labor has an important place, such as forestry activities with medium and low mechanization level. The indirect input (MJ m^{-3}) of machines and tools was determined by the average energetic values (MJ kg^{-1}) of raw materials in relation to: their quantitative presence (%) estimated and calculated on the basis of data reported by the respective manufacturers, the total mass of the machine (kg), the total service life of the machine (h m^{-3}), and the use of the machine in these