Available online at www.sciencedirect.com

SciVerse ScienceDirect

http://www.elsevier.com/locate/biombioe

Productivity and cost of biomass harvesting for energy production in coppice natural stands of *Quercus pyrenaica* Willd. in central Spain

Rubén Laina [a,*], Eduardo Tolosana [a], Yolanda Ambrosio [b]

[a] Universidad Politécnica de Madrid, ETSI Montes, Ciudad Universitaria, 28040 Madrid, Spain
[b] Universidad Politécnica de Madrid, EUIT Forestales, Ciudad Universitaria, 29040 Madrid, Spain

ARTICLE INFO

Article history:
Received 5 July 2011
Received in revised form
12 March 2013
Accepted 26 April 2013
Available online 5 June 2013

Keywords:
Quercus pyrenaica
Whole tree harvesting
Cut to length
Time study
Biomass
Diameter-based equation

ABSTRACT

Biomass growing stocks, harvesting productivity and costs of energy production, were studied in thinnings of Quercus pyrenaica. Eleven forest sites were selected in coppices located in Castilla y León (Spain). Three systems were employed for harvesting: a mechanised whole tree harvesting (WTH) system, which included chipping at landing; a fully mechanised cut-to-length (CTL) harvesting system for firewood; and a semi-mechanised CTL system with manual felling and bunching. Three WTH trials had a hauling off 34.7–44.1 oven-dried tonnes (odt) ha^{-1}. In contrast, only 11.6–30.0 odt ha^{-1} were obtained in the other eight CTL trials. Biomass weight equations for stems and whole trees were fitted. Worker operations were time-studied using software designed by the authors. The WTH system reached maximum productivity rates of 3.9 oven-dried tonnes per productive hour (odt h^{-1}) for the felling and bunching operation and 6.9 odt h^{-1} for the forwarding operation. The mechanised CTL harvesting method achieved a productivity range of 1.3–0.5 odt h^{-1} for the harvesting operation. Furthermore, the average forwarding productivity was 7.3 odt h^{-1}. Motor-manual felling and crosscutting in the CTL system accomplished a productivity range of 0.7–1.9 odt h^{-1}. Manual bunching resulted in similar values. The lowest firewood unit cost for trees with 10 cm of diameter at breast height (DBH) was 62.0 € odt^{-1} using a semi-mechanised CTL system. Under similar conditions, this cost was 85.2 € odt^{-1} for the mechanised CTL system. Finally, the cost corresponding to chips at landing from WTH sites (average DBH = 10 cm) was 65.3 € odt^{-1}.

1. Introduction

The Spanish Renewable Energy Plan (2005–2010) [1] has finished. This plan tried to increase renewable energy (RE) production rate of total primary energy production (4.77×10^{12} MJ) from 6.3% in 2005 to 30% in 2010. Bioenergy was an important part of the plan's goal. Currently, there are only 648 MW generating capacity installed [2] in biomass power plants; however, the plan had aimed to reach 1317 MW by 2010. The objective remained unaccomplished despite government subsidies for electricity production from forest residuals (0.11 € kWh^{-1}) and from forest woody crops (0.16 € kWh^{-1}) [3]. According to the RE National Action Plan 2011–2020 [4], renewable energies accounted for 9.4% of primary energy consumption in 2010, 132,000 Mtep, whereas the goal for 2020 is 20.1%. Regarding electricity production, RE

* Corresponding author. Tel.: +34 913367128; fax: +34 913366386.
E-mail address: ruben.laina@upm.es (R. Laina).
0961-9534/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.biombioe.2013.04.016

accounted for 24% of total Spanish electricity (21,410 Mtep) production in 2010, whereas the objective for 2020 is to reach a 36% contribution. Similarly, biomass and biogas are intended to grow at a yearly rate between 7.0% and 12.6% during the period 2009–2020. Measures fostering the energy use of forest and agricultural products or residues, in addition to woody crops, are aimed at producing an additional consumption of 5.5×10^6 tonnes of biomass per year. To achieve this aim would require tremendous efforts to mobilise all biomass sources, including woody biomass. In particular, the government of Castile and León approved a regional bioenergy plan in 2010 [5] with the goal of collecting 1.5×10^6 tonnes of biomass per year from biomass harvested in 60,000 ha of regional forests in the next 10 years. This Plan predicts 1.300 new employs will be generated [5].

Coppice areas of *Quercus pyrenaica* represent 64% of the total area covered by this species, which is 659,000 ha in Spain; moreover, half of this total surface lies within Castile and León [6]. In addition, the management of these coppices is one of the greatest problems faced in forestry research in Spain. In the past, the only silvicultural treatment, and forest management, was the traditional firewood harvesting. Stands were divided in parts and each 20–30 years a clear-cutting was performed in each part to obtain wood for combustion or making charcoal. After clear-cutting a subsequent shoot or root regeneration occurred. Over the last 50 years this activity was progressively abandoned because of rural emigration to the cities and the introduction of fuel heating in household [7]. The budget for forest administration is insufficient to perform an alternative forest management in high density coppices needed to avoid diseases, reduce forest fire risk or promote the health and growth of stands. New markets that increase the demand for forest biomass would enhance the development of new forest management systems or, alternatively, would update traditional treatments with new technologies and/or systems.

Here, we present the results of a time study of three different biomass harvesting systems: a mechanised whole tree harvesting (WTH) system followed by chipping at landing; a mechanised cut-to-length (CTL) harvesting system to produce firewood; and a motor-manual option for felling and manual bunching CTL. The hauling off was performed in every case by forest forwarders (Table 1). There are few references about the productivity of forest harvesting in Spain, and none of them focuses on this kind of forest [8–10].

In practice, WTH is a rarely used system for roundwood or biomass harvesting in Spain. However, it is widely used for harvesting biomass from small trees in selective thinning; mainly multi-tree harvesters followed by forwarders are used in Nordic countries [11,12] and North America [13]. In southern European countries, only a few articles in the local literature mention WTH applied to coppices [14]. Spinelli et al. [15] studied WTH followed by forest cable crane hauling off applied to beeches (*Fagus sylvatica*) with 15–30 cm of diameter at breast height (DBH). This study was conducted in mountainous stands and compared motor-manual versus mechanised processing. For *Quercus* or other natural coppices, the application of WTH has not yet been investigated, with some exception, for example a study on Italian *Robinia* and *Platanus* spp. with a different typology, i.e., linear coppices [16].

The CTL system is often adopted by local companies in Spain that mainly use short log lengths (2.0–2.5 m) of *Eucalyptus* pulpwood and young pine artificial stands; however, it is also used for firewood from *Quercus* or other hardwood forests. However, there are no published local references regarding the application of CTL systems to coppices.

Several articles explore non-conventional harvesting systems for collecting firewood in the mountainous conditions of southern European countries. In northern Italy, the hauling off firewood and the productivity of manual CTL system operations were measured in several silvicultural interventions with different methods [17]: sliding on terrain, using polyethylene chutes, skidding with winch-equipped farm tractors and hauling off with light to medium-sized cable cranes. The costs ranged from 111 to 143 € per green tonne.

Gallis [18] summarised the result of hauling off unevenly aged beech stands using mules compared with extracting trees with a mini-skidder ("iron-horse" type). A CTL system was chosen for small diameters from 10 to 20 cm. The results of that study always favoured the use of mules because they

Table 1 – Experimental design. Summary of stands, systems and machinery.

Sites	Work System	Felling and bunching (and also processing in CTL)	Forwarding	Chipping
WTH1 WTH2 WTH3	Whole tree harvesting system	Timberjack 1070 harvesting head 745 Accumulating arms	Timberjack 1410 forwarder	Pezzolato 900/1000 truck mounted drum chipper
CTL1 CTL2 CTL3 CTL4	Fully mechanised cut-to-length system	Timberjack 1270 C Harvesting head H270	Valmet 910 forest forwarder	No chipping (firewood)
CTL5 CTL6 CTL7 CTL8	Motor-manual felling and processing cut-to-length system	Husqvarna 359 and 372 chainsaws	Valmet 860.3 forest forwarder	No chipping (firewood)