Study performance of a new coppice harvesting system

<u>Guest researcher</u>

Dr. Giovanni Aminti
CNR-IVALSA
Via Madonna del Piano, 10
I-50134 Sesto Fiorentino, Italy
email: aminti@ivalsa.cnr.it

<u>Host institution</u>

Prof. Eduardo Tolosana
Universidad Politecnica de Madrid – UPM
ETSI Montes, Ciudad Universitaria s/n
E-28040 Madrid, Spain
email: eduardo.tolosana@upm.es

Short Term Scientific Mission held from 19th March to 15th April 2017

Read and approved by the host institution UPM

Madrid April 20th, 2017

Signature EDUARDO TOLOSANA

SUMMARY

1. Introduction

For what concern forest operations, the deployment of appropriate equipment and work systems for the specific forest type is crucial for the economic sustainability of the whole supply chain (Enache et al. 2015). This is even more important in the case of coppice forests, where the low size of stems require the use of specific solutions and machinery both for the economic (Spinelli et al. 2009) and environmental sustainability of the operations (Laschi et al. 2016). In general terms, a higher mechanization level leads to a higher productivity and lower unitary costs for woody products from coppice forests (Laina et al. 2013). Moreover The increase of mechanization level in forest operations contributes in reducing both the risks and the frequency of accidents and/or occupational diseases (Bell, 2002). For all these reasons, further mechanization is desirable. Nevertheless, harvesting of coppice forests is technically and economically difficult, because of the small stem size and the occurrence of multiple stems on the same stump. One of the main problems seems to remain the capacity of a harvester head to approach stems growing in a clump (Schweier et al. 2015).
In the specific case of the Spanish Castile & León Region, forests and other wooded areas cover more than 50% of total surface area. Forest area has increased by 41% during the past 20 years and this is the most important region in Spain in terms of growing stock (153.7 M m^3). The extraction rate in the region's forests (balance between felling and increment) is about 20% and the demand for wooden biomass is recently increased. Furthermore mechanization level is very low in hardwood stands (fig. 1).

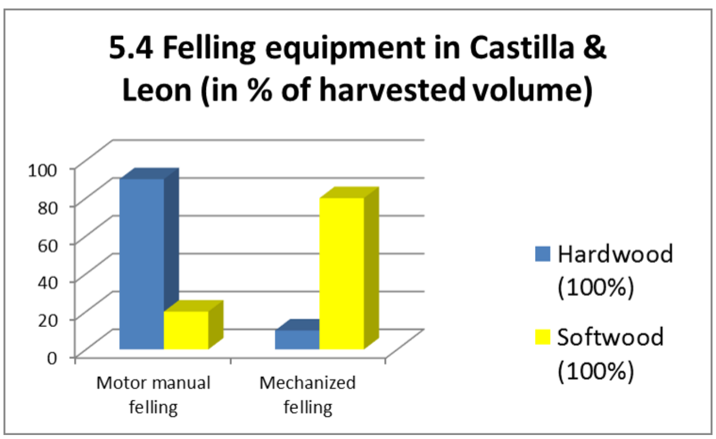


Figure 1: felling equipment in Castile & Leon Province (Spain).
Source: EU FP7-KBBE SIMWOOD Project, 2016

2. Purpose

This STSM aimed at studying new coppice harvesting systems in terms of productivity, fuel consumption, costs and work quality. In particular, the goal of this STSM was to provide detailed data about the performance of two different harvesting machines applied to coppice stands and to define the main parameters affecting productivity. Such parameters may be related to the physical characteristics of the stand (slope, terrain roughness) or/and to the forest characteristics (tree species, age, stump density, stems per stump, average diameter, basal area, etc.). Furthermore, differences in working method or harvest intensity may influence the productivity of the same machine.

3. Methods and activity locations

This study focused on a holm oak coppice forest with a surface of 100 hectares located close to the city of Palencia (Castile and Leon Province). The treatment applied was a selective thinning. The experimental design was based on coupled plots, each coupled plot represent a repetition of the two machines (fig. 2). The orography of the study site was homogeneous: in fact the forest is located in a flat area with an altitude of 800 m a.s.l.

The first stage of analysis included the stand survey, the detailed study of machines work-cycles, the evaluation of stand parameters, the positioning of the first two coupled plots and some tree measurements. In addition, we carried out a time-motion study for the first machine and we evaluated the damages to soil, stumps and standards. This was meant to test the preliminary measurement protocol and to arrange it, when needed, for the study of the following plots.

The office work was based at the Technical University of Madrid (UPM), however most part of the STSM was dedicated to the fieldwork.

4. Data collection

This task can be further divided in three sub-tasks:

a) Plot positioning, plot marking and stand measurements

The plots were located using a GIS software with the aim of including different stands features. Therefore we selected areas with different canopy cover using an ortophoto.

Each plot was reached using a portable GPS and all the corners were materialized with wooden stakes.

We marked 6 coupled plots, each emi-plot was a 25x25 m square. Than the diameter at breast height (DBH) of all trees was measured.

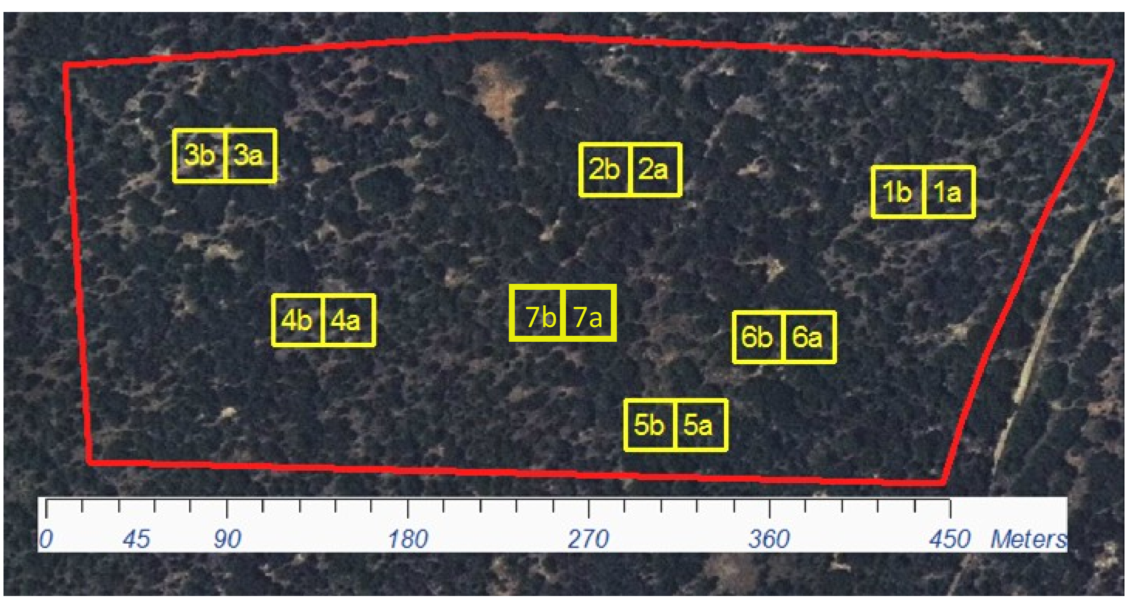


Figure 2: location of the first 7 coupled plots. The emi-plot with letter "a" and "b" were linked, respectively, to the heavy feller buncher and to the lighter feller buncher.

b) Time-motion study

In the proposed work plan it was expected to study two different feller-buncher machines with different size and weight. Within the STSM period it was possible to analyze only one of those, the heavier feller-buncher. We decided to harvest with this machine all the emi-plots with the letter "a".
However we studied also the extraction and the chipping phases. Each processing cycle was stop watched individually, using Husky Hunter hand-held field computers running the dedicated Siwork3 time study software (Kofman 1995). A cycle was defined as the time to process a single bunch, a single forwarder trip and a single chip load, respectively, for felling-bunching, extraction and chipping. Productive time was separated from delay time.

Figure 3: Time-motion study of the heavy feller-buncher

c) Post-harvest inventory, analysis of damages and other trees measurements

For each plot, post-harvest inventory was carried out in order to assess the amount of harvested trees and basal area. Moreover the damages on each standard were assessed. Damages on stumps and soil were evaluated on a circular area with the radius of 4 meters placed in the center of the plot.

5. Overview of collected data

The study is still ongoing. At the moment 7 coupled plot were marked, measured, time studied and damages on standards, stumps and soil were assessed. Furthermore 8 productive machine hour (PMH) of the heavy feller-buncher were studied in order to assess the influence of delays and the productivity in normal working conditions. Moreover 13 cycles of extraction with the forwarder and 4 cycles of chipping were analyzed.

6. Results based on the collected data

As the study is still ongoing, results are partial and some aspects cannot yet be analyzed. Anyway, from the collected data it is possible to draw the following provisional results:

- Regarding stand features, we observed a high variability both between plots and inside the plots (between the two machines). The values of trees per hectare ranged from 2 944 to 8 208, the basal area varied between 6.7 and 18.3 square meters per hectare (Table 1).
  The percentage of harvested basal area was also irregular and it ranged from 51% to 88%.
  Another uneven stand feature was the number of stumps per hectare that varied from 560 to 1408. However the average number of shoots per stump was quite homogeneous (Table 2).

plot		1		2		3		4		5		6		7	
machine		a	b	a	b	a	b	a	b	a	b	a	b	a	b
trees	n ha^{-1}	3984	5408	7040	5024	3456	2992	3488	2944	7856	8208	6000	7072	7920	4896
basal area	m^2 ha^{-1}	11.6	14.4	14.2	16.2	10.0	6.7	12	10.7	13.6	17.2	15.1	17.5	18.3	12.9
residual trees	n ha^{-1}	320	-	464	-	384	-	480	-	496	-	432	-	448	-
residual basal area	m^2 ha^{-1}	5.6	-	4.7	-	2.7	-	6.0	-	1.6	-	4.0	-	3.1	-
removal tree	%	-92	-	-93	-	-89	-	-86	-	-94	-	-93	-	-94	-
removal basal area	%	-52	-	-67	-	-73	-	-51	-	-88	-	-73	-	-83	-

Table 1 – Stand parameters before harvesting, post-harvesting and percentage variation for each plot.

plot		1		2		3		4		5		6		7	
machine		a	b	a	b	a	b	a	b	a	b	a	b	a	b
stumps	n ha^{-1}	816	1152	1152	560	608	608	736	560	1232	1248	992	1136	1408	688
shoots	n stump^{-1}	7.8	7.2	5.5	8.4	5.4	4.6	4.1	5.1	6.2	6.3	5.4	5.9	5.0	6.8

Table 2 – Number of stumps per hectare and average number of shoots per stump for each plot

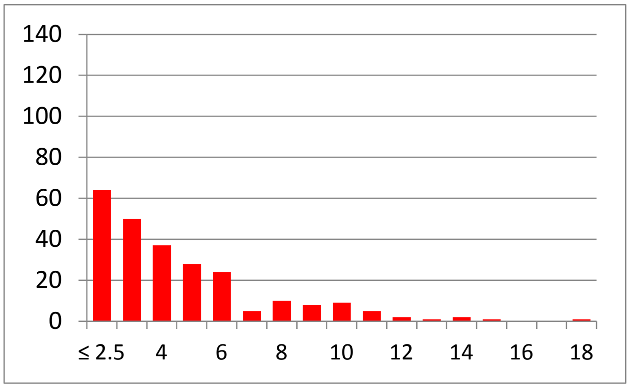
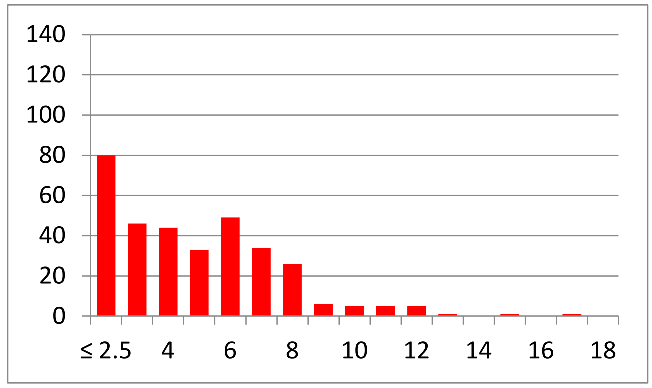
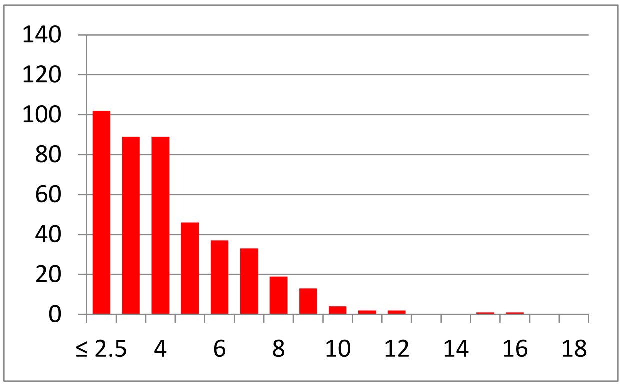
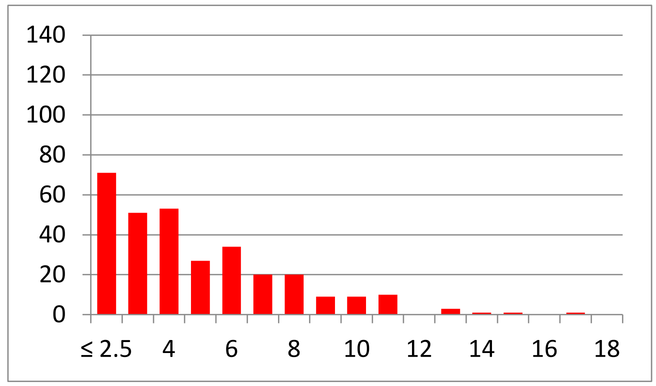
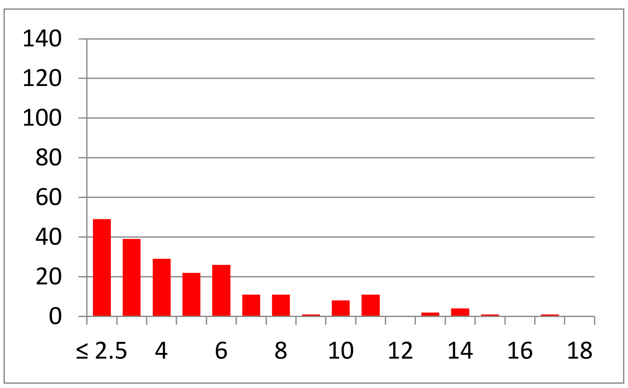
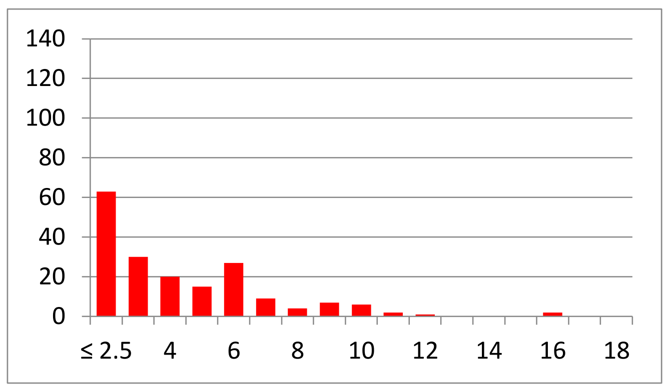
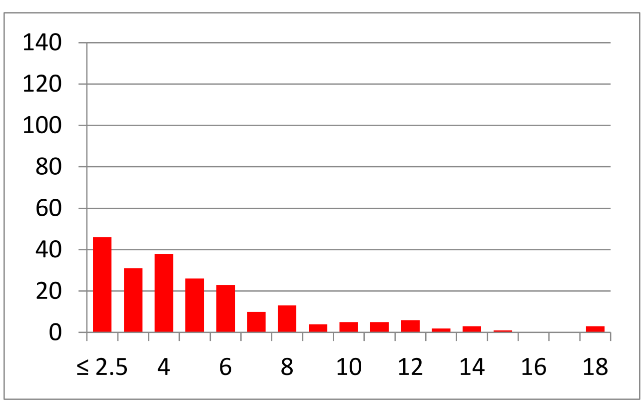
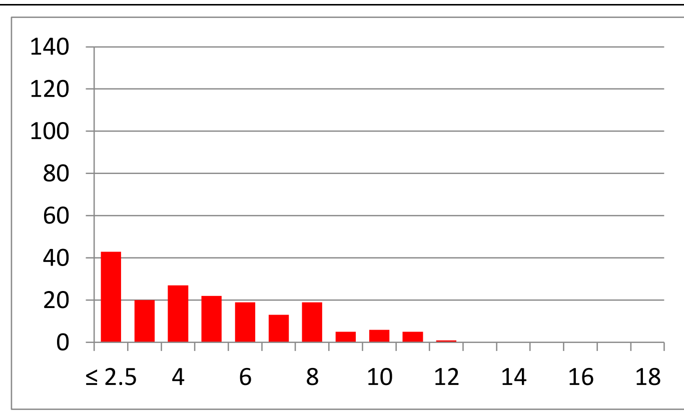
<table>
<tr><th>PLOT</th><th>MACHINE A</th><th>MACHINE B</th></tr>
<tr><td>1</td><td>
</td><td>
</td></tr>
<tr><td>2</td><td>
</td><td>
</td></tr>
<tr><td>3</td><td>
</td><td>
</td></tr>
<tr><td>4</td><td>
</td><td>
</td></tr>
</table>

Table 3a: Tree Frequency distribution among DBH classes per plot
y: number of trees per plot / x: DBH class [cm]

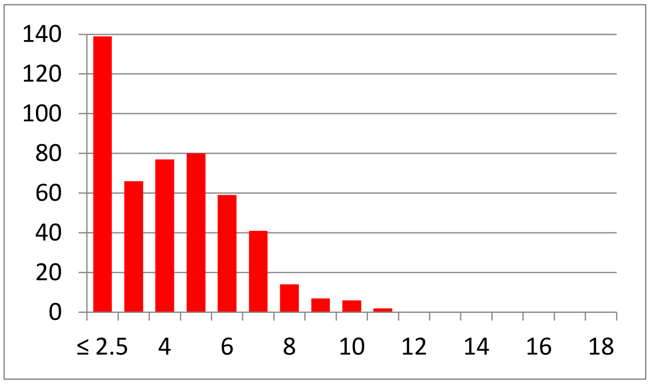
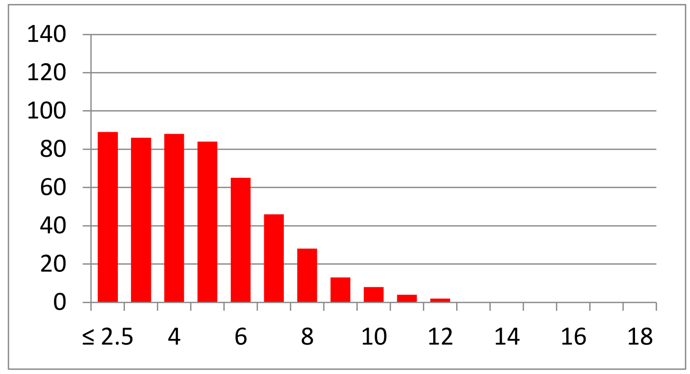
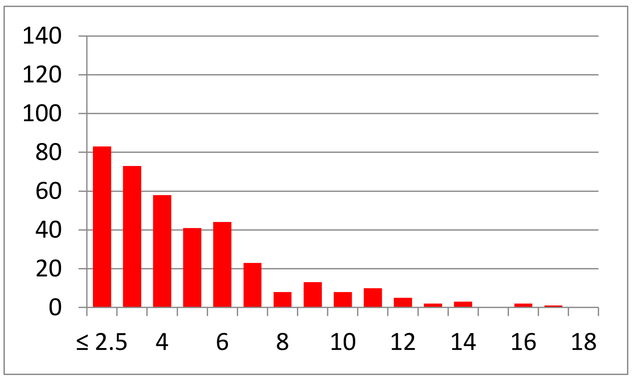
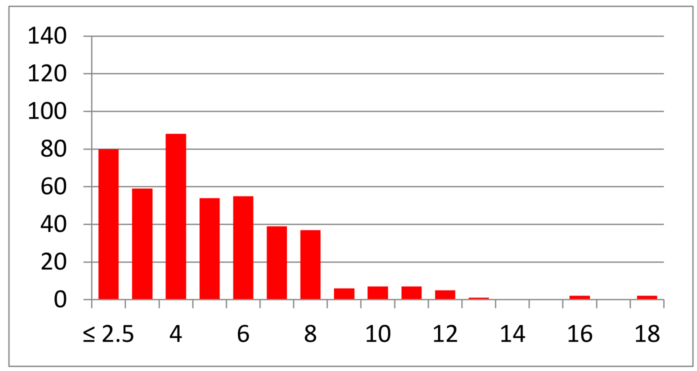
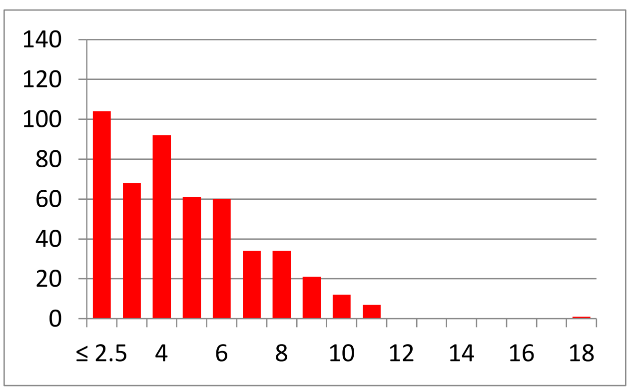
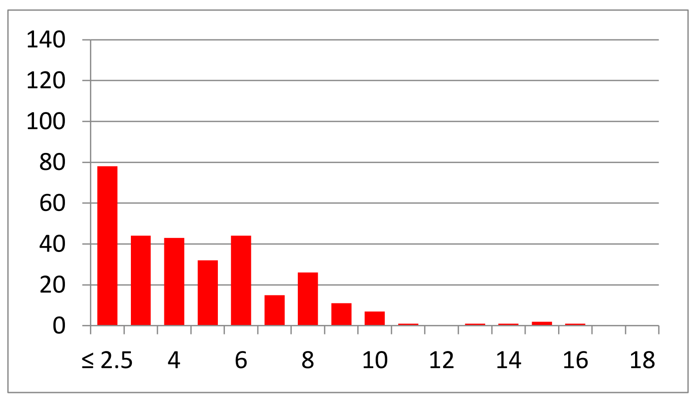
<table>
<tr><th>PLOT</th><th>MACHINE A</th><th>MACHINE B</th></tr>
<tr><td>5</td><td>
</td><td>
</td></tr>
<tr><td>6</td><td>
</td><td>
</td></tr>
<tr><td>7</td><td>
</td><td>
</td></tr>
</table>

Table 3b: Tree Frequency distribution among DBH classes per plot
y: number of trees per plot / x: DBH class [cm]

– The differences between stand features can be better explained by the tree frequency distribution among the DBH class (Table 3a-3b).
  Generally the majority of trees have a DBH lower than 8 cm and the diametric frequency distributions are similar to the young stand's one. We collected several samples of stem section from different plots in order to assess the stand age but this analysis is not yet carried out.

- DBH and height were measured from 50 felled trees sampled from every plot. The height ranged between 1.5 and 6.5 meters. Figure 4 shows the tree height-diameter relationship analysis, i.e. the hypsometric model. The already mentioned heterogeneity of stand features produced an evident scattering of height values that caused a weak coefficient of determination (R^2).

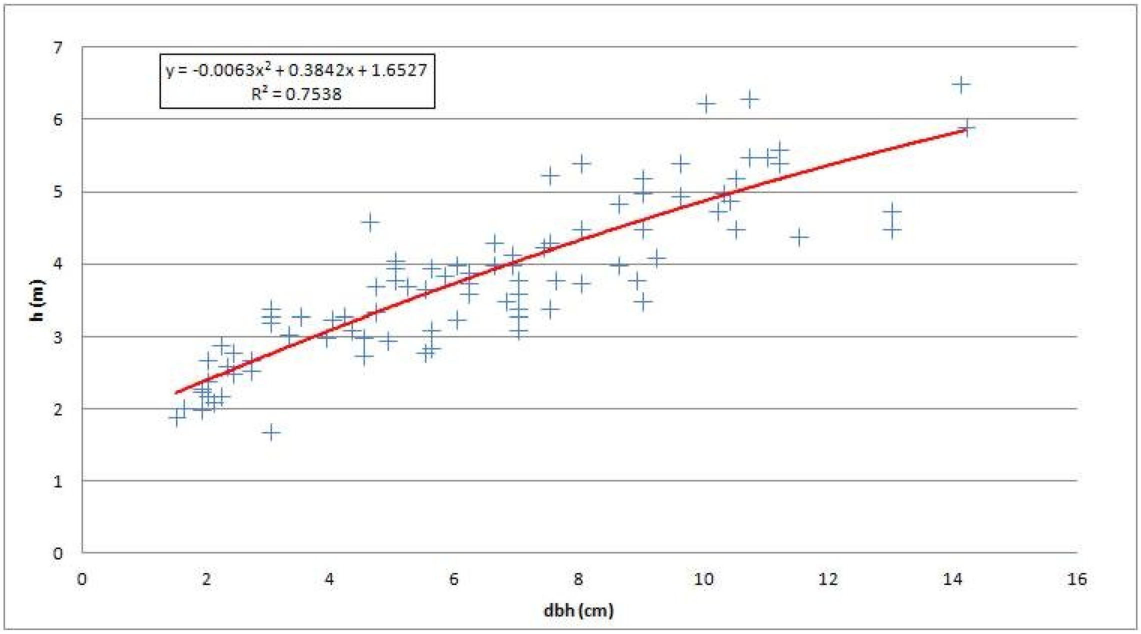


Figure 4: Hypsometric model

- In spite of all differences regarding stand features we were able to locate the plots in order to have a similar amount of basal area for the two feller buncher machines (table 4).

BASAL AREA (m^2 ha^{-1})		
plot	**machine**	
	a	**b**
1	11.6	14.4
2	14.2	16.2
3	10.0	6.7
4	12.1	10.7
5	13.6	17.2
6	15.1	17.5
7	18.3	12.9
TOTAL	**94.8**	**95.6**

Table 4: Pre-harvesting basal area per plot and per machine

– The main characteristics of the heavy feller buncher studied are shown in Table 5. In figures 5 and 6 the plot are ordered following the criterion of stand density: the plot 1, 4 and 3 were defined as low density both for basal area value and for having clearings. The time-motion study while felling the experimental plots provided the following results: felling and bunching occupied from 39 to 58% of productive time, while moving and piling accounted both for an additional 19-27%. Cleaning, that means cutting brush, occupied from 0.3 to 7.3% of time (Figure 5).

feller buncher		
producer	-	John Deere
model	-	643J
power	kw	130
weight	kg	12 696
felling head		
model	-	FD45
cut capacity	cm	51
accumulating capacity	m^2	0.64
weight	kg	2 200

Table 5: Main characteristics of the machine "a" on test (heavy feller buncher)

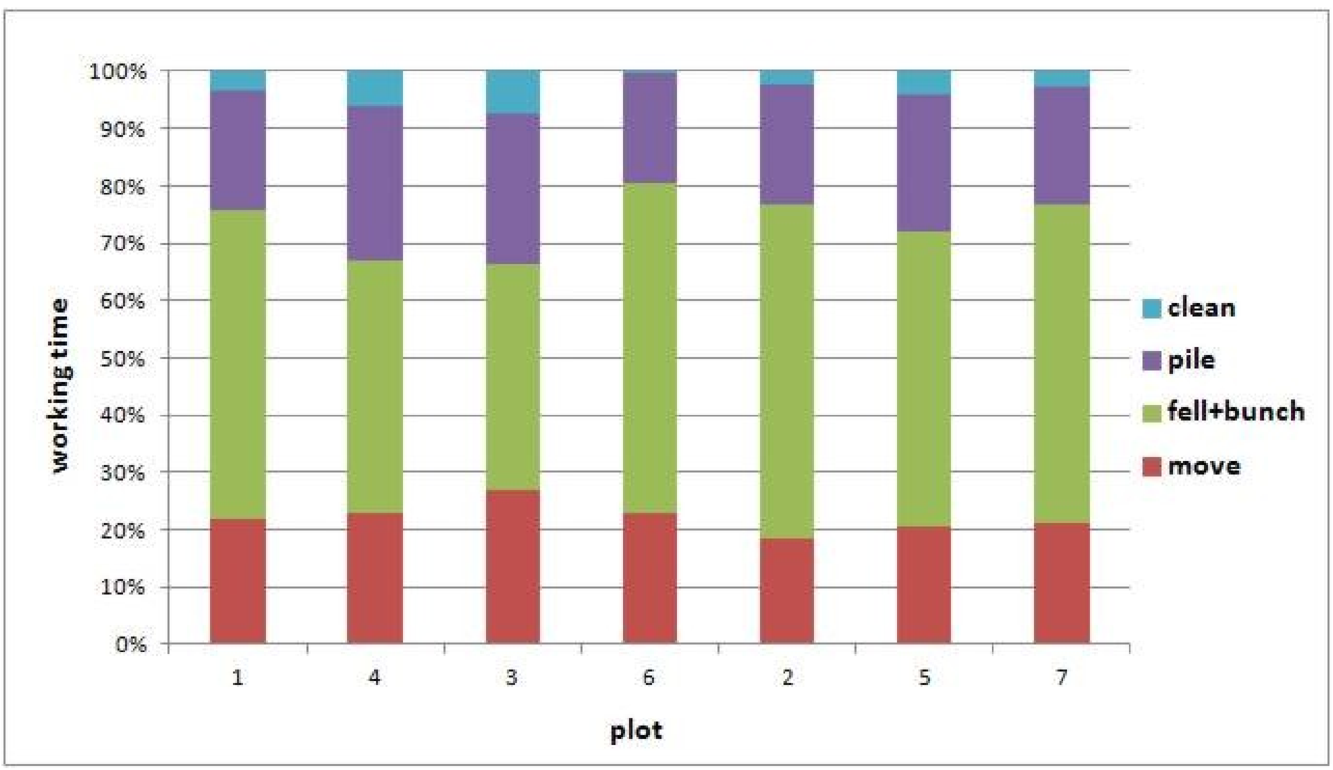


Figure 5: Percentage breakdown of productive time among different tasks, by plot.

Figure 6: Number of working cycles and number of felled trees by plot

- As expected, low density plots showed a lower number of cycles and a lower number of felled trees. In every plot all felled trees were separately extracted and chipped, this allow to assess the productivity using wood chip weight. After the chipping operation one sample for each plot was collected to assess the moisture content. The productivity of the felling and bunching operation ranged between 2.6 and 4.8 odt h^{-1} (oven dry tons per productive hour). The delays were mostly absent from the felling time of the plot, this occurred because the felling time varied between 25 and 54 minutes. For this reason we decided to carry out a time-motion study for the heavy feller buncher working in normal conditions. Overall the working time outside the experimental plots amount to 8.6 PMH (productive machine hour), 650 cycles and 102 bunches produced. The delays, including daily maintenance activity, accounted for a 10.1% of the total time. The productivity reached 3.2 odt h^{-1}.

7 Conclusions

Holm oak coppice stands can yield up to 55.3 odt ha^{-1} in terms of wood chips and represent an important source of wood raw material in Spain and in other Mediterranean countries. The productivity of mechanized felling reached 3.7 odt h^{-1} and 3.2 odt h^{-1} respectively inside the experimental plots and in normal work condition. Those values are similar to the results obtained in similar mechanized felling studies on *Quercus spp*. coppice stand in Spain (Laina et al. 2013). This study succeeded finding high variability in terms of stand features and will develop a preliminary productivity and cost model based on this. During this STSM were prepared and analyzed also the 7 plot needed for studying the lighter feller buncher. Despite of the high irregularity of coppice stand the total amount of basal area that will be harvested from the two machines will be very similar.

The study was relatively wide and time consuming, particularly for plot marking and trees measurements. For this reason, the STSM was meant to provide the basis of starting the study but not for completing. As anticipated in the work plan, the collaboration between CNR-IVALSA and the Technical University of Madrid will continue and once the second machine will arrive the remaining part of the data collection will be carried out.

9 Literature

Bell, J.L., 2002. Changes in logging injury rates associated with use of fellerbunchers in West Virginia. J. Safety Res. 33, 463–471.

Enache A, Kühmaier M, Visser R, Stampfer K. 2015. Forestry Operations in the European Mountains: A study of current practices and efficiency gaps. Scandinavian Journal of Forest Research [Internet]. 7581:1–39. Available from: http://www.tandfonline.com/doi/abs/10.1080/02827581.2015.1130849

Kofman, P., 1995. User Guide. Danish Forest and Landscape Research Institute, Vejle, Denmark, 37 pp.

Laina R, Tolosana E, Ambrosio Y. 2013. Productivity and cost of biomass harvesting for energy production in coppice natural stands of Quercus pyrenaica Willd . in central Spain. Biomass and Bioenergy. 6:1–9.

Laschi A, Marchi E, Gonzàlez-Garcìa S. 2016. Forest operations in coppice: Environmental assessment of two different logging methods. Science of the Total Environment. 562.

Schweier J, Spinelli R, Magagnotti N, Becker G, 2015. Mechanized coppice harvesting with new smallscale feller-bunchers: Results from harvesting trials with newly manufactured felling heads in Italy. Biomass and Bioenergy 72, 85-94.

Spinelli R, Magagnotti N, Lombardini C. 2009. Performance, Capability and Costs of Small-Scale Cable Yarding Technology. Small-scale Forestry [Internet]. [cited 2014 May 28]; 9:123–135. Available from: http://link.springer.com/10.1007/s11842-009-9106-2