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DISC SAW FELLER-BUNCHER PRODUCTIVITY ANALYSIS IN A HOLM-OAK (*Quercus ilex*) COPPICE BIOMASS HARVESTING OPERATION IN CENTRAL SPAIN

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CASTILLA Y LEÓN COPPICES

- **In this central Spanish Region, forests cover > 50%** of total surface, increased by 41% in the past 20 years, with the greater growing stock in Spain (153.7 Mm^3). **Fellings are only 20% of growth**, while **the demand of woody biomass and pulpwood is strongly increasing**.
- **Mechanization is very low in hardwood stands**, less than 15% (SIMWOOD Project Reports, 2016). **Coppices are very frequent**, most abundant Species: holm oak (*Quercus ilex*) and deciduous oak (*Quercus pyrenaica*).
- The Spanish forest public Company SOMACYL has begun in 2017 **field trials of mechanized felling in these Species' coppices,** using as base machine a **John Deere 643J (130 kW, 12,7 t) with a felling head JD FD45 ($ø_{Max}$ = 51 cm, 0,64 m^2 of accumulation capacity and weight = 2,2 t.)**


JOHN DEERE

- The studied stand is a **holm oak (*Quercus ilex* L.) dense coppice**, with average initial density of **5.250 trees/ha, average dbh around 6 cm** and average height of 4 m.

- The **treatment consists on a 68% average reduction of basal area, leaving 450 standards per ha** (reducing the number of trees in around 90% from their original density).

STUDY MAIN GOALS

- **Characterizing the coppice felling operations performed regarding their dasometric conditions.**

- **Developing a height equation and a dry weigh table to facilitate the future evaluation of similar stands.**

- **Evaluating the productivity of the felling operation through a factorial study, trying to identify the main factors affecting productivity and to develop productivity predictive equations.**

- **Estimating the cost range of the harvesting operations, including whole trees extraction, chipping and chip transport, under the studied conditions.**

MATERIAL AND METHODS (I)

- **Pre and Post harvest inventory**

  - **Nine 25x25 m^2 permanent plots** randomly distributed. **Prior to harvesting all dbhs were measured and the plots limits marked**.

  - **The treatment was performed around the plots prior to the time study** → the machine worked in close-to-real conditions within the plots.

  - **After felling, 10 dbh – height pairs and 3-4 weight-dbh-height were measured, besides moisture sampling**. **The remaining stand was measured** (all dbhs).

- **Dasometric characterization, height-dbh equation and weight table.**

  - **Treatment conditions obtained by inventories comparison**. **Height-dbh equations and dry weight tables fitted**.

MATERIAL AND METHODS (II)

- **Time study and production evaluation**

  - **Felling and bunching cycles** (bunch=cycle) were **recorded using a Husky Hunter hand-held field computer** with Siwork3 time study software. **Total, productive and delay time of all the cycles on each plot was recorded**.

  - To measure the production, **the forwarder piled the whole trees from each plot separately**. After chipping it, was **weighted and sampled for determination of moisture** content.

  - **A whole day forwarding shift was time-studied** to get an estimation of **productivity and cost**.

  - To assess the operational costs, **as the machines were hired, the actual hourly renting cost – or the unit cost** paid for chipping and chip transport - were used as references**.**


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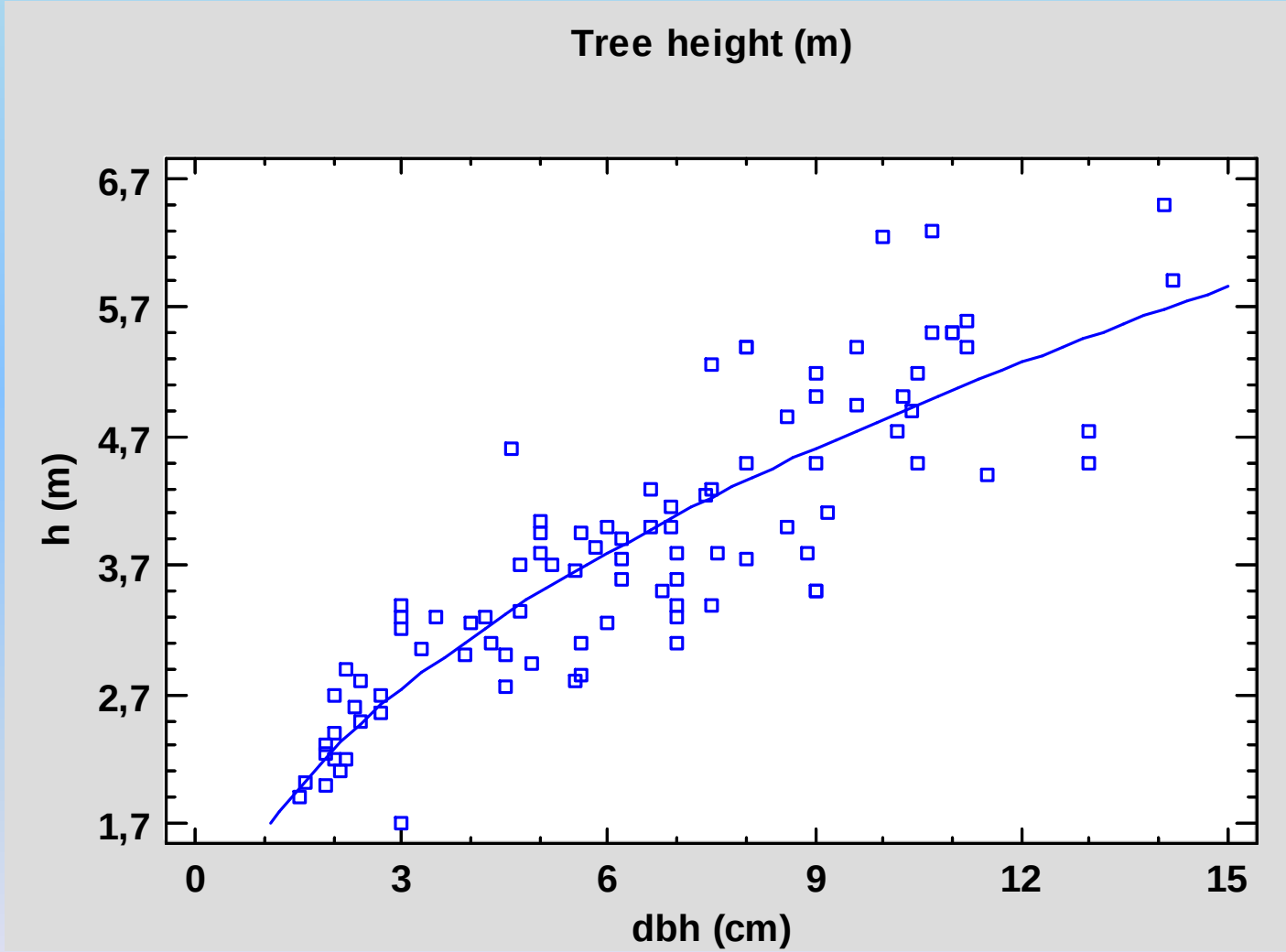
RESULTS AND DISCUSSION: DASOMETRIC CHARACTERIZATION

PLOT	density pre-harvesting	basal area pre-harvesting	density post-harvesting	basal area post-harvesting	Δ % trees felled	Δ% extracted basal area
units	tree ha^{-1}	m^2 ha^{-1}	tree ha^{-1}	m^2 ha^{-1}	% Initial nr	% initial BA
1	3984	11,6	320	5,6	-92	-52
2	7040	14,2	464	4,7	-93	-67
3	3456	10,0	384	2,7	-89	-73
4	3488	12	480	6,0	-86	-51
5	7856	13,6	496	1,6	-94	-88
6	6000	15,1	432	4,0	-93	-73
7	7920	18,3	448	3,1	-94	-83
8	5344	17,5	560	6,7	-90	-62
9	2224	7,3	400	2,6	-82	-65
AVERAGE	5256,9	13,3	442,7	4,1	-90,4	-68,3

Dasometric conditions of the studied coppice plots.

The **extracted biomass weight** from the chipped whole trees ranged **between 29,1 and 77,1 fresh tonnes · ha^{-1} (average 48,7 fresh tonnes·ha^{-1}**). Having into account the chips' moisture – as an average, 25,7% on humid basis – **the whole tree chips dry weight ranged between 21,6 and 55,8 odt·ha^{-1} (the average was 36,1 odt·ha^{-1}).**

RESULTS AND DISCUSSION: HEIGHT – DIAMETER CURVE



Height – dbh equation for Holm Oak coppice

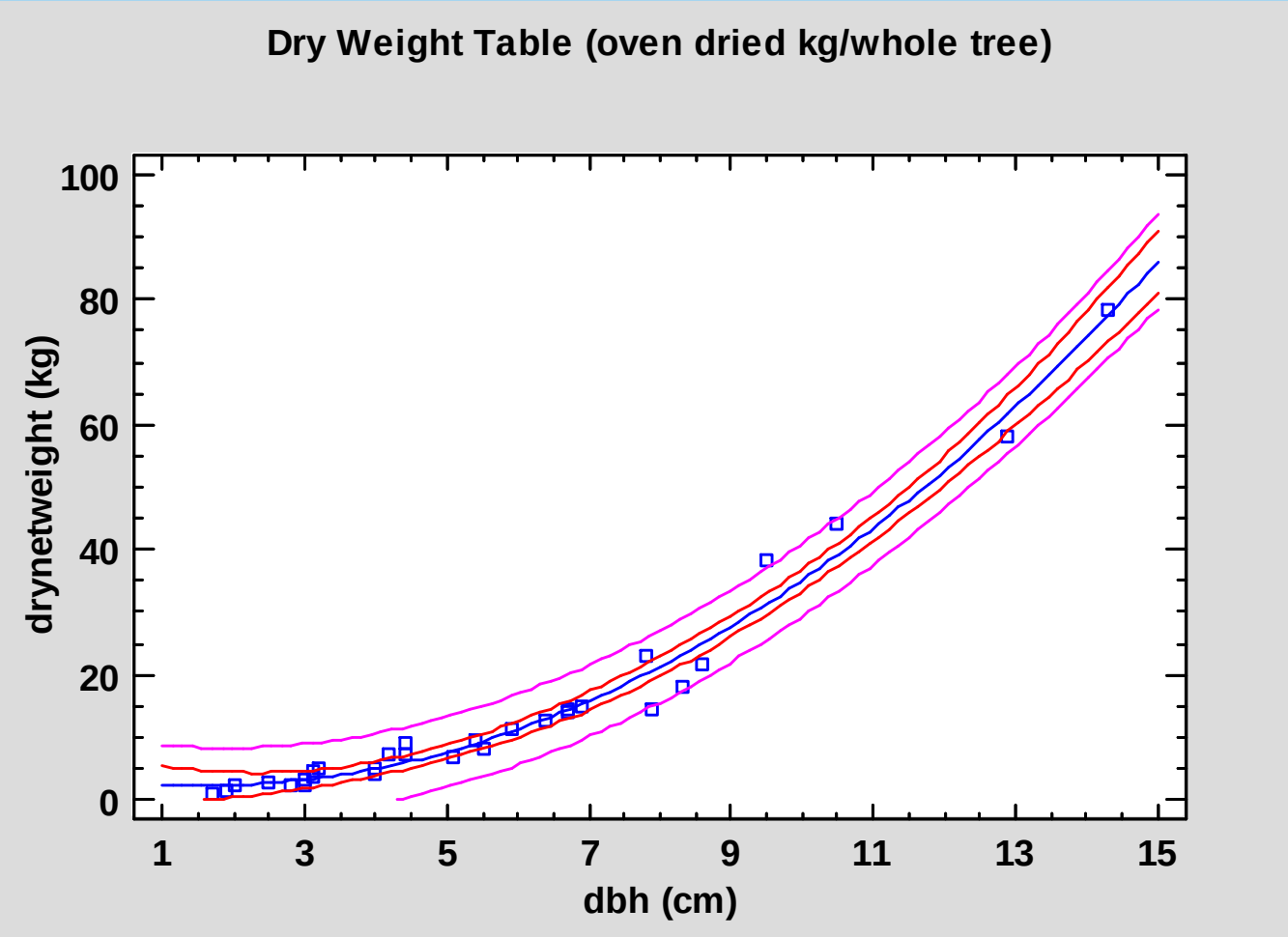
N = 93 trees

Fitted Model: **Height (m) = 1,64•dbh(cm)^{0,47}**

R^2 (adjusted by d.f.) = **74,8 %**

Absolute average error = **0,42** (average absolute value of residues, m)

RESULTS AND DISCUSSION: DRY WEIGHT TABLE



Dry Weight – dbh equation for Holm Oak coppice

N = 30 trees.

Fitted Model: **Weight (oven dry kg/whole tree) = 3,59-1,536·dbh(cm)+0,469·dbh(cm)^2** (2)

Height was not significant as predictive variable

R^2 (adjusted by d.f.) = **97,7 %**

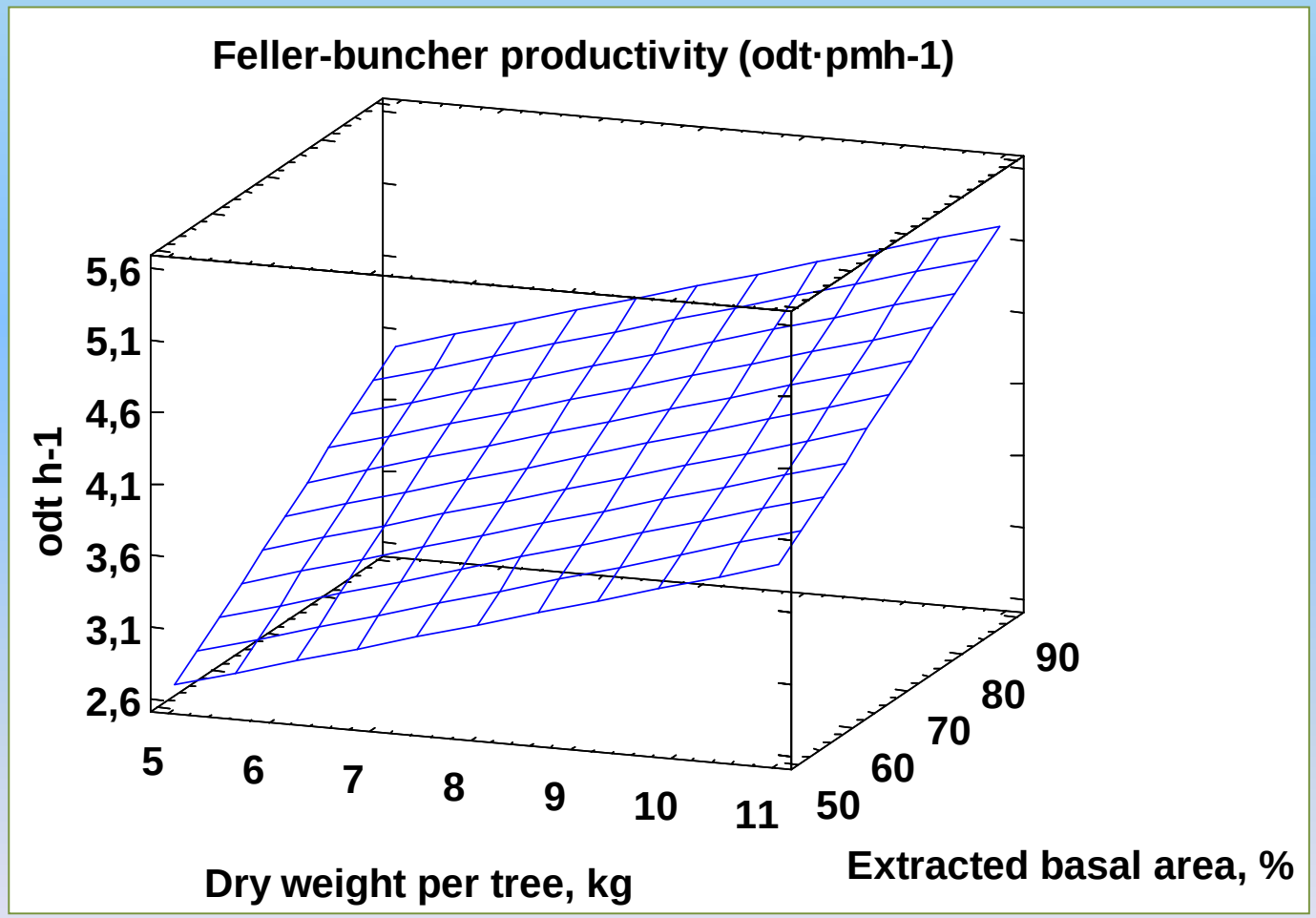
Absolute average error = **1,73 (average absolute value of residues, dry kg)**

RESULTS AND DISCUSSION: TIME STUDY

- Productivity of FELLING AND BUNCHING inside the experimental plots ranged between 2,66 and 4,85 odt•pmh^{-1} (Average productivity = 3,8 odt•pmh^{-1}). Besides these studies, a time-motion assessment in normal conditions **outside the plots** was carried out during an entire shift (8,60 pmh). This **"NORMAL CONDITIONS" PRODUCTIVITY = 3,18 ODT·PMH^{-1}**. **Delays** = **10,1% of total time**, including daily maintenance.

- WHOLE TREES FORWARDING was performed with a John Deere 1910E (power = 186 kW, weight =19 t and load capacity = 19 t), equipped with a **press collector Dutch Dragon PC-48** (weight = 3,7 t.). Time studied during a complete shift (8,67 pmh) → **PRODUCTIVITY = 6,99 ODT•PMH^{-1}**. **Delays = 12,2 % of total time**, including daily maintenance.

RESULTS AND DISCUSSION: FELLING AND BUNCHING PRODUCTIVITY MODEL



Productivity model for feller-buncher in the studied holm-oak coppice.

Fitted Model: **Productivity (odt·pmh^{-1}) = 0,0333·%ExtrBA + 0,202·DW(kg·tree^{-1})** (3)

R^2 (adjusted by d.f.) = **80,5 %**

Absolute average error = **0,23 (average absolute value of residues, odt·pmh^{-1})**

RESULTS AND DISCUSSION: COSTS ESTIMATION

Given the average moisture of the chips of 21,7% (humid basis) and assuming that the utilization coefficient (pmh/smh) = 0,9, the average unit costs are reflected in the Table. The total direct unit cost would be 66,6 €/odt. If this cost is increased by 15% (indirect and fixed costs), **the average unit total cost will equal 76,6 €/odt of chips unloaded in the power plant.**

Operation	Renting hourly cost (€/smh)	Renting hourly cost (€/pmh)	Average productivity (odt/pmh)	Average unit cost (renting, €/fresh tonne)	Average unit cost (€/odt)
Felling and bunching	**90**	100	3,18	**----**	**31,45**
Forwarding	**71,5**	79.4	6,99	**----**	**11,36**
Chipping	**----**	**----**	**----**	**11,0**	**14,05**
Chip transport (dist=80 km)	**----**	**----**	**----**	**7,66**	**9,78**
Total (direct costs)	**----**	**----**	**----**	**----**	**66,64**
+ 15% indirect and fixed costs	**----**	**----**	**----**	**----**	**76,64**

Average operational unit costs, based on renting costs.

RESULTS AND DISCUSSION: UNIT COST VARIATION

Regarding the influence of the identified felling productivity factors on this cost, if we correct the productivity equation (3) using the ratio between the average productivity in normal conditions and the average productivity inside the studied plots (3,18/3,84 = 0,83), the new productivity equation would be:

$$\textbf{Productivity (odt·pmh}^{-1}\textbf{) = 0,0276·\%ExtrBA +0,168 ·DW(kg·tree}^{-1}\textbf{)} \quad \textbf{(4)}$$

And the unit cost of feller-buncher:

$$\textbf{Unit cost (€/odt) = 100/[0,0276·\%ExtrBA +0,168 ·DW(kg·tree}^{-1}\textbf{)]} \quad \textbf{(5)}$$

RESULTS AND DISCUSSION: UNIT COST VARIATION

Comparing the two worst and best plots (minimum and maximum tree size and % of extracted basal area), the results are:

Observed conditions	Dry weight per tree (o.d. kg)	% basal area extracted	Felling & bunching unit cost (€/odt)	Rest of unit costs (€/odt)	Total unit cost (incl 15% of indirect and fixed costs), €/odt
Worst plot (Plot1)	**6,17**	**52**	**40,5**	**35,19**	**87,04**
Best plot (Plot 3)	**10,25**	**73**	**26,8**		**71,29**

Maximum and minimum coppice biomass harvesting unit cost in the observed conditions.

The **increase in felling and bunching direct unit cost from the best observed conditions to the worst ones is 51% (same as the increase in productivity** from the worst to the best observed conditions). **The correspondent total cost would increase a 22%.**

CONCLUSIONS (I)

- **Productivity of the disc saw felling head tested in traditional coppice forest in Spain is comparable with other studied operations in Mediterranean coppices, even slightly better** given the smaller dimensions of the trees – average **dbh around 6 cm** – and/or the **selective treatment**.

- **A height-dbh curve and a dry weight table, both with dbh as independent variable have been developed** for this kind of common coppices in Central Spain, providing a tool for estimating biomass production in such stands.

- **Feller and bunching productivity has been analyzed**, identifying as the **main affecting factors the unit dry weight of the extracted trees and the percentage of extracted basal area**, so the productivity grows with stem size and if the felling is less selective. **A productivity model has been developed**.

- **Between the observed stand conditions, the estimated felling productivity grows a 51%** from a stand with Dry weight per tree = 6,2 kg and %ExtrBA=52% to another with Dry weight per tree = 10,3 kg and %ExtrBA = 73%.

CONCLUSIONS (II)

- **The analysis of the unit costs**, based on the renting cost of the machines and the transport cost to a power plant located at 80 km from the coppice forest, and considering a 15% of indirect and fixed costs, **gives estimations between 71,3 and 87,0 €/odt of chips delivered to the plant (average for the studied coppice conditions of 76,6 €/odt)**. This cost is **greater than the present market prices, so subsidies may be needed, at least in the smaller unit volume stands and more selective treatments**.

- **The main possibilities to improve the operational cost-efficiency may consist on using a lighter disc saw feller-buncher** (the one used is oversized for the felled trees dimensions), **self-managing the operations – instead of renting the machines - and of course reducing the transport distances**, greater than the recommended for forest biomass.

- **Further tasks to complete the harvesting analysis are the short-term quality and environmental effects analysis** (data already recorded) **and the mid-term study of results of the mechanization regarding regeneration and stand health**.

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Thank You for your Attention!

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