Comparation of two harvesting methods for bioenergy thinning in Mediterranean pine forests

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Summary

Mediterranean forests in Valencian Region are continuously growing but remain mainly unmanaged. Bioenergy market is offering a leverage to mobilise untapped potential helping to prevent and reduce forest fires. Despite the existent knowledge on wood harvesting, there is a lack of practical knowledge about best methods for bioenergy. The objective of this study is to compare thinning harvesting methods in a 60 years old reforestation of *Pinus halepensis* in a low timber stage for bioenergy uses. Time studies were performed over six plots of 0.25 ha in Navalón (Spain). Three plots were treated through the traditional long wood method combined with the logging of forest residues, “integrated system”, and three more through a “whole tree” system. Damage over vegetation and soil was recorded and compared. Time, productivity, fuel consumption and impact analysis were performed for both systems. Quality of woodchips assortments was determined in laboratory according to European standards. Time consumption and productivity were similar between integrated harvesting system and whole tree system. Fuel consumption, costs and damage degree were slightly higher in whole tree system due to the more intensive forwarding operation. The two assortments of woodchips from integrated system had a higher (EN Plus A2) and lower quality than whole tree woodchips (EN Plus B1). To diminish fuel consumption, cost and damages, integrated harvesting could be more recommended. Nevertheless, more research is needed to optimise bioenergy harvesting on Mediterranean areas.

1. Introduction

Following large reforestation programmes in Spain since 1950, extensive areas were reforested in public forests in the Mediterranean regions, especially between 1950 and 1970, mainly with *Pinus halepensis* for the production of quality timber. Nevertheless, there has been a continued lack of public forest management. Only 2% of the public forest has an active management plan in Valencian Region. The investment level in private forestry is very low due to the low reward that forest sector offers. So generally, forest stands lack of any silvicultural works (PATFOR, 2011). High tree density, strong declining of the radial tree growth and continuous accumulation of dried biomass result in a low valuable and very vulnerable stock with a high risk of forest fires (PROFORBIOMED, 2012).

Several forest development programmes have as main objective the energetic valorisation of residual forest biomass, understood as logs and branches under 22,5cm, as leverage for mobilising high quality biomass, for providing local employment in rural areas and for preventing large forest fires (PATFOR, 2011).

On the other hand, forest companies supplying roundwood mainly for sawmills and particleboard industries have low experience in producing chips for bioenergy (Life 07 BEST4VARIOUSE, 2011). Little research in forest harvesting has been performed and published. Real market prices, on one side, and real harvesting and logistic costs are actually unknown for forest owners and harvesting companies. Therefore, there is a need for a better knowledge of advanced harvesting technologies to produce woodchips in Mediterranean pine forests.

2. Objectives

The general goal of this research is to compare harvesting methods in a representative 60 years old reforestation of *Pinus halepensis* in a low timber stage for bioenergy uses. To achieve this goal, the research has following specific objectives:

1. To analyse two different harvesting methods: integrated wood-biomass and whole tree harvesting system
2. To analyse harvesting and logistic costs between forest and bioenergy plant
3. To analyse the assortment of woodchip quality in laboratory

3. Time study

3.1 Forest stand characterization and delimitation of plots

The selected representative stand was reforested in 1950 and any silvicultural treatment has been done since then. It is located in the forest district V074 Navalón/Enguera (38°55'10''N and 0°55'29''O). Six plots of 0,25 ha (50x50m) each have been selected by random sampling from an homogeneous forest stand of 4 ha. Descriptive forest data is shown in table 1. The average slope is 10% and the soil is classified as 2.2.1 (firm mineral soils, intermediate ground roughness with a gentle slope) according to Forestry Commission (1974).

Table 1. Forest inventory data

Average DBH (cm) ± SEM	20,05±1,86
Basal area (G, m^2/ha)	24,94
Density (trees/ha)	718
Volume (m^3/ha)	106,5
Average Tree heigh ($H_{0,}$ m) ± SEM	14,2±0.99
Hart-Becking Index (S)	28,23
Unitary volume (m^3/tree)	0,14
Average quadratic diameter (cm)	28,61

3.2 Case study planning and execution

Low selective thinning has been carried out with the same harvesting intensity (35% of the standing trees) over the six plots. The two harvesting techniques to be compared are the traditional long wood system combined with the extraction of logging residues (integrated system) and the whole tree system. Each system has three test plots assigned. The felling operations were made manually (Stihl chainsaw MS-261, 2,8kW). Extraction has been carried out by forwarder (Valtra-Hitraf A83, 88 CV) to a loading area located at maximum 800m distance and 40m height uphill from forest plots. Here, a semi-mobile chipper (Stark SH-4585, 385 CV) connected to a truck comminutes the biomass collected in three different piles at the forest road (logs, forest residues and whole trees). The chipping process was carried out four weeks after the forest work in order to air-dry the biomass with twofold objectives: on the one hand to obtain chips with lower moisture content and on the other hand to obtain chips with less fine material (especially needles and pinecones). The same company with the same staff and machinery has performed all harvesting processes.

Samples of the chipped material from the three different piles were separated and sent to the biomass laboratory of the Wood Research Institute AIDIMA.

3.3 Analyses

3.3.1 Time

The methodological approach for the time study followed is based in Magagnotti and Spinelli (2012). It is a comparative observational study at plot level. All time to harvest the plot was registered (manually with a stopwatch) and assigned to the different operations (felling, extraction and chipping) through a continuous time measurement. In the felling phase, the time for felling, delimbing and cross-cutting of the crown was registered together with fuel recharging and chainsaw sharping time. The extraction phase was measured at a cycle level registering the time consumed by forwarder loading, transport to the loading area, unloading time and unloaded transport back to the plot. The chipping phase was measured at a continuous time for each biomass pile. Mechanical, personal or organizational delay times are taken into account and registered. When no delays occur, 35% of delay time is assumed for gross calculations of time and productivity. Only one chainsaw followed by the forwarder worked simultaneously per experimental plot, for proper monitoring. Furthermore, the same operators have performed all test plots in order to avoid variability due to experience and working conditions.

3.3.2 Biomass yield and fuel consumption

Number of trees and biomass volume and weight at 45% moisture content were calculated per each plot and per hectare. In the felling, number and quantity of fuel and oil recharging has been registered. The forest company provided the forwarder and the chipper fuel consumption.

3.3.5. Productivity

The gross and net productivity of each harvesting phase (felling, forwarding and chipping, in t/h) has been calculated.

3.3.6. Damage over remaining vegetation, standing trees and soils

Remaining trees damaged are counted and the damage degree of damage of damaged part (bark of stem and branches or xylem of stem) estimated as mild, medium or severe. Each damaged part and grade have been assigned an increasing value of 1, 2 or 3 respectively. On the other hand, percentage of removed vegetation and percentage of plot surface soil damaged by forwarder tracking are estimated *de visu.*

3.3.7 Biomass quality assessment

Quality tests are performed over woodchip samples from biomass piles. The quality classification followed standard EN 14961.

3.3.8. Costs

Machine rates were calculated based on conventional costing methods (Miyata 1980; Arno and Masip, 2003) using personnel and machinery costs input from the harvesting company.

4. Results and discussion

4.1 Time and productivity per forest operation

Table 2 shows the main results of felling time and productivity per harvesting system. Results about felling time show, as foreseen, higher average time consumption (211 min) by the integrated system than the whole tree system (119 min). Nevertheless, fuel and oil recharge have approximately the same time percentage over the total time (12,4% and 11,9%, respectively). More significant are results comparing net productivity as it takes into account the biomass produced per unit of time. Net productivity of the whole tree system is in average 3,12 t/h. This mean value is higher than the integrated system (1,90 t/h), as this system requires further wood processing (delimbing). Nevertheless, a t-test analysis was carried out to compare productivity means between both systems and results show no significant differences for a confidence level of 95.0% (P value = 0.104) between whole tree and integrated harvesting system.

Table 2. Comparisons of time consumption and productivity of felling operations

Harvesting system	Test plot	nº trees	Biomass (t)	Felling time (min)	Fuel and oil recharge (min)	Net total time (min)	Gross total time (min)	Net prod (t/h)	Gross prod (t/h)
Whole tree	1	99	6,07	133,83	18,00	133,83	151,83	2,72	2,40
	2	94	6,11	137,00	20,00	137,00	157,00	2,68	2,34
	3	83	5,64	85,50	10,30	85,50	95,80	3,96	3,53
	Mean	**92**	**5,94**	**118,78**	**16,10**	**118,78**	**134,88**	**3,12**	**2,76**
Integrated	4	117	7,26	217,80	30,53	217,80	248,33	2,00	1,75
	5	89	5,87	188,00	23,50	188,00	211,50	1,87	1,67
	6	85	6,86	226,16	35,50	226,16	261,66	1,82	1,57
	Mean	**97**	**6,66**	**210,65**	**29,84**	**210,65**	**240,50**	**1,90**	**1,66**

The net felling productivity obtained for the integrated system (2,5 m^3/h) highly coincides with Ambrosio et al. (2005) that obtained 2,7 m^3/h for a manual selective thinning of a similar stand of *Pinus sylvestris* L. in Northern Spain.

Regarding forwarding, total loading time of felled trees inside the test plots was in average of 201 min for whole tree system and of 156 min for the integrated system. Number of cycles was bigger for whole tree system with an average of 4 times of displacement to loading area and 3 for integrated system. It shows that the loading capacity of the forwarder was reduced by the bigger volume occupied by the whole tree and therefore less load transported in each cycle. Tolosana et al. (2013) show similar results with a Timberjack 1410 and a Dingo, demonstrating that the critical factor is the volume instead of the machine loading capacity.

The time of transport loaded is quite similar (33 min for whole tree system and 24 min for integrated system). The slight differences could be explained due to the speed reduction of the forwarder with bigger load in the case of integrated system. Unloading time is very similar

(36 min and 32 min respectively). Finally, a clear difference can be appreciated in the time of transport unloaded from landing area. This may occurs due to despite a similar speed in both systems when the forwarder is empty, whole tree system has more cycles done.

Table 3. Comparisons of time consumption and productivity of forwarding

System	Test plot	Loading time (min)	Transp. loaded (min)	Unloading time (min)	Transp. Unload. (min)	nº cycles	Dist. (m)	Net time (min)	Gross time (min)*	Net prod (t/h)	Gross prod (t/h)*
Whole tree	4	213,16	36,00	33,06	27,77	4	800	309,99	418,49	1,17	0,87
	5	192,63	33,40	30,06	27,32	4	700	283,41	382,60	1,29	0,96
	8	197,90	28,50	43,50	19,00	4	700	288,90	390,02	1,17	0,87
	Mean	**201,23**	**32,63**	**35,54**	**24,70**	**4**	**733**	**294,10**	**397,04**	**1,21**	**0,90**
Integrated	1	105,00	20,00	23,00	17,00	2	850	165,00	222,75	2,64	1,96
	3	174,90	28,50	34,90	19,50	3	750	257,80	348,03	1,37	1,01
	6	188,54	24,33	38,32	17,32	3	750	268,51	362,49	1,53	1,14
	Mean	**156,15**	**24,28**	**32,07**	**17,94**	**2,7**	**783**	**230,44**	**311,09**	**1,85**	**1,29**

*assuming of 35% of delays

Integrated system has a significant higher net productivity (1,85 t/h) than a whole tree system (1,21 t/h), what can be translated as a bigger productivity of integrated system of 1,52 times more than whole tree system. The bigger apparent volume occupied by the branches of the whole trees in comparison to the loading of tree logs and logging residues could explain this. These are quite low productivity rates and they differ from higher productivities from Tolosana et al. (2013) that obtained 10,2 t/h for the Timberjack and 3,2 t/h for the Dingo forwarder. Nevertheless, it has to be noticed that in this present work neither forest residues nor whole trees and logs were arranged along a forest track, and that the forwarder had to go selectively from one tree to another.

Moreover, the higher forwarding productivity obtained with the integrated harvesting system coincides with Heikkilä et al. (2006), who state that the forwarding of delimbed logs without crowns has a higher productivity than forwarding whole trees.

Again, a t-test analysis was carried out in order to compare forwarding productivity means between both systems. The results show no significant differences between whole tree and integrated harvesting system for a confidence level of 95.0% (P value = 0.253).

Finally, regarding the chipping productivity, the forest company provided one time for each system. Therefore, data available are total net productivity of whole tree system (17,8 t/h) and total net productivity of integrated harvesting (16,6 t/h). Results show a higher productivity of whole tree system. This can be explained as the chipper didn't need to displace from one pile to another. Tolosana *et al.* (2013) obtains a closer productivity (14 t/h) for the chipping of branches and tops piled up in the landing area.

4.2 Biomass yield and fuel consumption

Table 4 shows the main results for the comparison of biomass yield and fuel consumption between the two analysed systems.

Table 4. Comparisons of biomass yield and fuel consumption

			Consume				
System	**Test plot**	**Biomass yield (green t/ha)**	**Chainsaw (l/t)**	**Forwarder (l/t)**	**Chipper (l/t)**	**Total litres per tonne (l/t)**	**Total litres per ha (l/ha)**
Whole tree	4	24,27	0,42	3,76	1,12	5,30	21,21
	5	24,46	0,42	3,41	1,12	4,95	19,80
	8	22,56	0,22	3,77	1,12	5,11	20,45
	Mean	**23,76**	**0,35**	**3,64**	**1,12**	**5,12**	**20,49**
Integrated	1	29,04	0,65	1,67	1,21	3,53	14,11
	3	23,50	0,58	3,23	1,21	5,01	20,06
	6	27,44	0,65	2,88	1,21	4,74	18,96
	Mean	**26,66**	**0,63**	**2,59**	**1,21**	**4,43**	**17,71**

The obtained average value of green biomass yield for integrated system is slightly higher than for whole tree system (23,76 t/ha). Nevertheless, the t-test analysis shows no differences statistically significant for a confidence level of 95.0% (P value = 0.213).

Average fuel consumption by the chainsaw in integrated system (0,63 l/t) almost duplicates the whole tree system (0,35 l/t), being these differences significant (P value = 0.046) for a confidence level of 95.0%. This can be explained by the further processing (delimbing) needed in the integrated system. For the forwarder, the obtained fuel consumption data are not significantly different (2,59l/t for integrated and in 3,64l/t for whole tree system with a P value = 0.148 for a confidence level of 95.0%). Also the fuel consumption of the chipper is similar (1,21 l/t for integrated and 1,12 l/t for whole tree system) and no differences can be appreciated. As total consumption, the whole tree system consumes 5,12 l/t in front of 4,43 l/t of the integrated harvesting system. Therefore, chainsaw fuel consumption is the critical factor for a higher or lower fuel consumption in these harvesting systems.

4.5. Damages over remaining vegetation, standing trees and soil

The analysis of damages on remaining standing trees, removal of vegetation and soil shows a slightly higher environmental impact of the whole tree system in comparison to the integrated harvesting system. So, damage degree over remaining trees is 8,7% higher in whole tree system. It can be explained due to the wider space of manoeuvrability needed by the forwarder.

Table 5. Environmental impact comparisons between whole tree and integrated harvesting system

Harvesting system	**Test plot**	**Removed vegetation (%)**	**Soil damaged (%)**	**Remaining trees damaged (%)**	**Damage degree**
Whole tree	4	60	10	12	31
	5	40	10	12	20
	8	50	13	19	45
	Mean	**50**	**11**	**14**	**32**

Integrated	1	30	5	9	22
	3	40	7	15	29
	6	30	5	9	20
	Mean	**33**	**6**	**11**	**24**

4.6 Biomass quality

Biomass quality depends on the fraction analysed. Results of chips obtained from the whole tree harvesting system show that the obtained material can be classified as EN PLUS B1 chips. In the case of chips from integrated harvesting there are two different qualities: EN PLUS A2 for log chips (if they could be dried up to 35% moisture content) and the rest that does not pass the EN quality tests due to a slightly bigger content of ashes than allowed (3,24%).

Table 6. Comparisons of biomass quality of chips from whole tree and integrated harvesting system

Harvesting System	Origin of chips sample	Particle size (mm) EN 15149	Moisture content (% od weight) EN 14774	Ash content (%, od weight) EN 14775	Net calorific power (MJ/Kg) EN 14918	Quality EN 14961
Whole tree	Whole tree	P31,5	41,00	2,00	17,53	ENPLUS B1
Integrated	Stem	P31,5	45,18	1,09	17,59	ENPLUS A2
	Branches	P31,5	38,13	3,24	17,27	-

4.7 Costs

Assuming a transport with a multi-lift truck from the forest landing area to a bioenergy plant located 40km away, the unit cost in the whole tree system (75 €/t) is slightly higher than in the integrated harvesting system (63 €/t). Table 7 shows that the major cost factor is the forwarding operation followed by the manual chainsaw felling. The lower productivity of forwarding in the whole tree system is compensated by the higher felling productivity. These values are within the ranks estimated by the European project ENERSILVA (2007) of 45-91€/green tonne for logging and transport cost of biomass in Spain. Also Frühwald (2007) estimates that the cost of chips from logging residues are lower than those of the chips coming from whole tree harvesting in Central and Northern Europe.

Table 7. Comparisons of harvesting costs of whole tree and integrated harvesting system

Harvesting system	Forest operation	Hourly cost (€/h)*	Effective working time (h/t)	Gross productivity (t/h)	Unit cost(€/t)
Whole tree	Felling	25	0,32	3,12	8,01
	Forwarding	53	0,83	0,90	58,89
	Chipping	79	0,06	17,79	4,44
	Transport (40km to plant)	73	0,05	22	3,32

	Total				**74,66**
Integrated	Felling and delimbing	25	0,53	1,90	13,09
	Forwarding	53	0,54	1,29	41,40
	Chipping	79	0,06	16,55	4,77
	Transport (40km to plant)	73	0,05	22	3,33
	Total				**62,59**

**As result of fixed and variable cost plus industrial profit and overheads (calculated as 6% and 8% of hourly operating cost respectively)*

5. Conclusions

The main conclusions of the research are:

a) In general terms, productivity is similar between an integrated harvesting system and a whole tree system in thinning operations in *Pinus halepensis* low timber forests.

b) Total harvesting costs are slightly higher in whole tree system due to the more intensive forwarding operation. Nevertheless, it has to be considered that with bigger forwarders these costs could be reduced. Additionally piling up forest residues and alignment of logs or whole trees along forest tracks could increase forwarding productivities and reduce costs.

c) It has to be taken into account that productivity and costs may vary considerably from company to company. Also, experimental trials are normally more cost-intensive than real working processes. Derived from own experiences, productivities will increase with bigger harvested areas and higher biomass productivities per hectare.

d) Depending on regional market prices of the different chip quality assortment, one or the other system will be more convenient. Generally, obtaining two qualities of chips as in the integrated harvesting system, the total revenues could be higher. Only this could justify the processing (delimbing) of the logs and the separated piling and chipping.

e) To diminish damages over soil, biodiversity and remaining trees, integrated harvesting could be more recommended. Nevertheless, further research continued in time is needed to obtain ultimate conclusions to estimate damage extent and environmental impact.

f) Finally, more research is needed to optimise harvesting and logistic processes for each forest stand type in the Mediterranean area, taking into account the limited technology level of the forest companies, the lack of structure of the bioenergy value chain and lack of previous forest management, especially in private forests.

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