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FIRST THINNING IN A CONIFEROUS PLANTATION FOR BIOMASS PRODUCTION: PRODUCTIVITY AND COSTS

Stefano Verani[1], Giulio Sperandio[2], Rodolfo Picchio[3]

[1]CRA-PLF,
Via Valle della Questione, 27
Roma, Italy
e-mail: stefano.verani@entecra.it

[2]CRA-ING,
Via della Pascolare, 16
Monterotondo (Roma), Italy
e-mail: giulio.sperandio@entecra.it

[3]UNITUS-DAF,
Via S. Camillo de Lellis
Viterbo, Italy
e-mail: r.picchio@unitus.it

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Abstract: *This paper deals with the study of mechanized yard for the thinning of a coniferous plantation (Pinus halepensis and pinaster). The systematic selective thinning was adopted with a 50% trees removal. The final product was chips for energy use. The machines used were: one harvester for trees felling and bunching, one agricultural tractor with log grapple for trees extraction, one forest loader and one forwarder with chipper for trees chipping. The gross productivities for felling and bunching was of 23.4 t/h, for skidding 21.7 t/h and for chipping 46.5 t/h. The cost per unit of mass product (chips) was about 14.94 €/t. Considering the stumpage (10.00 €/t), the transfer machines (2.09 €/t) and transport (13.00 €/t) the total production cost of chips was 40.03 €/t. The results, compared with a market price of the chips 50.00 €/t, underline the light economics sustainability of thinning.*

Introduction

The positive role of thinning in enhancing the stability and growing of plantation, and to reduce the exposure to fire hazards, is well known (Ciancio, 1986; Piussi 1986; Bianchi *et al.,* 2010). Unfortunately at the moment the low value of the traditional products resulting from first thinning of coniferous plantation (saw logs for pallets and billets for the pulping industry) and the harvesting costs, contribute to increasing abandonment of such beneficial silvicultural practice (Malinen et al. 2001; Yeo, Stewart, 2001; Bergström et al., 2007; Heikkila et al. 2007; Savelli et al., 2010). The new market of biomass for energy, very important to contrast the greenhouse effect, and the diffusion and employment of the high mechanization in the thinning operations are two reasonable aspects to carry out the thinning (Verani and Sperandio, 2005; Spinelli et al., 2006; Spinelli et al., 2007; Cavalli and Bergomi, 2006; Fabiano and Piegai, 2007; Spinelli, 2009; Verani, 2009).
Resorting to advanced mechanization often involve substantial investment and above all accurate planning of intervention, not even justified by the resulting high productivity in first thinning (Mederski, 2006; Savelli et al., 2010).

Full Tree System (FTS) was adopted as working method since it guarantees levels of productivity that justify the economics of the intervention, even if it causes a greater loss of organic substance from the forest (Heikkila et al. 2007; Savelli et al., 2010).
The main objective of the research was to determinate, in technical-economic and environmental terms, the sustainability of thinning operation, the high degree of mechanisation (advanced mechanization) using, to produce the biomass for energetic use.

Materials and methods

The study was conducted on a pine stand, 24 years old, located in the Latium region in the Rome district (Figure 1).

Figure 1. Plantation before the thinning

The stand was a coniferous young high-forest (*Pinus halepensis* Mill. and *Pinus pinaster* Ait.). The planting pattern was square with a 3 m between the trees. The type of thinning is mixed with systematic elimination of one row out five and selective elimination of the four standing rows' worst trees. Before the logging many parameters (average diameter at the breast height - DBH -, average height, average weight) of the plantation tree were determined. The characteristics of the stand were described in Table 1**.**

Table 1 Description of experimental stand

Description of the stand	
Place	Rome
Surface (ha)	2.40
Slope gradient (%)	15
Elevation (m a.s.l.)	35
Species	*P. halepensis , P. pinaster*
Age	24
Density (trees/ha)	906
Characteristics of the thinning	
Type	mixed
Intensity (% number)	50
Removal (tree/ha)	453
Average DBH (m)	0.21
Average height (m)	18
Average weight (t)	0.422
Wood characteristics (chips)	
Bulk density (kg/mst)	418.6
Moisture content (%)	50.9

The machines used were: one harvester for trees felling and bunching (Figure 2), one forest loader for trees bunching, one agricultural tractor with log grapple (Figure 2) for skidding, one forwarder with chipper for trees chipping (Figure 3).

Figure 2. On the left side the harvester at work, on the right side the agricultural tractor with forestry log grapple

Figure 3. Chipper during the work

The forestry operators were two. The work system applied was the *Full Tree System* (FTS) and the final assortement chips. During the logging operations the working time was recorded. The cycle times of the machines were divided into time elements (working phases) that were considered typical of the work.
For felling and bunching the time elements were: *positioning*, begins when the machine to approach the tree and ends when the machine head is resting on a tree; *felling*, begins when the felling cut start and ends when the tree touch the ground; *bunching*, begins when the tree touch the ground and ends when the tree is dropped onto the stack of trees.
For skidding the time elements were: *trip without load* begins when the tractor releases the load at the landing and ends when the tractor arrives at the logging area; *positioning*, begins when the tractor approaches the trees to charge and ends when the load is finished; *loading* begins when the loader starts to charge the trees on the grapple of tractor and ends when the trees are loaded; *trip with load* begins when the tractor leaves the logging area and ends when the tractor is arrived at the landing; *unloading* begins when the tractor stops at the landing and ends when the load is released at the ground.

For chipping the time elements were: *positioning* is the time necessary to the trailer truck to approach the chipper; *chipping* is time during which the chipper produced the chips; *moving* the time necessary at the trailer truck and chipper to approach the stack of trees. For all operations the *delay,* the time not related to productivity work (e.g. repairing or maintenance of the chipper; personal breaks), was also recorded.

Machine costs were calculated considering coefficients and mathematical formulas of the main methodologies proposed by different authors (Baraldi and Capelli, 1973; Biondi, 1999; Hippoliti, 1997; Miyata, 1980; Ribaudo, 1977). Further details on cost calculation were reported in Table 2.

Table 2. Main technical and economic elements employed to calculate the hourly machine costs

Description	Unit of measure	Timberjack 1270 C Advance	Chipper Eryo on Forwarder	Loader OP T80	Massey Ferguson 6490	Log grapple
Purchase price	€	380,000	520,000	127,000	90,000	5,000
Salvage value	€	84,094	115,076	20,786	19,917	818
Life time	years	10	10	12	10	12
Annual employment	hours	1,200	800	600	1,000	200
Power	kW	173	440 (+118)	132	136	
Interest rate	%	5	5	5	5	5
Fuel consumption	liter/hour	15	35	13	13	
Lubrificant consumption	liter/hour	0.6	1.4	0.52	0.52	
Space of replacement	m^2	35	45	23	25	10
Driver cost	€/hour	23	23	15	15	
Fuel cost	€/liter	1.04	1.04	1.04	1.04	

The cost of the manpower (considering the rate of all social costs) was 23 €/h for the driver of the harvester and the chipper and of 15 €/h for the driver of the forest loader and the tractor with log grapple. The cost of the fuel was referred to July, 2009.
The influence of the skidding distance and the transported load on the skidding cycle time was assessed by a regression of the type $T = A + Bx + Cx_1$ where T was the total gross time per skidding cycle; A constant; B and C coefficients of variables and x and x_1 respectively the skidding distance and the load transported. Experimental data for felling concerning 224 trees; for skidding 46 trips and for chipping 10 trailer trucks.

Results and discussion

The average gross time for felling and bunching the tree was 1.08 minute with the average gross productivity per man of 23.4 t /h. The gross time for skidding cycle was expressed by the equation $T = 8.79 + 0.011\, x + 0.61\, x_1$, $R^2 = 0.570$, 46 observations.
The average skidding distance and load transported were respectively 442 m (range 190 m to 710 m) and 6.33 t (range 4.22 to 10.50 t). The average gross time for trip was 17.51 minutes with a gross productivity of 21.7 t/h. Table 3 and Figure 1 shows respectively the variation of total gross time for skidding cycle and the productivity as a function of the skidding distance and the load transported.

Table 3. Total gross time (minutes) for skidding cycle as a function of transported load and skidding distance

Skidding distance (m)	2.5 t	5 t	7.5 t	10 t
100	11.42	12.94	14.47	15.99
200	12.52	14.04	15.57	17.09
300	13.62	15.14	16.67	18.19
400	14.72	16.24	17.77	19.29
500	15.82	17.34	18.87	20.39
600	16.92	18.44	19.97	21.49
700	18.02	19.54	21.07	22.59

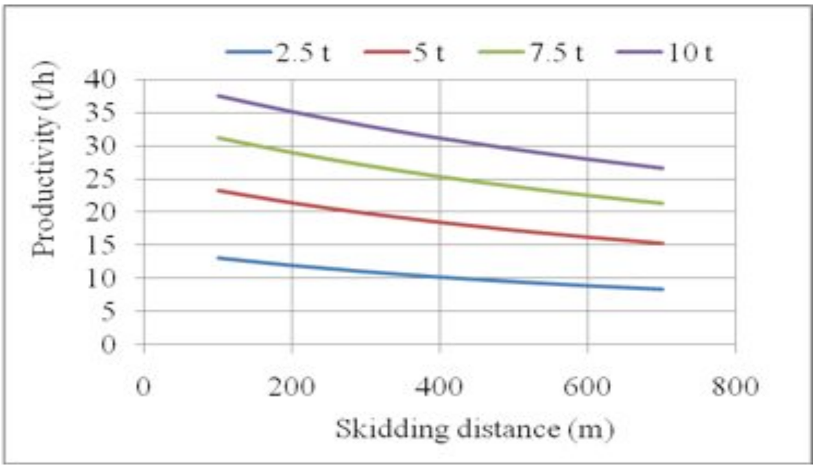

Figure 1. The productivity as a function of the skidding distance and the load transported

The chipping average gross time for loading one trailer truck (29 t) was 37.41 minutes getting an average gross productivity of 46.5 t/h.
The percentage of time elements of the felling, skidding and chipping are presented in Figure 2.

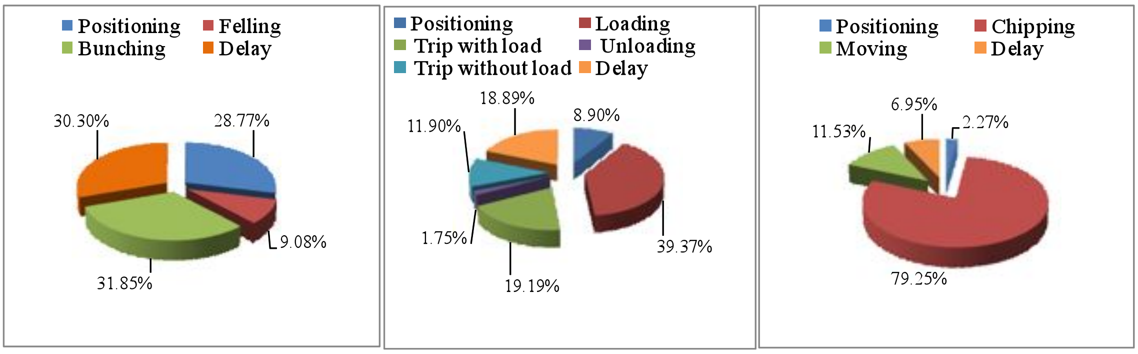

Figure 2. Percentage of time elements in the felling, skidding and chipping

In Table 4 are shown the total hourly machine costs calculated and in Figure 3 the percentage of the single cost elements of the yard is reported.

Table 4. Costs analysis of the machines. The total costs including the manpower cost

Description	Unit of measure	Timberjack 1270 C Advance	Chipper Eryo on Forwarder (Tbj 1100)	Loader OP T80	Massey Ferguson 6490	Log grapple
Annual fixed costs	€/year	49,866.58	70,494.24	14,517.78	11,371.21	648.93
Hourly fixed costs	€/hour	41.56	88.12	24.20	11.37	3.24
Hourly variable costs	€/hour	66.31	114.93	47.57	41,83	1,21
Total costs	**€/hour**	**107.87**	**203.05**	**71.77**	**53.20**	**4.45**

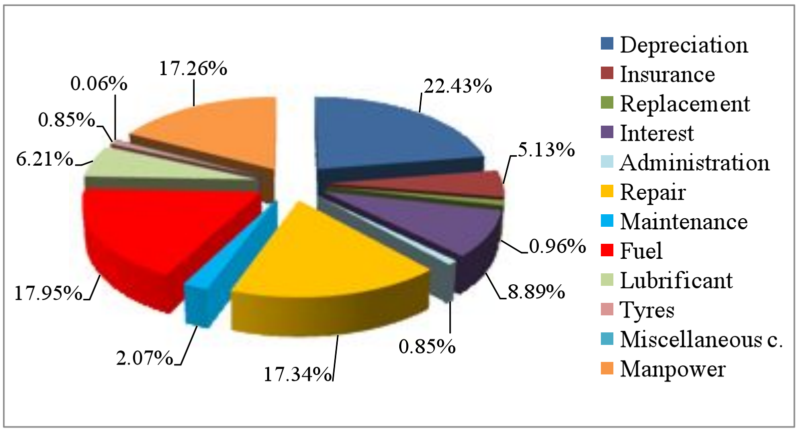

Figure 3. Percentage of the cost elements of the machines

In the Figure 4 the hourly costs and the productivities obtained for the different operations of the thinning are presented.

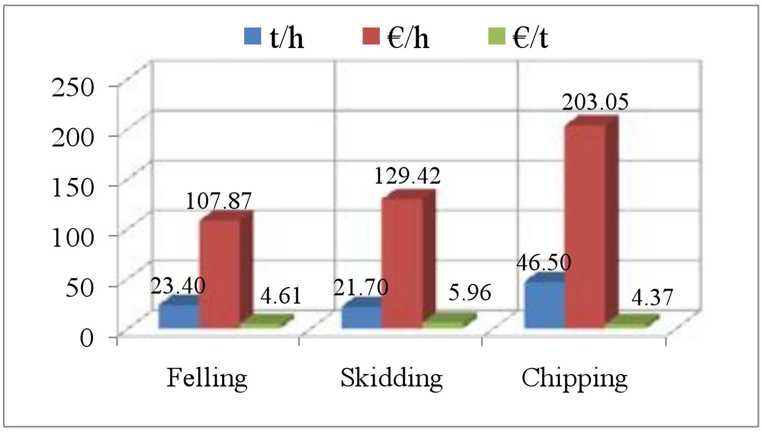

Figure 4. Productivity and costs of the thinning operations

The Figure 5 shows the results of the economic budget. The total thinning cost was 14.94 €/t. The transport were effected with trailer trucks for a distance of about 150 km and the calculated cost was 13 €/t. The relocation costs for the transfer of the machines is reasonably esteemed in around 2.09 €/t (400 €/hectare).

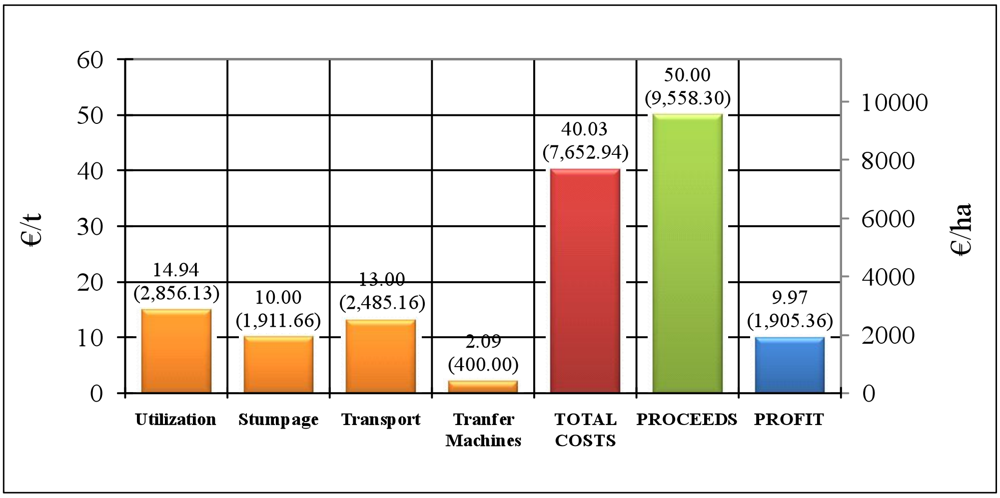

Figure 5. Economic budget analysis of the thinning (values in €/t and €/ha)

In the Figure 6 the variation of the transport cost as a function of distance is shown; in the Figure 7 a sensitivity analysis of the enterprise profit varying the transport cost and the chips price is reported.

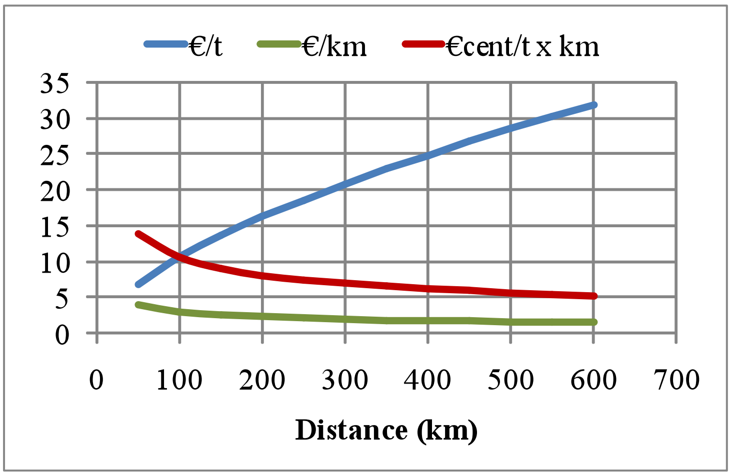

Figure 6. Variation of the transport cost in relationship to the transport distance (values in €/t, €/km and €cent/t per km)

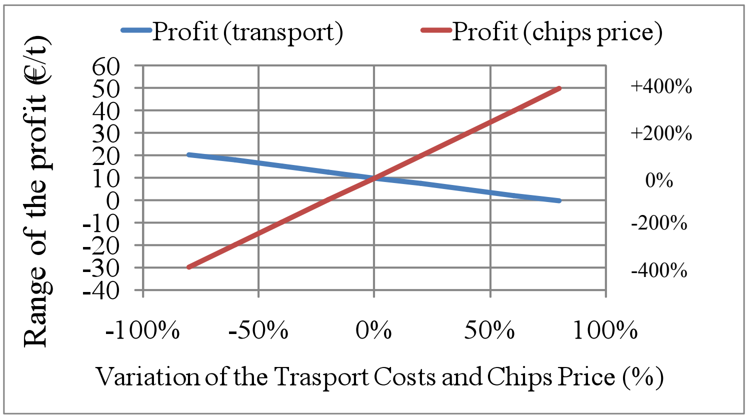

Figure 7. Sensitivity analysis of the enterprise profit varying the transport cost and the chips cost

Conclusions

The elaboration of experimental data underline a good gross productivity of employed high mechanization even if the percentage of time elements underline the high percentage of delay. To carry out this type of thinning 21.1 h man-^{1} hectare^{-1} are necessary: 8.2 h man-^{1} hectare^{-1} for felling, 8.8 h man^{-1} hectare^{-1} for skidding and 4.1 h man-^{1} hectare^{-1} for chipping.

The production total cost of chips results of 40.03 €/t, while the sale price is 50 €/t. The economic budget originates a light positive economic profit for the enterprise of 9.97 €/t or 1,905 €/hectare (Figure 5). The costs analysis underlines like the main restrictive factor is the transport cost (about 32% of the total cost). For distance over 200-250 km is possible to suppose a substantial reduction of the enterprise profit (Figure 6). Also the level of the chips price is very important for the enterprise budget: the variation of the profit is very more sensitive to the variation of this element. An increase of the 20% of the price produces a doubling of the profit. The same result is possible to obtain reducing the transport cost of the 80% (Figure 7).

The high mechanization employed, indispensable for reaching the economics sustainability of thinning leads to limitations:

- because the market value of chips is rather low, and start-up investment capital is rather great, work activities must be constant and carried out on large surface (considering also the cost of transfer

machines) to facilitate the amortization of the invested capital and achieve economies of scale to lower the production costs. In fact, in the same condition as that described it's necessary to work more of 60 hectares per year to recover the machines initial investment in less of 10 years;
- the manpower must be qualified to best exploit the potential of machinery and work without causing damages to the environment. This again brings up the problem of setting up training centers for forestry workers non-existent in our country.

In the last years the number of harvester, forwarder and big chipper is very growing. At the moment is necessary the application of forestry policy finalized to start up the program to disseminate the information to high mechanization working, and to support the development of forms of association to overcome problems linked to break-up of private property, one of the major obstacle for the use the high mechanization.

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