Test of Mechanized Logging Systems in First Thinnings of Oak and Beech Stands

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Abstract:
For ONF, the State Forest Service in France, identifying efficient, cost-effective and low-impact mechanized logging solutions for first thinnings in young oak and beech stands has become a real challenge: less and less motor-manual workforce is available to perform such operations, yet crucial for the silviculture of this kind of forests, and conventional machinery are generally too costly, large and heavy to perform well in these conditions (very small trees to remove, in dense stands, mainly situated on flat very sensitive soils).
Following an analysis of the diversity of the conditions of first thinnings (in terms of tree dimension and characteristics, stand density…), 4 logging systems have been chosen to be tested in 8 case studies: Vimek 404 – Timbear Lighlogg C; Vimek Biocombi 608.2; HSM 405 H1 – HSM 208 F; SIFOR 404 - Novotny LVS 5000. The tests took place in fall 2011-winter 2012, and each lasted several weeks. Overall productivity data have been recorded, and assessments of impacts to the soil and remaining trees have been carried out, as well as detailed time studies.
These case studies have demonstrated that from the technical point of view, mechanization of the first thinnings in oak and beech stands is possible. All the machines have been able to cut every tree marked by the forest manager, and the understorey has been preserved, which is important for oak quality. Damages to the remaining trees are limited (less than 23% among dominant trees), but a particular attention to the future crop trees is essential from the forest machine operators. There is a certain flexibility in term of organization of the respective traffic patterns of the harvester and forwarder (depending on their weight, width and boom reach) permitting to keep the surface area affected by machinery traffic below 25%. But, for rainy periods, light forwarders (loading capacity of 9 tons max) and special equipment (tracks) have to be preferred to bigger machines, even if equipped with extra large wheels. From the economic point of view, most of such mechanized thinnings cannot permit today to gain any revenue from the wood products (energy wood, firewood or pulpwood).

Keywords: thinnings, harvesting, mechanization, biomass, impact, soil

1 Introduction

1.1 The problem and the context

Identifying efficient, cost-effective and low-impact mechanized logging solutions for the first and second thinnings in young oak and beech stands is a challenge that ONF, the State Forest Service in France, has to take up.

Less and less motor-manual workforce is indeed available to perform such operations, yet crucial for the silviculture of oak and beech forests, and the surface area concerned is not marginal: 10 000 to 12 000 hectares per year in the forthcoming 20 years period 2011-2015, corresponding to a removal of 420 000 to 504 000 m^3/year (ONF estimations for the 5 northern of its 9 metropolitan regional districts; mean hypothesis: 42 m^3/ha). These high figures are partly due to the numerous natural regenerations consecutive of the large Lothar windstorm in 1999.

Pulpwood and round firewood are the traditional products of the trees removed in first and second thinnings of oak and beech. But, if the demand of such products is steady, the market of other energy wood (roundwood or pieces of trees for chips) is developing. There is then some questioning about the best product assortment (energy wood, firewood, pulpwood or a mix).

While mechanization remains limited for the harvesting of hardwoods in France (< 10% ; Cacot 2010), conventional logging machinery and especially CTL harvesters are anyway considered as too costly, heavy and large to perform well in the specific conditions of young oak and beech stands (Ulrich *et al.* 2010):

⇒ The average size of trees to remove, very small (from less than 0.050 m^3 in the worst case to 0.150 m^3 in the best case), is at the source of low harvester productivity and so high cost;

⇒ Most of the oak and beech stands are situated on very sensitive flat soils, and forest managers feel very reluctant to see harvesters coming in, compressing and rutting the soil in a significant proportion of the surface area;

⇒ The high number of trees per hectare (2000 to more than 6000) and the necessity of preserving the understorey for favoring the quality of the crop trees (especially for oak) make the crane and head movements difficult without damages on the future crop trees.

1.2 The state of the study in course

In order to feed its strategy regarding mechanization development in first and second thinnings in oak and beech stands with the finding of efficient and acceptable mechanized logging solutions, ONF launched a study in 2010, with a working group composed of a mix of its own experts and field practicians and experts, and researchers from FCBA.

The first task in this study was to qualify the different profiles that first and second thinnings could have in the field, using parameters known as being constraints for mechanization, and to define the list of specifications for the machines to be used in these different first and second thinnings. The methodology used for this task has been described by Cacot et al. (2011). Figure 1 illustrates the main types of the typology, based on 2 main criteria: the average DBH of the trees to remove, and the total number of stems in the stand per hectare (with a DBH > 2.5 cm). Specifications for the machines of the logging system (harvester and forwarder) were defined as follow:

⇒ capable to handle all the trees that have to be removed, in the different types of the typology (these trees are generally marked by the forester), while preserving enough stems in the understorey or as accompanying trees of the future crop trees, and with limited impact on the soil (compression, rutting) and on the future crop trees;

⇒ being efficient, reliable and cost-effective, when producing short logs or pieces of trees for the pulp and energy markets;

⇒ usable during periods as long as possible during the year, whatever the weather conditions (rain) may be.

Using these prerequisites as inputs, a review of the existing machines across Europe meeting these specifications has been carried out, with visits on the field for the most promising of them (Ulrich and *al*., 2011). Schematically, compact or very compact carriers (Vimek 404T4, Komatsu 901, Sampo SR 1046X, Rottne H8, HSM 405H1…) were preferred, to be equipped either with a light harvesting head capable of processing hardwoods (like Vimek, Keto 51 or Forst Eco, HSM CTL 40 HW), either with a felling head (Bracke C16b or C12, Vigneau head). As far as forwarders are concerned, light (< 9 tons) or tracked machines were elected, to be as preservative as possible for the soil. Harwarders meeting these specifications were found interesting too (Biocombi 608 Vimek, Lightlogg C Timbear). All of these machines were expected to be operable with low or at least reasonable cost.

Then, at this stage of the study, the ambition of ONF was not to run a comprehensive research project (because of time and money constraints) but to collect enough data and convincing experience for stating about potential satisfying solutions in terms of logging machinery and systems for the first and second thinnings. As far as methodology is concerned, the choice has then been made to organize case studies, consisting in testing different logging systems in real conditions for a couple of weeks.

2 Material and methods

2.1 Setting up the case studies

Contacts with logging contractors using machinery identified during the first step of the study as potentially interesting, have been taken in France or European countries, with the perspective of making these contractors come and operate for several weeks their machinery in ONF first and second thinnings. The final number, content and duration of these tests are a compromise between the objective of the study (test as many interesting machines as possible), and budget and time constraints from both the ONF and the logging contractors perspectives.

Finally, 8 case studies could be organized in 2011/12, for a focus on machines listed in table 1, and the choice has been done to concentrate the tests in the intermediate types of the stand typology (n°2 and 5), in order to make more easy the extrapolation of the feed-back to the bordering types n°1, 3, 4 and 6 (Figure 1).

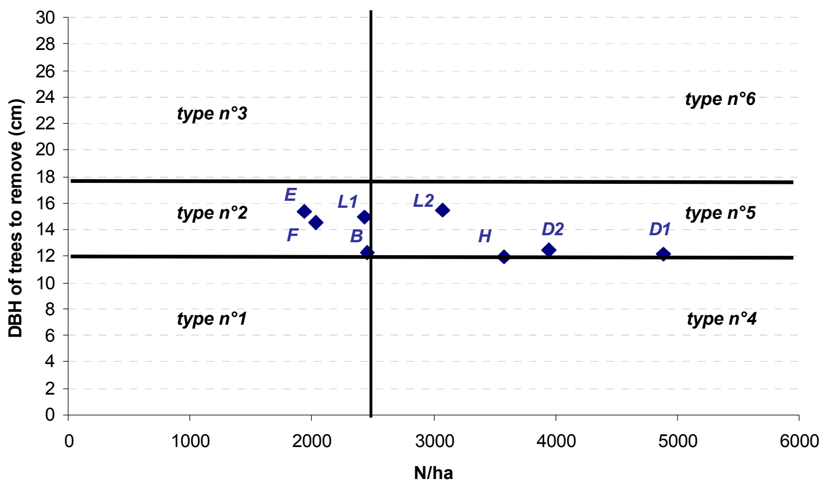


Figure 1: Position of the case studies in the typology of first and second thinnings of oak and beech stands

2.2 Content of the case studies

At the logging site level, overall time and production data have been recorded in accordance to AIR3-CT94-2097 protocol, thanks to specific data sheets distributed to the operators of the logging machines, who have been instructed to fill them correctly on a daily basis. Complementary data have been recorded concerning the work organization, the corridors (width and space), the machine and the operator experience. A sample of trees has been measured in term of height and DBH in order to adjust a volume model calculated on an existing data basis (Deleuze et al. 2010, Rivoire et al. 2010).

On transects, remaining stems have been recorded in terms of number, and their DBH and diameter at the stump measured. The removal of trees has been quantified by counting the number of stumps and measuring their diameter. Assessments of damages to the soil and remaining trees have been carried out according to a protocol adapted from the AIR3-CT94-2097 by Cacot (2006).

Detailed time studies have been performed on a sample of trees for the different harvesters, and a sample of cycles for the forwarders and the harwarder, according to the AFOCEL protocol, which is compatible with the AIR3-CT94-2097. Samples of wood products have been measured too (length and diameter). Finally, the annual and hourly costs of the different machines have been calculated with the hypothesis presented in appendix 1.

Table 1: Description of the logging machines tested in the case studies

Machine type	Machine model	Boom Length [m]	Weight [tons]	Width [m]	Number of wheels (W) or tracks (T) ; Tyres or tracks width [mm]	Cutting / Loading capacity [cm / tons]	Case study
Harvester XS (very compact)	Vimek 404 T4 / KETO Forst Eco	4.0	4.1	1.8	4W ; 405	30	D1 D2
Harvester – S (compact)	SIFOR 414 / SIFOR 450	6.8	11.0**	2.5	4W ; 500	50	B E
Harvester – M (medium-sized)	HSM 405 H1 / CTL 40 HW	10.0	18.0	2.7	6W (+tracks) ; 710	53	F L1 L2
Forwarder – L "light"	NOVOTNY LVS 5000	6.1	7.0	2.1	8W ; 500	5.0	B E
Forwarder – T "tracked"	TIMBEAR Lightlogg C	8.0	14.0	2.2	6T ; 620	13.0	D1 D2
Forwarder – LW "large wheels"	HSM 208 F 11	8.6	16.0	2.98	8W ; 940	11	F L2
Forwarder – M "medium"	HSM 208 F9	10.0	12.2	2.6	8W (+ tracks) ; 710	9	L1
Forwarder – M "medium"	JOHN DEERE 810	7.2	12.5	2.7	8W (+ tracks) ; 700	9	L2
Harwarder – H	VIMEK Bio-kombi 608.2	5.2	3.7	1.9	6W ; 400	4.5	H

**Water-filled wheels.

3 Results and discussion

3.1 Impact on the stand

The reduction of stems in the stand is conformed to the forest manager prescriptions (table 2). First, the machine has been able to cut all the trees that he had marked, which correspond to a removal varying between 13 and 45%, depending of the species and the height of the canopy. Secondly, the understorey has been preserved: less than 10% of removal in all cases, excepted in case D2 and L2 where it is higher – respectively 15 and 26%. There, some of the former « silviculture corridors », regularly cleaned by tractors equipped with a mower to make the cleaning and spacing job of motor-manual operators in the stand easier, have been enlarged in order to enable the traffic of the forwarder in the future (Figure 2).

Table 2: Stand description and impact of the thinning in terms on number of stems per hectare, in the understorey and the rest of the stand

Case study	Main species	Canopy height [m]	Number of trees per hectare before thinning			Number of trees per hectare after thinning			Stem reduction by the thinning	
			Stems with DBH < 7,5 cm (understorey)	Stems with DBH > or = 7,5 cm	Total	Stems with DBH < 7,5 cm (understorey)	Stems with DBH > or = 7,5 cm	Total	Stems with DBH < 7,5 cm (understorey)	Stems with DBH > or = 7,5 cm
B	Oak	14	880	1571	2451	866	1215	2081	-1,6%	-22,7%
E	Beech	18	565	1373	1938	542	968	1510	-4,1%	-29,5%
D1	Oak	15	3407	1481	4888	3090	1032	4122	-9,3%	-30,3%
D2	Oak	15	2267	1676	3943	1919	1245	3164	-15,4%	-25,7%
H	Oak	14	3767	2500	6267	3446	1622	5068	-8,5%	-35,1%
L1	Oak, beech	23	948	1479	2427	880	1016	1896	-7,2%	-31,3%
L2	Beech	20	2000	1080	3080	1480	592	2072	-26,0%	-45,2%
F	Oak	19	757	1271	2028	686	1100	1786	-9,4%	-13,5%

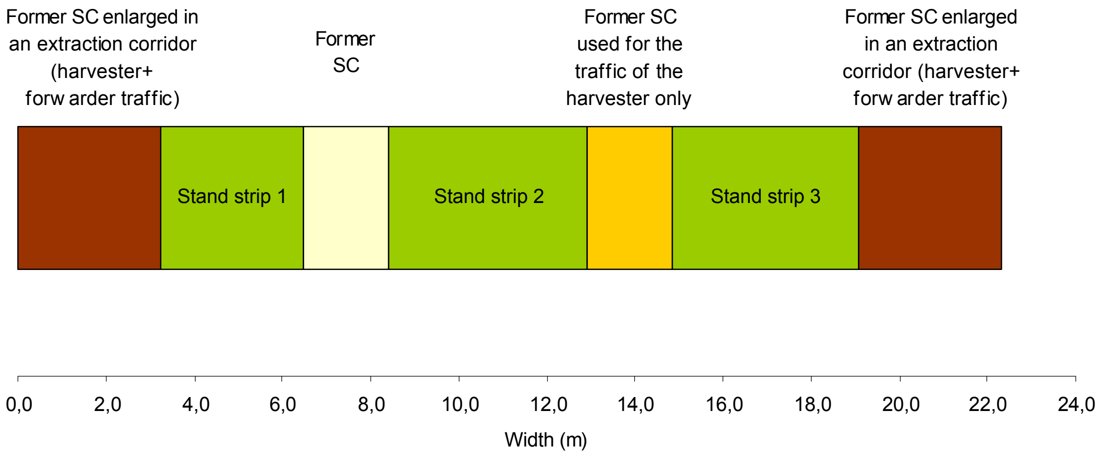


Figure 2: Corridors and machines pattern in case study D2 (the XS harvester (4m boom; 1.8 m width) has circulated in 2 out of 3 former SC (silvicultural corridor, 1.9m width) and enlarged the one which will serve to the tracked forwarder (8m boom, 2.2m width))

The proportion of damaged trees varies between 3 and 23% among dominant trees, and between 0 and 17% among co-dominant (Figure 3). There might be two reasons for explaining that dominant trees are more damaged than the co-dominant. First, it is mostly close around the dominant trees (future crop trees in general) that the harvesting head has to remove stems during a thinning, so the risk of damage is higher. Secondly, dominant trees are quite often at the edge of corridors (because they have more space) and then more susceptible to be injured by logging machines movements. Most of the damages are however slight damages; heavy damages (fiber scratched and/or extension > 200 cm^2) are rare. These figures are in the range of what has already been observed in hardwoods stands with less trees per hectare (Cacot 2006). The highest proportion is in case E, F and L2: beech, the cork of which is more sensitive, is the main species in E and L2. No specific explanation has been found in case F, but a more important proportion of working time after the night fall may be the cause.

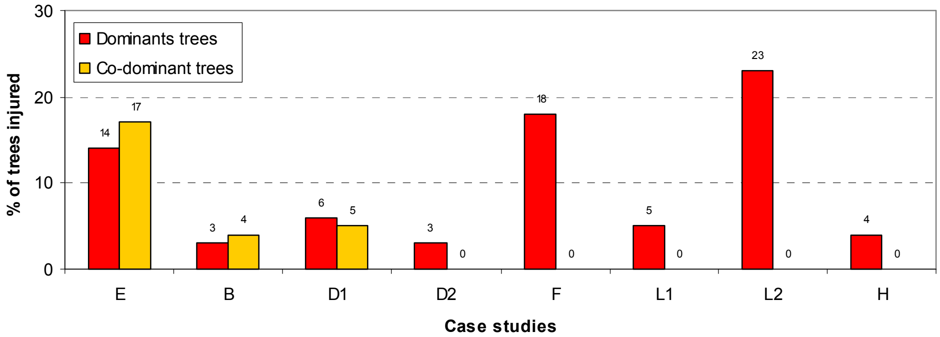
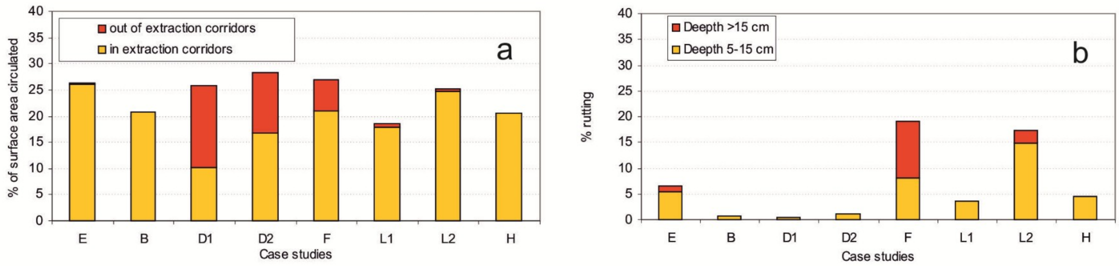


Figure 3: Proportion of trees damaged during the thinning operation

3.2 Damage to the soil

The surface area affected both by the harvester and the forwarder traffic varies between 10 and 26% and is confined to the extraction corridors (Figure 4a). In addition, outside the extraction corridors but in the former silvicultural corridors, in cases D1, D2 and F, 6 to 16% of the surface area has been affected by the harvester traffic only. In D1 and D2, it was a 4.1-ton machine (which is lighter than conventional tractors used for the silvicultural operations) but it was a 18-ton machine in F (which is much heavier than the light forwarder loaded in cases E and B). The overall ratios belong anyway to the two most satisfying categories from the Cacot data basis (2006): very good (< 15%) and good (15-25%) and the different figures reflect the different patterns of both the corridors set in the stand (in term of spacing and width) and machine traffic (see Figure 2 for an example).

Three cases (B, D1 and D2) are affected by rutting on less than 5% of the surface area, so belong to the "satisfying" category of the Cacot classification (2006), two (L1 and H) between 3 and 5 % (average), one (E) between 5 and 10% (poor) and two (F and L2) more than 10% (16 and 18%) which is the worst category (Figure 4b). Weather conditions (rainy period) are the main explicative factor. Despite its large wheels (940 mm), the 16-ton forwarder did no miracle and has been finally replaced by a lighter "medium forwarder" (12,5 tons, 8 wheels equipped with tracks) in order to keep damages acceptable.



Figures 4: Proportion of the surface area circulated (4a) and affected by rutting (4b) during thinning

3.3 Harvesting productivity

Figure 5 gives an overview of the productivity of the harvesting process in the different case studies (except for H, where it is a global productivity harvesting + forwarding, as the machine was a harwarder). The effect of the average tree volume on the harvester productivity is clearly visible (H excluded, $r^2 = 0.78$), despite the facts that the stands, the machines and the wood products were different from one case to the other. It has to be noted that each type of harvesters was used according to its capacity: the XS harvester and the harwarder in the case studies with the smallest trees (D1, D2 and H: DBH of removed trees mainly between 4 and 12 cm, 22 cm max), and the S and M harvesters in the others (DBH of removed trees mainly between 8 and 22 cm, up to 32 cm sometimes).

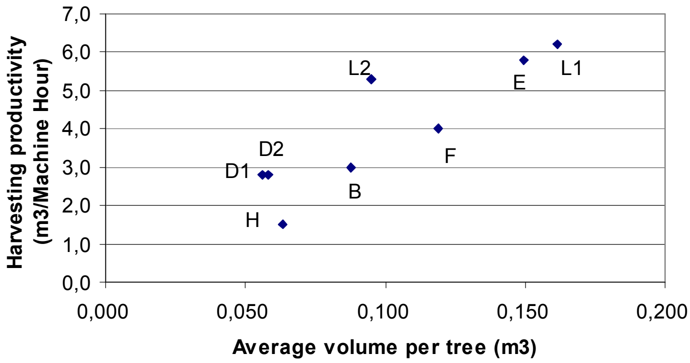


Figure 5: Productivity of the harvesters in the different case studies (except H: harwarder) (these figures are calculated as the ratio between the total volume extracted from the working site (measured according to the common practice) divided by the total number of Machine Hours recorded by the computer of the machine)

To enable comparison between the productivity data recorded for the different machines in the detailed time studies per tree, a homogenization of the time dedicated to operations independent to tree size like non-merchantable trees removal, machine traffic from one tree to another one, slash piling…has been made. Further more, time dedicated to forwarding in case H, harwarder, has been ignored. The superposition of the harvesting productivity per tree reveals then no significant difference between the different machines for the smaller trees (< 0.08 m^3). Over 0.08 m^3, the harwarder (H) reaches its limits in term of capacity, and is quickly followed by the very compact harvester (D1), when the productivity of the two other harvesters (compact and medium-sized) still increase with the tree volume and become significantly higher.

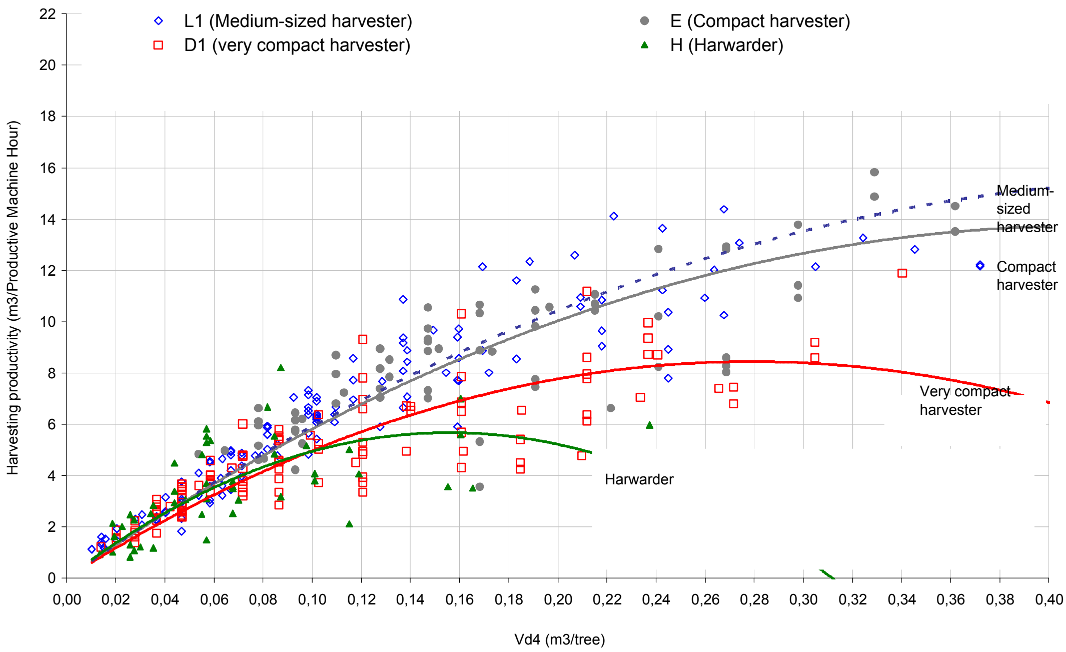


Figure 6: Comparison of harvesting productivity with the different machines (detailed time studies per tree have been processed in order to make them comparable. Vd4: volume in the tree (main stem + branches) up to top-end diameter of 4 cm)

3.4 Forwarding productivity

Figure 7 gives an overview of the productivity of the forwarding process in the different case studies (except for H, where it is a global productivity harvesting + forwarding, as the machine was a harwarder). At this level, the influence of the type of product and extraction distance cannot be segregated; the main factor is the loading capacity of the machine.

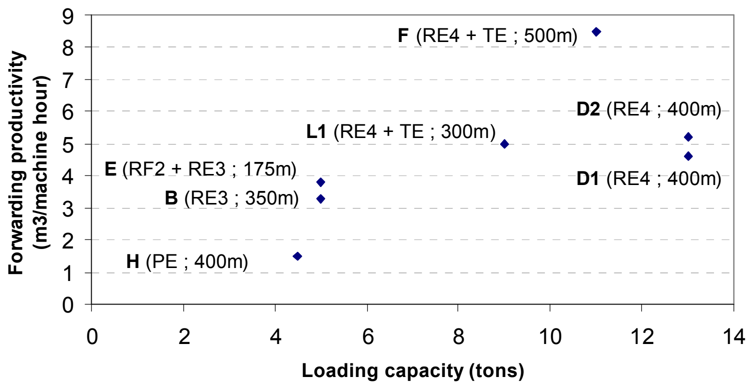


Figure 7: Productivity of the forwarders in the different case studies (except H: harwarder) (these figures are calculated as the ratio between the total volume extracted from the working site (measured according to the common practice) divided by the total number of Machine Hours recorded by the computer of the machine. In brackets: wood products (RE3, RE4: roundwood for energy in 3 and 4m length; RF2: round firewood in 2m length; TE: tree parts for energy, length fitted to the forwarder) and average forwarding distance)

The detailed time studies performed on a few forwarding cycles for the machines the less common in France (Light and Tracked forwarders, Harwarder) reveal that the speed of these machines during the travel between the forest and the piling area at roadside is quite "usual" (3 to 4,5 km/hour range), by reference to data recorded for other forwarders commonly found in France (unpublished). Under-utilisation of the loading capacity is notable: the ratio between the loaded volume and the loading capacity varies between 43 and 67%. Complementary data, on more cycles would be necessary to confirm such ratios, refine the relationship between wood products characteristics (types and length) and the utilisation ratio of the loading capacity, and state about the conditions in which harwarder would be more advantageous than the combination harvester + forwarder.

Table 3: Main characteristics of a few cycles for the tracked and light forwarders, and the harwarder

Machine (case study)	Tracked (D1)	Light forwarder (B)	Light forwarder (E)		Harvarder (H)
Wood product	RE4	RE3	RE3	RF2	TE
Nb cycles observed	5	2	3	1	3
Volume / log (m3)	0.037	0.026	0.024	0.050	nd
Number of logs / load	228	128	93	67	90
Load volume (m3)	8.34	3.30	2.22	3.33	2.30
Ratio Load volume / Loading capacity	**64%**	**66%**	**44%**	**67%**	**51%**
Cycle duration (minutes)	47	35	20	21	62
Travels forest - road site	13.2	6.1	4.3	1.2	12.4
Loading	24.9	19.6	11.9	15.1	42.8
Unloading at road side	8.8	8.9	3.7	4.37	6.8
Forwarding distance	382	220	116	38	394
Average speed during travel forest - roadside (km/h)	3.5	4.3	3.3	3.7	3.8
Productivity (m3/Productive Machine Hour)	9.2	5.7	6.7	9.6	2.2

RE3, RE4: roundwood for energy in 3 and 4m length. RF2: round firewood in 2m length. TE: tree parts for energy, length fitted to the forwarder.

3.5 Economic approach

The application of the hourly cost of the harvesters (calculated according to annexe 1 hypothesis) to the hourly productivity which can be expected from them (figure 6), when using a ratio of 0.8 between machine hour and productive machine hour, indicates that the very compact harvester is more competitive than the compact or medium-sized harvester when the volume of the trees to process do not exceed 0.1 m^3 (figure 8a).

In the case of a thinning of trees with an average tree volume of 0.1m^3, the harvesting costs could be around 20 € /m^3 (whatever the harvester), and a solution for the forwarding may be found between 10 and 15 €/m^3 (Figure 8b), so the total costs for a cubic meter would be between 30 and 35 € (these costs do not include the logging company margin, neither the price of the wood). For smaller trees (about 0.06 m^3), the total would range 40-45 € at the best (with the very compact harvester). This is comparable to the costs of the harwarder calculated in the case study H (average tree volume 0.063 m^3; 42 €/m^3). These costs exceed the revenue which can be expected by the selling of the wood products today in France. The costs are, of course, lower for bigger trees (0.15-0.2 m^3), and the negative balance between costs and revenue reduced.

These figures might be improved in the future, with the development of the experience of the harvesters' operators and with the optimisation of the systems: doing the right choice concerning the wood product assortment (one only) and the length of the product in order to optimize the utilisation ratio of the loading capacity of the forwarder for example. A more visible marking of the trees to be cut (pink rather than orange, or even worse, red and blue) has been tested in a sub-test and it also leads to an increase in productivity. There is nevertheless still some questioning about the technical reliability of the smaller machines when working on a regular basis in such operations in hardwoods.

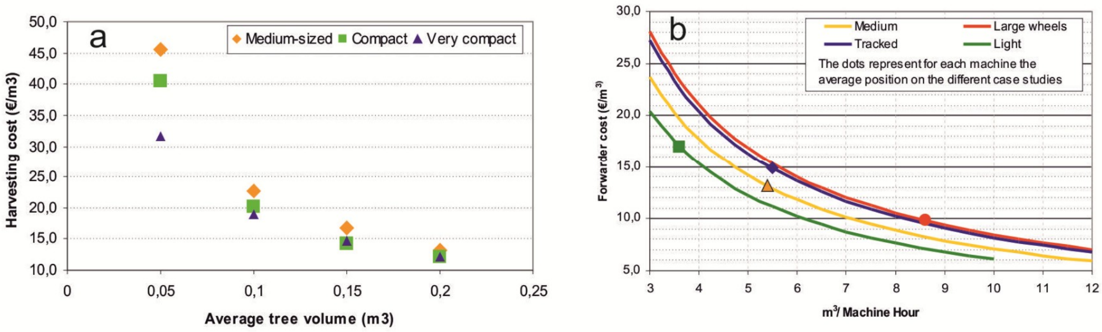


Figure 8: Examples of comparison of the harvesting costs with different harvesters (8a) and different forwarders (8b)

4 Conclusion

These case studies have demonstrated that from the technical point of view, the mechanization of the first and second thinnings in oak and beech stands is possible (Ulrich *et al.* 2012). Reduction of the number of stems per hectare can be done according to the foresters conventional silviculture schemes, and with the preservation of a protective understorey, important for the quality of the crop trees in oak stands. Even if damages to the remaining trees are limited, forest machines operators should pay however a particular attention to the crop trees as the cumulated damages from the successive thinnings in the time may result at the end in a significant proportion of damaged trees (a certain part of them will however be cut at the 2nd or 3rd thinning and will thus not affect the overall healthiness of the stands).

Another important issue is the traffic pattern of the forest machines, as most of these hardwoods stands grow on soils that turn very sensitive as soon as it starts to rain. The utilization of corridors, rationally spaced, proved its efficiency to keep the surface area affected by machinery traffic below 25%. In dense stands, where it might be difficult to reach and cut trees situated 10 m from the corridor, the utilisation of a light and compact harvester, with a short boom (4 m) can be a good solution because such machine can circulate in the existing silvicultural corridors (generally 1,9 m width and space every 6-7 m) to cut and process the trees, and pile the products so that they can be reached by a forwarder from extraction corridors only. These will be spaced no more than every 20-25 m (taking into account the usual boom length on forwarders) and have to be settled at the first thinning so that they can be re-utilised for the future thinnings.

As far as forwarders are concerned, if the organisation of the respective traffic patterns of the harvester and forwarder permits some flexibility in term of boom reach of the forwarder, the soil sensitiveness in case of rain will impose its constraints: light forwarders, with a limited loading capacity (9 tons max) and special equipment (tracks), have to be preferred to bigger machines, even if equipped with extra large wheels… unless they are not on wheels but tracks. And in case of persisting rain, there will not be any miracle: even the light forwarders will have to stop working in such sites. Transfer to other working areas, with more favourable site conditions, has to be prepared in advance.

As far as the economic point of view is concerned, even if progress can be expected thanks to the development of know-how and expertise among foresters and loggers, most of these mechanized operations in first thinnings will not permit to gain any revenue from the wood products (energy wood, firewood or pulpwood) unless their market price increase significantly. Nevertheless, it is a way to make the preparation of future hardwoods stands at reasonable cost possible, despite the lack of motor-manual workforce.

The case studies realised in 2011 have been the support of several demonstration activities in the field, open to logging contractors and forest managers, in order to make them more friendly with such operations and their specific constraints. Complementary case studies are envisaged, with felling heads mounted on excavator, or with harwarders, in order to explore other logging systems or forest machine traffic patterns (Laitila 2012, Roy and Desrochers 2010) or complete the 2011 results.

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Appendix 1: Hypothesis for the cost calculation of the logging machines

Hypothesis for the cost calculation of the logging machines

Machine operated by an employee in a logging SME;
First 5-year period after the buying for harvesters and harwarders (first-hand);
First 6-year period after the buying for forwarders (first-hand).

Heading	Item	Hypothesis
Machine fixed costs	Initial value	Selling price communicated by the forest machine saler
	Final value	Taken from the national price list of second-hand machines published by the French salers: 10% of the initial value for a 5 years-old harvester and 20% of the initial value for a 6 years-old forwarder.
	Subsidies	"0" (not taken into account)
	Amortization	5 years for harvesters and harwarder 6 years for forwarders
	Interest charges	4%
	Insurance	1% of the initial value
	Other	"0"
Machine variable cost	Fuel consumption	From technical documentation and validated by data recorded during the case studies
	Fuel price	1,05 €/l
	Lubricants consumption	From technical documentation and forest machine user feedback
	Hydraulic oil price	4,5 €/l
	Wheels and tracks	Harvester: no change. Forwarder: 1 change every 4 years, 2000 €/standard wheel and specific cost for the tracks of the Timbear and HSM large 940 mm wheels.
	Maintenance and repair	7% of the initial value per year for harvesters, and 5% for forwarders
	Transfer of the machine	6000 €/year (about 2 transfers/month)
	Other	"0"
Employee salary and other operating costs	Salaries and wages	Harvester: 1800€ net/month *12 * 2 (for wages) = 43,2 k€ Forwarder: 1500€ net/month *12 * 2 (for wages) = 36 k€
	Special equipment	1000 € (Individual protection equipment, phone…)
	Working days / year	220 days
	Lunch	15 €/day
	km/vehicle/day	120 km
	Cost/km/vehicle	0,3 €/km
	Other	"0"
Machine production	Utilisation ratio	87
	Machine hours / year	1700
	Productivity	Average from the feed-back of case-studies