FEC- FORMEC 2014: "Forest engineering: propelling the forest value chain"

September 23-26, 2014, Gerardmer – France

Mechanized harvesting of big broadleaves crowns

Philippe Ruch, Xavier Montagny, Alain Bouvet
Institut Technologique FCBA
Pôle Première transformation - Approvisionnement
10 avenue de Saint Mandé, F-75012 Paris, France
e-mail: philippe.ruch@fcba.fr; xavier.montagny@fcba.fr; alain.bouvet@fcba.fr

Erwin Ulrich, Pascal George
ONF
Direction Forêt et Risques Naturels, Département R&D
Boulevard de Constance, 77300 Fontainebleau,
e-mail: erwin.ulrich@onf.fr; pascal.george@onf.fr

1 Introduction

1.1 The problem and the context

Identifying efficient, cost-effective mechanized logging solutions for the processing of big crowns in mature broadleaves 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 relatively dangerous operations and the demand for biomass is increasing. Round firewood and pulpwood are the traditional products of the big crowns removed in mature oak and beech stands. But, if the demand of such products is steady, the market of other energy wood (roundwood or pieces of trees for chips) is developing. ONF's subsidiary specialised in biomass (ONF Energie) plans to mobilise 550 000 tons in 2014 and crowns represent, with the first thinnings in broadleaves stands, the largest potential source of new biomass.

The surface area concerned is relative high. An assessment realised in 3 of its 9 metropolitan districts (Burgundy-Champagne-Ardenne, Lorraine, Franche-Comté) estimates the surface to about 17 500 ha/year for the period 2012-2017, corresponding to a removal of 247 000 to 411 000 m^3/year (ONF's harvest forecasts, proportion of crown wood between 30 and 60% of the timber volume over bark; Burban, 2012). The operations concerned are the two last thinnings and the regeneration's cuttings in high forests and coppice with standards.

Moreover, in the department of Moselle (district Lorraine), motor manual processing is nowadays increasingly difficult to do, due to the invasion of irritating caterpillars (*Thaumetopoea processionnea*) in oak stands. The tiny allergenic hairs of these caterpillars are carried by the wind causing important human health problems: edema, ocular defects, dizziness… These effects occur not only when the caterpillars are present, but also during several months and even one to two years after, because of the persistence of allergenic hairs in the remains of winter nests (Département de la Santé des Forêts, 2006).

1.2 The state of the study in course

In order to feed its strategy regarding mechanized harvesting of big broadleaves crowns in oak and beech stands with the finding of efficient and acceptable mechanized logging solutions, ONF launched a study in 2012, with a working group composed of a mix of its own experts and field practicians, and researchers from FCBA.

The first task in this study was carried out by a forest engineer student to define, after a field trip visit in each district of the north east of France, the list of specifications for the harvesting system to be used in the different stands:

- A maximum length of the extracted products for the preservation of the trees in liaise with the remaining density

The total number of stems in the stand per hectare after the last two final thinnings is about 60 to 100 N/ha, representing a spacing from 10 to 13 m. After the first regeneration cut (in general 3 progressive regeneration cuts before the final clear cutting), the density is about 40 N/ha (spacing 15.8 m). As, the length of the crowns measured on several site is about 14 m, it is necessary to reduce the length of the extracted products to preserve the remaining trees (9 m maximum). For the following regeneration cuts, it can be possible to extract longer parts even the whole crown depending on the height of the existing regeneration (Burban, 2012).

- Products adapted to the morphology of the crowns

A broadleaf crown is made of several relative sinuous strong branches with narrow insertion angles. These characteristics are a real handicap for mechanized processing with traditional harvester heads (Cacot, 2008) for the production of roundwood for pulpwood or firewood. For chips, curved long branches can be cut within the crowns, as the standard in France for fuelwood is chipping the trees at the roadside. So, it is just necessary to cross cut some branches of the crown to extract them easily.

- Circulation on permanent corridors

Soil preservation (compression, rutting) is a very important issue in forest management. One solution adopted is to allow the circulation of the machines only on permanent corridors (skid trail). The recommended spacing is 16 to 24 m (Pischedda, 2009). The impact on the corridor has also to be limited to preserve their trafficability.

Finally, specifications for the machines of the logging system were defined as follow:

- capable to handle all the crowns that have to be removed from the permanent corridors, while preserving the remaining trees, the regeneration and with limited impact on the soil;
- being efficient, reliable and cost-effective, when producing short logs or pieces of trees for the energy and pulp markets;
- in caterpillar infested areas, capable to process the crowns while the operator is in an enclosed cab.

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 mechanized harvesting operations of big broadleaves crowns. 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.

Three logging systems have been identified using a grapple saw mounted (i) on a forwarder with long crane (10 m) (single machine system), (ii) on an excavator and (iii) on a skidder with crane, both process the crown for a conventional forwarder (two machines system).

The test of these machines, on several stands, started in autumn 2013 with the single machine system and results are presented in this paper. The two machines systems will only be studied at the end of 2014.

2 Material and Methods

2.1 Setting up the case studies for the single machine system

Two entrepreneurs working for ONF in the department Moselle equipped recently themselves with machines in order to perform oak crowns in infested caterpillar stands. The specifications for the modified forwarder to work for the local forest service are:

- 10 m long crane to be able to harvest the crowns from the permanent corridors
- 8 wheeled machine equipped with tracks (flat tiles) to reduce the impact on the soil
- Chainsaw grapple to process the crowns (in order to reduce the length and the volume)
- Enclosed cab with filtration to protect the pilot against the urticant hairs

The characteristics of the two machines are listed in table 1. They are quite similar except for the Combi, which is equipped with a rotating cab and a more powerful crane. The entrepreneur of the HSM forwarder built himself a compactor for his machine in order to load more volume when he extracts biomass. This machine is named in the following article F12_C and the traditional version with stub stakes F12_S.

	HSM 208F 12T		Valmet COMBI 801
Original function	8*8 Forwarder		8*8 Harwarder
Engine power	Iveco 6-cylinder, 238 hp		Sisu 6-cylinder, 190 hp
Crane (length, lifting capacity)	10 m; 125 kNm		10,6 m; 139 kNm
Grapple Saw	Hultdins SuperGrip II 420S (2,05 m width) Hultdins SuperSaw 550 S		Hultdins SuperGrip II 360S (1,90 m width) Hultdins SuperSaw 550 S
Weight (empty without tracks)	16,5 t		19,8 t
Load capacity	12 t		13 t
Length	10,0 m		9,4 m
Load space	Stub stakes Area: 11,4 m^2 Length: 4,65 m	Compactor Area: 16 m^2 before compressing to 9 m^2 Length: 3,90 m	Stub stakes Area: 10,7 m^2 Length: 4,30 m
Case study	FEN-P054	FEN-P083 FEN-P191	SAN-P194 FEN-P076

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

Five case studies could be organized in 2013/14, for a focus on machines listed in table 1. Each machine was tested at least in a last thinning stand and in a regeneration stand (see figure 1) all in oak stands. The site SAN-P194 presents the most favourable working conditions: high harvest tons/ha and low density of remaining trees.

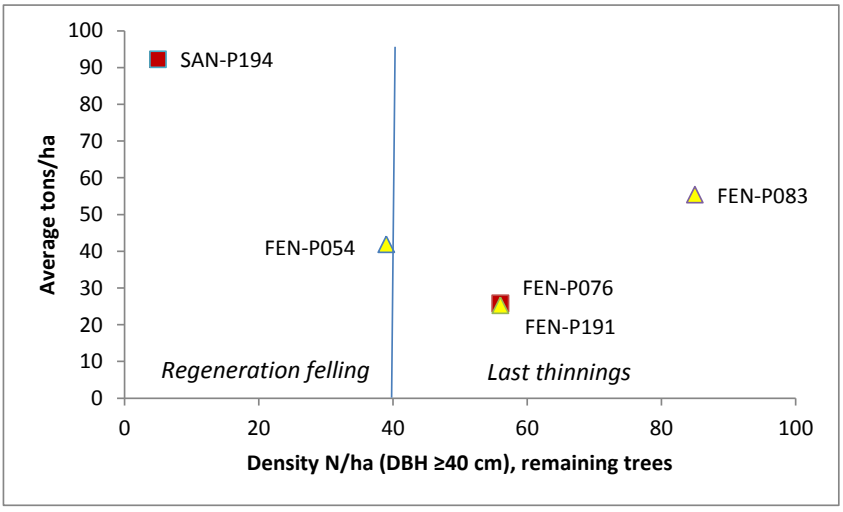


Figure 1: Position of the case studies

Triangles = HSM, Scares = Valmet. Tons concern fresh wood

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 stand (density, species), the machine and the operator experience.

Time sampling has been performed on a sample of crowns and a sample of cycles for the two machines, according to the AFOCEL protocol, which is compatible with the AIR3-CT94-2097. Four main functional steps are identified for each cycle level, whose duration was measured:

- Moving empty (from the landing area to the first crown)
- Processing-loading comprising several sub-steps: moving out the boom, preparation of the crown, crosscutting, loading the crowns and moving from one crown to another
- On load moving (back to the landing area)
- Unloading comprising also several sub-steps such as boom loaded, boom empty, moving

As there is no existing protocol description for the crowns, we measured several characteristics in order to find out the most relevant element influencing productivity: diameter at the crown basis, length and distance crown-corridor. The variability is very important, nevertheless the size of the crowns can be linked to the type of stand: bigger and longer crowns for the regeneration cuts (FEN-P194, FEN-P054) than for the last thinnings (see figure 2). Maximum diameters measured are comprised between 70 cm (SAN-P194, FEN-P076) and 100 cm (FEN-P054).

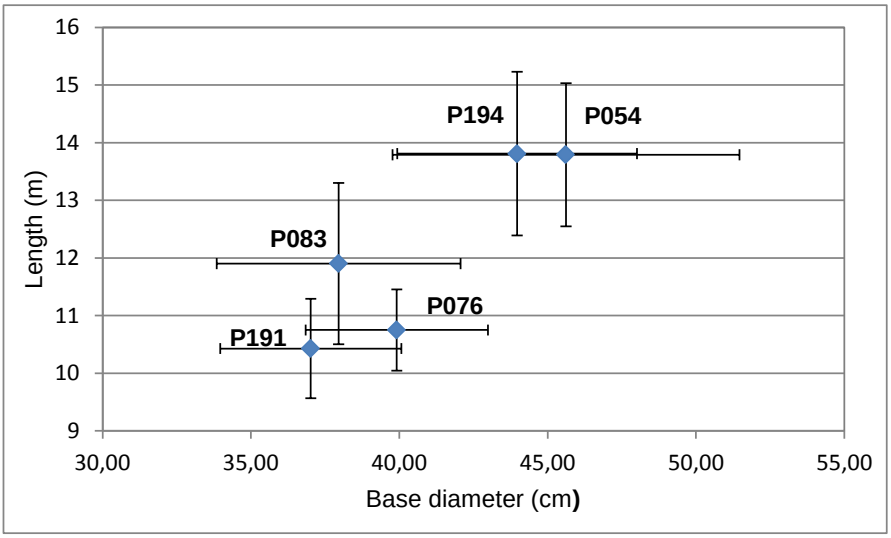


Figure 2: Diameter at the base and length of the crowns (mean and confidence interval of 95%)

As the volume is not easily measurable, the machines were equipped for the tests with a boom scale to determine the fresh weight loaded for each cycle. These boom scales were calibrated daily with field standards, the weight corresponded to the lower and higher range of the loaded crown parts (330 and 1670 kg).

3 Results and discussion

38 cycles were studied for the 5 case studies representing 312 extracted fresh tons and 5.674 observations (see table 2).

Case study	SAN-P194	FEN-P076	FEN-P054	FEN-P083	FEN-P191
Machine	Combi	Combi	F12_S	F12_C	F12_C
Crop (tons/ha)	92,2	25,8	41,9	55,4	25,3
Nb of cycles observed	10	9	9	5	5
Total harvest (kg)	73 532	61 116	64 804	62 121	50 493
Mean load weight/cycle (kg)	7 353	6 791	7 200	12 424	10 099
Mean forwarding distance (m)	255	228	358	140	163
Mean distance crown-corridor (m)	2,4	3,0	5,8	3,5	2,1
Mean productivity (kg/pmh)	17 846	15 480	9 711	15 371	11 259
Mean cycle duration (min)	24,7	26,3	44,5	48,5	53,8
Moving empty	11%	15%	14%	7%	11%
Processing-loading	56%	64%	54%	67%	67%
Moving on loaded	15%	9%	11%	3%	5%
Unloading	18%	12%	21%	23%	17%
Mean cross cuttings (nb/tons)	1,7	2,4	2,1	1,3	1,8

Table 2: Main characteristics of each case study

3.1 Machines suited for the processing of the crowns

The first and the most important result is that the machines had been able to process all the crowns on all sites, whatever their size. The only exceptions concern:

- Crowns placed at more than 10 m (observed in FEN-P083 and FEN-P076, both stands with 40 m spacing). To improve the processing it would be useful to either place a corridor in the middle (20 m spacing), or that the skidder moves the crowns with his cable at least 8 m near to the corridor, after the extraction of the stems.
- The crowns placed in high regeneration (FEN-P191), which are not visible from the cab or to avoid damages. In the last case, the pilot preferred to give up the crowns.

Figure 3 gives an overview of the global productivity (processing and forwarding) in the different case studies. It varies from 9,7 fresh tons per productive machine hour (t/pmh) (FEN-P054) to 17,8 t/pmh (SAN-P194) (see also table 2).

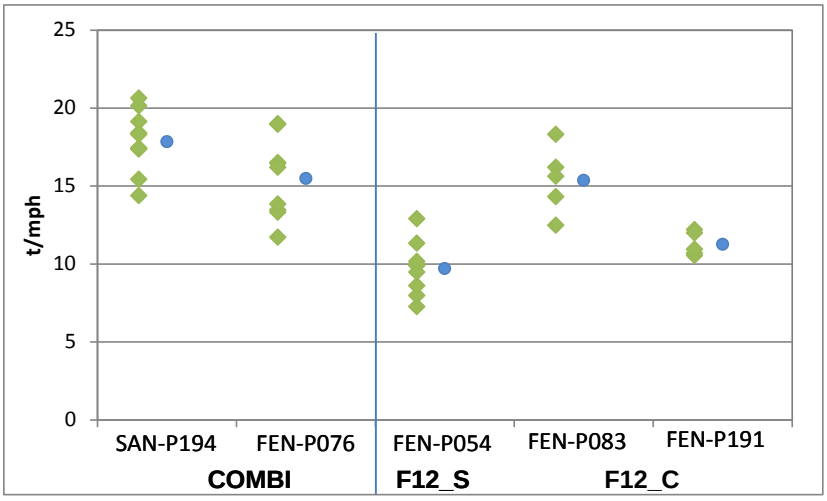


Figure 3: Global productivity in the different case studies (each cycle in green, and mean in blue). Tons concern fresh wood.

Three sites present similar figures: it takes between 200 and 235 seconds to mobilize a fresh ton for SAN-P194, FEN-76 and FEN-P083. For the other sites, time consumption is relative higher 320 s/t for FEN-P191 and 370 s/t for FEN-P054 (see figure 4).

The functional step that takes most of the time is processing-loading the crowns (54 up to 67% of the time) followed by the step unloading (12 up to 23%).

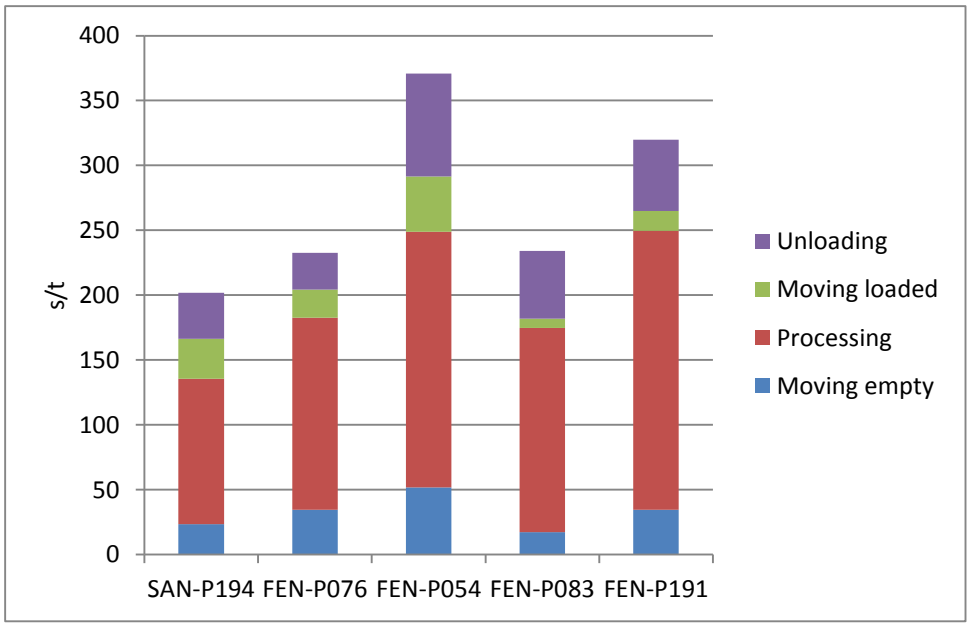


Figure 4: Time consumption for the mobilization of a fresh ton

3.2 Working phases moving (empty and on load): influence of the forwarding distance and the practicability of the corridor

On four sites, the operator had to make a round trip cycle (back and forth) to harvest the crowns. First, the pilot drives empty to the end of the corridor and processes the crowns on the way back. On the site SAN-P194, he had the opportunity to make a loop. The distance, as forwarding is concerned, is one of the main factor influencing the productivity especially when the mean distance exceeds 500 m, but this occurred rarely (see figure 5).

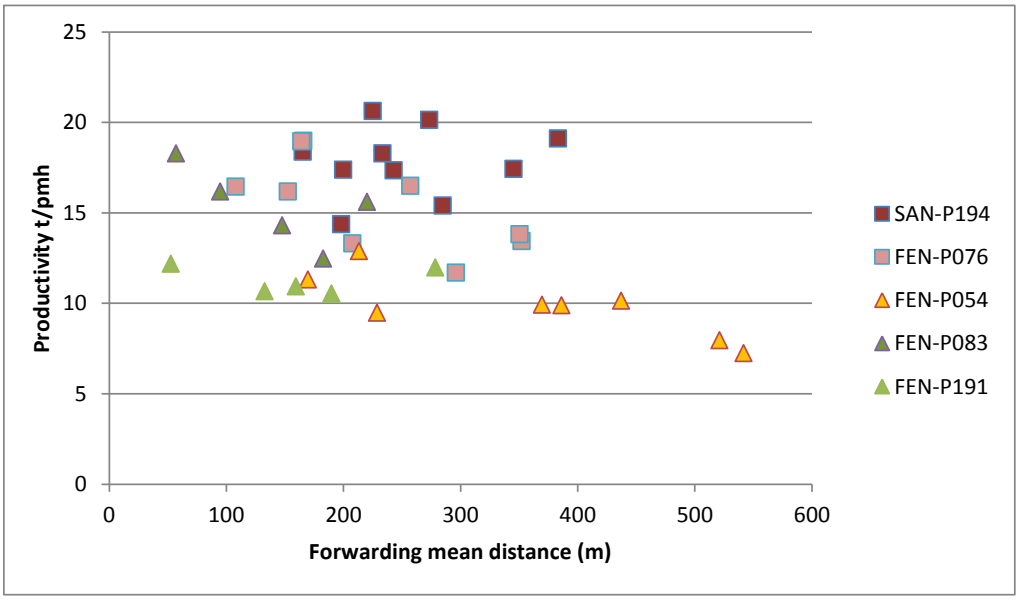
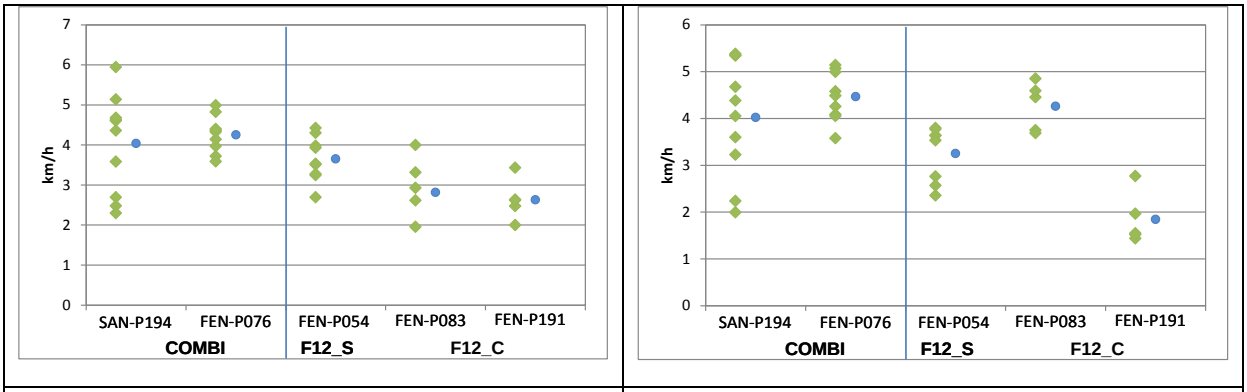


Figure 5: Productivity and forwarding distance

The speed was also calculated for each cycle (see figure 6)



No load speed | On load speed

Figure 6: Speed (km/h) empty and on load (each cycle and mean)

The low “no load” speeds for the HSM F12 machine in two stands are due to:

- FEN-P083, several stops to process the crowns lying in the corridor for the first cycle in each corridor. The stems of this stand were extracted by cable yarder as all the others were extracted by a skidder so that the corridor was free for the machines.
- FEN-P191, small scale corridor, so that the pilot had to manoeuvre to avoid damages on the trees and wet soil conditions. For the same reasons the loaded speed is low on this site.

3.3 Working phase: processing-loading

The technical work consists in (i) cutting the big and long branches and (ii) in loading them directly on the machine. For the small branches, the pilot collects them and prepares a significant load (up to 10 branches). The phases Processing-collecting and Loading take the most of the work time (56 s/t and 51 s/t). The Cross-cutting time is quite low (11 s/t). The phase Moving corresponds to the moving from a crown to another (see figure 7). It is not possible to make a difference between the different machines due to a high variability for each site.

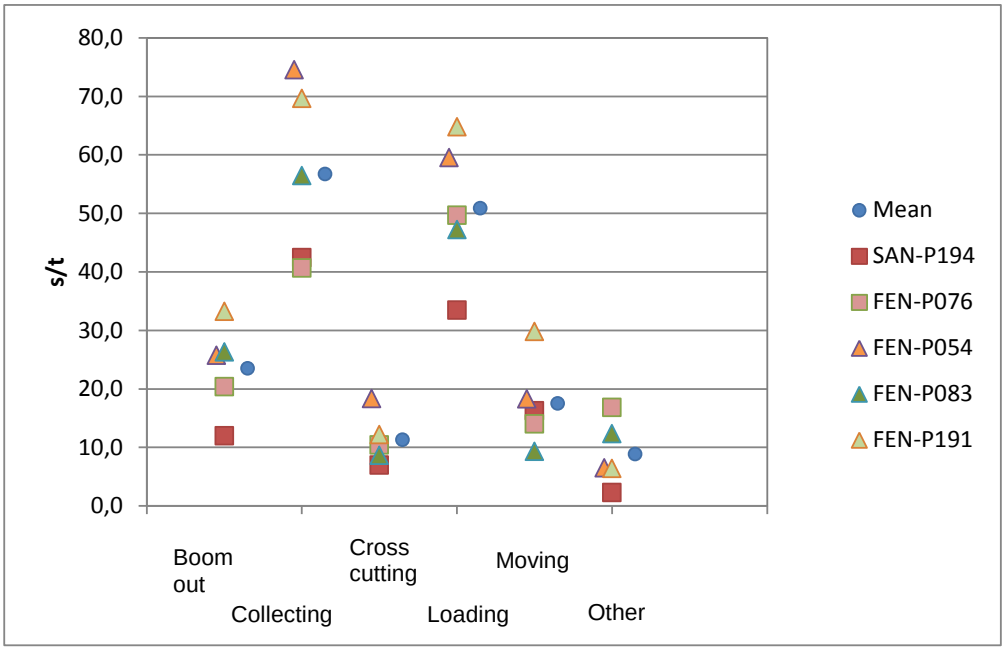


Figure 7: Time consumption for the processing of a fresh ton

Nevertheless, the analysis of the productivity during this phase reveals that the most significant parameter influencing time consumption is the diameter at the base of the crown. Another result is that there is no difference for a same diameter between the different sites except FEN-P054 where time consumption is significantly higher (covariance analysis) (see figure 8), probably due to more important crown-corridor distances, making the work more difficult (see table 2).

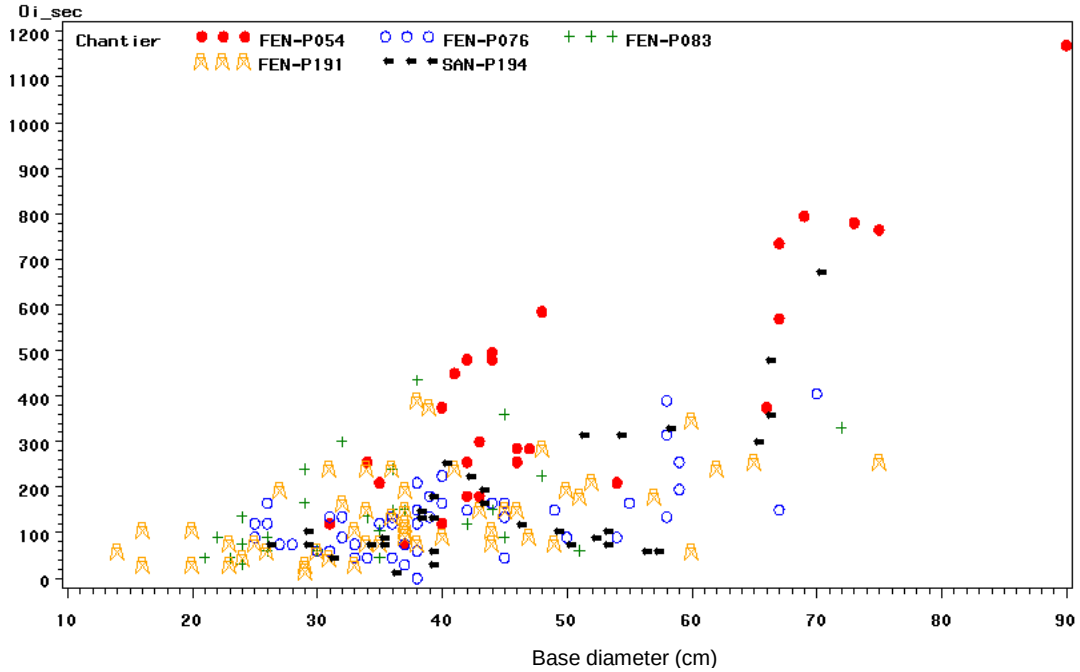


Figure 8: Time consumption (s) during the work phase processing-loading and base diameter

On site FEN-P083, we could observe that partly processed crowns by the motor manual workers where more difficult to handle for the machine than whole unprocessed crowns, especially when they are far away from the corridor. Indeed, the machine can pull more easily a whole unprocessed crown to the corridor and the pilot can choose the branches he has to cut for an optimized loading.
Cross-cuttings represent between 1,3 to 2,4 cuts per fresh tons (see table 2).

3.4 Working phase: unloading

Detailed time study shows a difference between the two machines. The productivity of the Combi is over 100 t/pmh as the HSM is under 70 t/pmh (see figure 9). The more powerful crane of the Combi (see table 1) explains probably most of the difference (not measured).

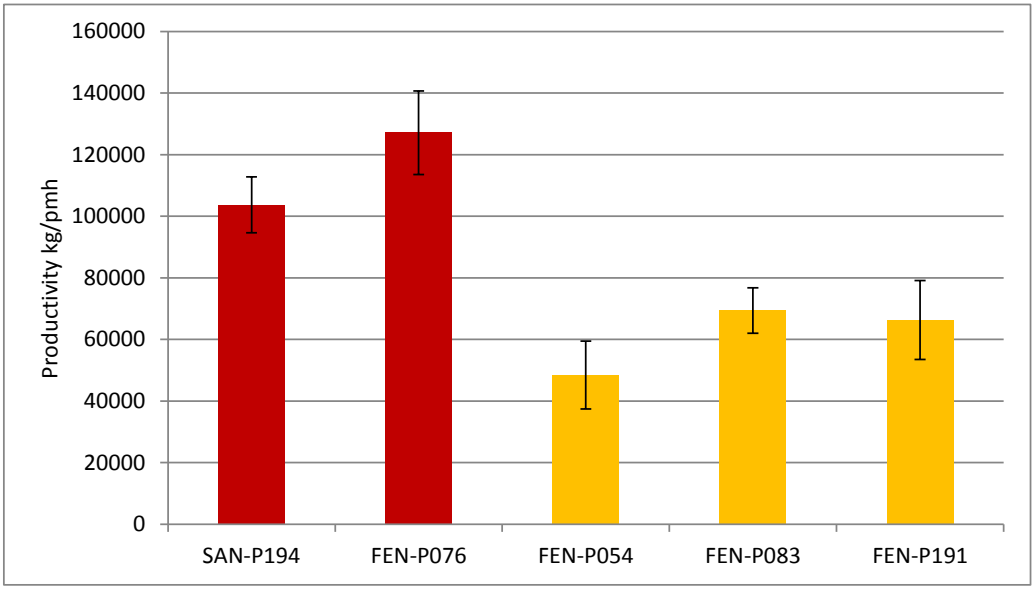


Figure 9: Productivity during the phase unloading (mean and confidence interval)

Furthermore, a detailed analysis of this phase reveals that the pilot of the HSM machine spends time to clean the working place and has to pick up fallen trunks during the unloading. The time consumption represents 27 to 29% of the time as it is only 5 to 7% for the Combi machine (see table 3). This is partly due to the fact that the pilot harvests small branches not easy to handle, which fall down during unloading (due to the thrashing of branches) and lead to cleaning and up-taking of fallen branches. An improved working technique should lead to increase the productivity of this phase.

Case study	Boom out	Loaded boom	Moving	Taking up	Cleaning	Other
SAN-P194	27%	68%	0%	5%	0%	0%
FEN-P076	33%	60%	0%	2%	2%	3%
FEN-P054	19%	52%	5%	7%	15%	3%
FEN-P083	27%	46%	4%	11%	10%	2%
FEN-P191	29%	47%	3%	14%	9%	0%

Table 3: Time distribution for unloading a ton

4 Conclusion

These case studies have demonstrated that from the technical point of view, the mechanization of the big broadleaves crowns is possible while staying with the machines in the corridors for soil protection. Therefore machines must be equipped with long crane (10 m) and the spacing of the corridors should not exceed 24 m. Otherwise, during the extraction of the logs, the skidder has to approach the crowns with his cable to at least 8 m from the corridor. That means a good coordination between the different actors especially as there are often not from the same company.

The global productivity is high in the 5 case studies (9,7 to 17,8 t/pmh) due to the fact that the mean haulage distances are under 500m. This factor should be taken into account for sites with higher distances for it's influence on the forwarder's productivity.

The phase processing-loading represents for the 5 case studies 53 to 67% of the time consumption. The base diameter has the biggest influence on the productivity; nevertheless to build up, productivity models it will be necessary to collect much more data on several sites. The crown-corridor distance has probably also a strong influence on the productivity. This has to be verified on other sites.

With the grapple saw the crown can be processed exactly as needed for loading and the available space on the forwarder, while working safely. Cross-cutting takes only 10 s/t. The pilot needs to leave his cab only when there is a problem with the machine (for example replacing the chain of the saw). As a consequence, no more manual preparation of the crowns is needed.

Harvesting small branches (under 10 cm) has probably a negative impact on the productivity (not measured). Leaving them in the forest is also more interesting for the preservation of the soil fertility and better for the quality of the chips.

Another issue is the impact of the forest machines. There was no specific study about the damages on remaining trees or on regeneration but impacts were rarely observed during the time studies, due to careful pilots. Nevertheless, it should be measured in order to accumulate objective data.

The test of the two machines systems, i.e. a grapple saw mounted (ii) on an excavator and (iii) on a skidder with crane, followed by a forwarder, will soon be performed and, followed by an economic analysis.

References

Burban J. : La mécanisation de la récolte des houppiers des gros feuillus. Mémoire de fin d'études AgroParisTech-FCBA. 2012.

Harmonised protocol for harvesting operation, including in storm damaged forests (2003). Concerted Actions AIR3-CT94-2097 & QLRT-CT-2001-00645.

Les protocoles AFOCEL pour l'étude de chantiers d'exploitation forestière (1998). Document de complément de formation de P. Cassotti d'après J.P.Laurier.

La processionnaire du chêne (*Thaumetopoea processionea*). Département de la Santé des forêts. Ministère de l'Agriculture. 2006.

CACOT E. (2009). La mécanisation du bûcheronnage dans les peuplements feuillus – Synthèse opérationnelle. FCBA, 2009. 26 p + annexes.

Pischedda D. et al. : Pour une exploitation forestière respectueuse des sols et de la forêt PROSOL. ONF FCBA. 2009

FEC- FORMEC 2014: "Forest engineering: propelling the forest value chain"

September 23-26, 2014, Gerardmer – France

Mechanized harvesting of big broadleaves crowns

Philippe Ruch, Xavier Montagny, Alain Bouvet
Institut Technologique FCBA
Pôle Première transformation - Approvisionnement
10 avenue de Saint Mandé, F-75012 Paris, France
e-mail: philippe.ruch@fcba.fr; xavier.montagny@fcba.fr; alain.bouvet@fcba.fr

Erwin Ulrich, Pascal George
ONF
Direction Forêt et Risques Naturels, Département R&D
Boulevard de Constance, 77300 Fontainebleau,
e-mail: erwin.ulrich@onf.fr; pascal.george@onf.fr

Summary:

For the French State Forest Service (ONF), identifying efficient, cost-effective mechanized logging solutions to secure the processing of big crowns in mature oak and beech stands has become a real challenge. Less and less motor-manual workforce is available to perform such relatively dangerous operations and the demand for biomass is increasing. Moreover, in the department of Moselle, motor manual processing is nowadays increasingly difficult to do, due to the invasion of irritating caterpillars (*Thaumetopoea processionea*) in oak stands, causing important human health problems.

Following an analysis of the diversity of the stand conditions (last thinnings and regeneration fellings) and the characteristics of the crowns (architecture, dimensions…), three logging systems have been identified using a grapple saw mounted (i) on a forwarder with long crane (10 m) (single machine system), (ii) on an excavator and (iii) on a skidder with crane, both processes the crown for a conventional forwarder (two machines system).
The test of these machines on 5 sites in Moselle, started in autumn 2013 with the single machine system (Valmet Combi and HSM F12, both with Hultdins grapple saw), and results are presented in this paper.

These case studies have demonstrated that from the technical point of view, the mechanization of the big broadleaves crowns is possible while staying with the machines in the corridors for soil protection. Therefore machines must be equipped with long crane (10 m) and the spacing of the corridors should not exceed 24 m. The global productivity is high in the 5 case studies (9,7 to 17,8 t/pmh) due to the fact that the mean haulage distances are under 500m.

Keywords: crowns, mechanization, broadleaves, grapple saw, biomass.