Developing full-mechanized harvesting systems for broadleaved trees: a challenge to face the reduction of the manual workforce and to sustain the supply of hardwood industries*

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Abstract
The pool of the 4 forestry leaders in Europe (Germany, Finland, France and Sweden) totalises about 60% of the European wood growing stock and timber harvest: their total annual roundwood production is more than 180 million cubic meters. In Finland and Sweden, where 80% of the forest is composed of spruce and pine, close to 100% of the annual harvest are achieved by harvesters (Cut-To-Length system). In Germany and France, where the proportion of hardwoods in the growing stock is respectively 46% and 69%, the rate of mechanization is much more limited: respectively about 35% and 28%; the motor manual system (chainsaw + skidder/forwarder) is still dominating. However, full-mechanized solutions will be needed for broadleaved stands. Indeed, as it has been clearly demonstrated in France, while the number of new entrants in the logging business does not stop decreasing, mechanization is the only solution to sustain the supply of raw material to wood industries. However, taking into consideration the feed-back from loggers, the CTL machinery (harvesters) currently on the market, initially purposed-built for cutting and processing conifers, seem not to be adapted for processing all types of trees, especially broadleaved trees of temperate forests (oak, beech, chestnut…) characterized by an irregular shape, a wide crown and large branches. Besides, the economical feasibility of North-American systems combining at least 3 machines (ex: feller-buncher + skidder + processor) is not proved in small-sized logging sites (a few hectares only) as it can be common in many parts of Europe. Several other alternatives are currently experimented, especially in France, to find cost effective solution to harvest hardwoods with machines.

1. INTRODUCTION

All over Europe, mechanization of logging operations has expanded during the 3 last decades, and still expands, in the Western and Central Europe countries (UK, Norway, Germany, France…) but also, recently, in the Eastern countries such as Poland. Thus, in Finland and Sweden, close to 100% of the annual harvest are achieved by harvesters (Cut-To-Length system). In Germany and France, the rate of mechanization is much more limited: respectively about 35% and 28%; the motor manual system (chainsaw + skidder/forwarder) still dominates. Meanwhile, in many countries, jobs in logging business are less and less attractive and the number of new entrants in this sector does not stop decreasing. An enhancement of

mechanization, especially in hardwoods, is needed to ensure the supply of raw material to wood industries. But are the CTL machinery (harvesters) developed for conifers suitable also for harvesting all kinds of broadleaved trees, especially those of temperate forests (oak, beech, chestnut…), with irregular shape, wide crowns and large branches?

To face this challenge, several experiments of mechanization in hardwoods are currently ongoing, particularly in France. This paper aims at presenting more in details the stakes of mechanization as well as presenting the state of the art regarding experiences of hardwood mechanization, with a special attention to the French situation.

2. WORK FORCE AND MECHANIZATION: THE STAKES SEEN FROM THE FRENCH POINT OF VIEW

2.1 Harvested volumes: facts and perspectives

In Europe, the pool of the 4 forestry leaders (Germany, Finland, France and Sweden) totalises about 60% of the European wood growing stock and timber harvest: their total annual roundwood production is more than 180 million cubic meters. But when in the two Nordic countries, 80% of the forest is composed of spruce and pine, the proportion of hardwoods in the growing stock in Germany and France is respectively 46% and 69%.

In France the biological forest growth (top end diameter of 7cm) is close to 92 million cubic meters per year. The annual marketed harvest of roundwood has been quite stable for several years, around 35-37 million cubic meters. Besides, about 24 million cubic meters are also harvested by individuals as firewood for self-consumption. So, there is a big potential for harvesting more wood every year, which is of particular interest considering the current increasing international demand of wood.

The new French Forest Policy elaborated in the last two years takes these facts into account: the objective is to develop the economy of the forest wood based industry through harvesting more wood in the French forest. It is expected that the increase of the harvest will be concentrated on softwood timber (time to harvest has come for pine, spruce and Douglas fir plantations resulting from the large campaign of reforestation that took place after the second world war, and European softwood sawmills production is expanding) as well as on fuelwood (to sustain the supply of energy plants that are to be installed in the short and medium term according to the national plan for increasing the level of production of renewable energy). This fuelwood should be found in logging residues (softwoods + hardwoods) but also in poor quality stands (mainly hardwoods).

<table>
<thead>
<tr>
<th></th>
<th>Marketed harvest in France (Million cubic meter)</th>
<th>2004</th>
<th>2005</th>
<th>2010 (Estimation)</th>
<th>Variation 2010 / 2005</th>
</tr>
</thead>
<tbody>
<tr>
<td>Softwood roundwood</td>
<td></td>
<td>22</td>
<td>22.6</td>
<td>25</td>
<td>+2.4</td>
</tr>
<tr>
<td>Hardwood roundwood (including firewood)</td>
<td></td>
<td>13.2</td>
<td>14.4</td>
<td>15</td>
<td>+0.6</td>
</tr>
<tr>
<td>Chips for energy</td>
<td></td>
<td>0.2</td>
<td>0.5</td>
<td>2.5</td>
<td>+2</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td>35.4</td>
<td>37.5</td>
<td>42.5</td>
<td>+5</td>
</tr>
</tbody>
</table>
Harvesting more wood means a need of extra machinery and workforce. But, right now and for several years already, both loggers and forestry schools do not stop complaining about the difficulties in recruiting motivated candidates.

### 2.2 Forest workforce evolution and its consequence on mechanization development in France: facts and prospective

Official statistics concerning the population of loggers are quite scarce, and focus on wage-earners only. To approach the whole population of loggers (including self-employed people and contractors), it is necessary to cross-check different sources of data (numbers of logging companies, of wage-earners, of machines, average productivities…) and to consolidate regional and national analysis. According to this system of calculation, the total number of people working in the logging business in France (excluding office jobs and people in charge of wood trade only) would be approximately 14 600 whom 11 000 chain saw operators (Laurier, 2005).

*Cf. figure 1 & 2.*

Figure 1. Loggers population in France (managers + wage-earners) in 2004.

Figure 2. Forest machines fleet in France in 2004.

Laurier showed that the population of loggers considerably decreased for the last 25 years: it has been divided per 3 while the national annual harvest has been multiplied by 1.3 along the same period (figure 3). This was possible thanks to mechanization, initially developed in the first thinnings in softwoods (end of the eighties), but which came to second and third thinnings and finally to final cuts (figure 4). The Cut-To-Length system combining harvesters and forwarders has been more and more taking over from the “traditional system”, where trees were cut and trimmed by motor manual operators and extracted in full length by cable skidders. In the European project ERGOWOOD, Le-Net *et al.* (2005) clearly demonstrated that in France, the development of mechanization has been a “follower phenomena”, that is to say a consequence of different driving forces, among which the increasing difficulties for loggers to find qualified chainsaw operators. The hardness of the job as well as the little attraction for manual jobs in general in the current French society, are the main reasons explaining the lack of new comers in this business.
Figure 3. Number of wage-loggers and annual marketed harvest from 1978 to 2004 in France.

Figure 4. Evolution of the mechanization rate in softwood harvest in France.

3. SURVEY OF THE CURRENT HARDWOOD MECHANIZATION

3.1 A few examples of hardwood mechanization in Europe

In Northern Europe (Sweden, Finland, Norway, Denmark), forests are mainly composed of coniferous species, with 80% of spruce and pine. There are broadleaved species (birch, aspen…), but quite easily processed with conventional single-grip harvesting heads as trees in these boreal or sub-boreal forests look like conifers: they are relatively straight and have little branches.
In Spain, 300 harvesters work in pine stands or in eucalyptus stands. The 225-240 harvesters working in eucalyptus are mostly CTL harvesting heads mounted on tracked excavators.

In Germany, 90% of the broadleaved stands are high forests, and the number of stems kept per hectare is quite important. So trees can be cut and processed without too many difficulties by conventional harvesters. The rate of mechanization would be about 20% (close to 2 Mm³ per year) in German hardwoods, with some variations between Länders. Due to the lack of manual workforce and storm damages in the nineties, mechanization is more developed in West Germany.

Picture 1. Straight stems, few and little branches: these German trees can be quite easily cut and processed by conventional single-grip harvesters

3.2 Hardwood mechanization in France

Hardwood mechanization really started in France at the end of the nineties and in 2000, just after the 2 large windstorms. There, the work was so dangerous for chainsaw operators that hardwood mechanization seemed to be a good solution. But, according to the results of the 2 national surveys carried out by AFOCEL (Bigot & Cuchet, 2003; Cacot & al., 2006), the situation did not really evolve between 2002 and 2005: the rate of mechanization remains about 2-3% of the annual hardwood harvest (350 000 m³ on a total of about 13-14 million cubic meters). There are 50 harvesters of various trademarks common used for softwood harvesting operating in hardwoods (but 30 full-time equivalent harvesters). They belong to 45 logging companies; 30 of these were of the pioneers. Most of them are located in Middle-West France (Limousin, Poitou-Charente, Dordogne), where the rate of mechanization is up to 15% (chestnut coppices mainly).

Loggers operate according to various systems of organization but also in different conditions. For example:

- If most of the harvesters work alone, some loggers employ a chain saw operator to cut the too big trees and the non-merchantable stems, and if necessary to re-cuts the stumps and check/correct quality and grading of the logs bucked by the machine, in order to improve
the quality and the productivity of its work. Nevertheless, with the higher and higher lack of chainsaw operators, this system is less and less used;

- Some loggers are specialized in the value recovery of small and medium sized trees, processing up to 8 different kinds of logs per logging site, others concentrate on pulplogs production. As a result, the hourly productivity is very variable (figure 5) as well as the annual production: from 7 000 to 15 000 m³/year/harvester, for a machine operated in a single shift, full-time in hardwoods. With an average daily productivity of around 50-60 m³ and prices between 8 and 15 €/ harvested m³, the daily turnover varies from 400 to 900 €, while the daily costs of the machine can reach 800 €. Such conditions are economically hard for loggers.

Figure 5. Example of harvester productivities in clear cuts of chestnut coppices in France.

3.3 Limits of hardwood mechanization with the current harvesting heads

Loggers operating harvesters in hardwoods use 3 kinds of harvesting heads (Bigot and Cuchet, 2003):

a) Conventional single-grip softwood heads without modification, except the adjustment of knives pressure, rolls speed…

b) “Hardwood” heads as their manufacturers call them, but that are conventional softwood heads on which special modifications have been made (addition of a top saw, adaptation of the number and the shape of the knives…),

c) Purpose built harvesting heads, specifically designed for hardwoods.

In the category c, there is just one model (Charlier CA 562HW, existing in 2 exemplars), operating only in chestnut coppices until now. From a technical point of view, this equipment proved itself but the economic feasibility has not been demonstrated yet in such stands. As far as the category b is concerned, loggers did not rush on the so-called “hardwood” heads proposed by the manufacturers: they preferred to develop their own technical solution from conventional heads of the category a (KETO 150, AFM 60, TJ 746 & 742...). These individual solutions are appropriate to the type of logging operation (thinning or clear cut) and broadleaved stands they have been developed for. But, they quickly reach their technical and economic limits in other
types of broadleaved stands and/or operation, especially as soon as the trees look like less to coniferous. Harvesting heads are then subjected to hard working conditions, particularly during the delimming process (strikes against the big branches). Consequently, costs and time dedicated to maintenance and repairs are very important.

Besides, North-American systems combining at least 3 machines (ex: feller-buncher + skidder + processor) are not attractive to European loggers because of the small-size of logging sites (a few hectares only), common in many parts of Europe. The small size of logging operations compromises very much the economic feasibility.

Despite the lack of motor-manual workforce, especially for processing pulp logs in small sized hardwoods, we can expect that loggers will not come more to hardwood mechanization until manufacturers will not propose real adapted solutions. Loggers as well as wood supplying companies belonging to pulp & paper groups think there is no efficient and cost effective solutions yet for harvesting hardwoods with machines. Several of these professionals then, with the support of public funds, AFOCEL and/or some manufacturers, experiment alternatives.

4. EXPERIMENTS OF ALTERNATIVE TECHNIQUES IN PROGRESS

As there is a large diversity among broadleaved stands, there should be the place for different technical solutions. For each major kind of stand found in France, AFOCEL analyzed the specific constraints and experimented techniques that seemed a priori adapted (see table 2).

Table 2. Techniques experimented for different types of broadleaved stands found in France, taking the specific constraints of the stands into account.

<table>
<thead>
<tr>
<th>Logging operations</th>
<th>A - Clear cuts or thinnings in coppices</th>
<th>B - Thinnings in high forests</th>
<th>C - Clear cuts or thinnings in a mix coppice / high forest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main species</td>
<td>Oak, hornbeam, chestnut, beech</td>
<td>Oak, beech, birch, sycamore tree, ash…</td>
<td>Same species than for A and B.</td>
</tr>
<tr>
<td>Main constraints</td>
<td>- Volume of the average stem can be very small (&lt;0,2m³).</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Reaching and cutting stems in a clump can be difficult. (Picture 2).</td>
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<tr>
<td></td>
<td>- Special attention is needed to avoid damaging the remaining trees.</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>- In the youngest stands, volume of the average stem can be very small (&lt;0,2m³).</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>- In older stands, forks and big branches in large trees are hard working conditions for the harvesting head. (Picture 3).</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Great variability of the diameters</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>An addition of the constraints of A (coppice) and B (large trees).</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technical solution experimented or close to be experimented</td>
<td>- Separation of felling and processing ①</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Integrated solution for both pulpwood and energy wood ②</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Multi-stem harvesting head ③</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- In young stands: see case A (① ② ③)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- In older stands: a specific harvesting head for large trees ④</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- techniques of case A (① ② ③) for coppice</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>- a special processing head to buck logs in the crowns of the large trees ⑤</td>
<td></td>
<td></td>
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</tbody>
</table>
Pictures 2 and 3. Numerous stems per clump and big branches are not favourable to mechanization.

The results or, at least, the work in progress for the different technical solutions are successively presented for the 2 types of trees the most challenging for mechanization:

- small sized trees (stem volume under 0.2 m$^3$). With trees of such a size, the low productivity is very compromising. Moreover, trees may be difficult to reach and cut if they are grouped into clumps (coppices); *Cf.* Picture 2.
- large sized trees (between 0.4 m$^3$ and 1.2 m$^3$). Big branches and forks are unfavorable to an efficient trimming (*Cf.* Picture 3). Besides, crowns of large trees are a non negligible source of pulp logs in France but the productivity of the harvester when bucking logs in the crown is quite low.

4.1 Solutions for small sized-trees

Being the first field deserted by chainsaw operators, it is the one for which experiments are the most numerous. We present here the full-mechanized technical solutions only.

**Separation of felling and processing - Solution ©**

A 2 machine-system has been experimented for nearly 2 years by one of the most important wood suppliers of the International Paper French pulpmill in Saillat. Before, this logger used to work for 4 years in chestnut and oak coppices with 2 conventional harvesters but he was not satisfied with the results: average productivity was about 5-6 m$^3$/machine hour only. So he kept one of its conventional harvester equipped with a Keto head specially modified for hardwoods (KETO 150) to trim and buck the trees, and he invested in a Naarva grip 1500-40 to take in charge the felling of the trees.
The Naarva head is a guillotine with a cutting capacity of 32 cm initially developed in Finland for energy wood. The results of such a system were encouraging: the average productivity of the processing machine raised to 10.2 m³/hour. Unfortunately, after 6 months of working in hardwoods, the Naarva head was almost destroyed, not strong enough despite changes in the cutting system. A few months ago, it has been replaced by a heavy duty QUADCO feller-buncher equipped with a shear of a cutting capacity of 58 cm. This is the first machine of this type in France.

Pictures 4 and 5. The Naarva guillotine and the Quadco shear tested in chestnut and oak coppices.

This solution will be studied as soon as the training period of the operator is completed, regarding work organisation (task allocation between the 2 machines), productivity and cost but also:

- the ability of the shear attachment to fell stems in dense clumps, with a good quality of the cutting (no damage on the stump, cutting as close to the ground as possible) in order to allow a new generation of the coppice,
- the minimum size of the logging site for absorbing the cost of the transfer of 2 machines instead of 1.

**Integrated solution for both pulpwood and energy wood - Solution 2**

Recently, some manufacturers have developed small-sized feller-bunchers, particularly adapted for harvesting small trees. One of these machines – Timberjack’s Energy Harvester, equipped with a felling head and an accumulating arm – has been tested in the European project Forenergy1 on 3 of the most promising resources of small trees in Europe: Finnish young conifer forests, French coppices (hornbeam, oak) and Italian single-row plantations of black locust. The average productivity recorded was between 4 and 8 green tonnes per net working hour. Best results (8 tonnes) were obtained in single-row plantations, where the machine can manoeuvre with ease and has only to fell and bunch the trees (that will be chipped in a further step). Worse

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1 Project NNE5-2000-00395 “FORENERGY”. Budget: 4.6 M€. With the participation of 9 partners from Austria, Finland, France, Italy, Sweden and United Kingdom. Tests conducted by R. Spinelli, E. Cuchet and P. Roux.
results were found in thinnings of coppices, where the machine was in charge of both felling the trees and cutting pulp logs in suitable stems. Moreover, in this type of operation, the constricted work space limits the degree of freedom to approach the target stems, so the head has to manoeuvre before getting the right position to fell the stem.

This project finished 3 years ago, and no such a machine has been sold by the manufacturer in France. Like the Naarva, this head specially built for felling energy wood is not strong and productive enough to also cut pulp logs or small diameter sawlogs in French broadleaved stands on a full-time basis.

**Multi-stem head – Solution 📈**

Tests on another and stronger multi-stem head (a Logmax 4000 mounted on a TJ 1070) are programmed in the coming months, as part of a 3-year research program launched in 2006 by several pulpmills using hardwoods in France and belonging to the pulp & paper groups Saïca, Burgo, Tembec and International Paper companies.

### 4.2 Solutions for large sized trees

Until now, solutions for large broadleaved trees have not been investigated much.

**A specific head to process the crowns of the trees – Solution 📈**

In 2002, AFOCEL tested in forest conditions 2 grapple-saw initially designed for a use on wood yards but reputed for their ability to process twisted stems without having to drop them, thanks to special rolls: the HUET grapple (Belgium manufacturer) and a prototype of the Swiss company AFICOR. This was done with partners from the pulp and paper industry and contractors. The tests have been carried out on 4 logging sites with beech and oak crowns (roughly cut by the chainsaw operator who prepared the large pieces of timber in the main stem). The Huet grapple (1800 kg) was mounted on an excavator while the AFICOR (750 kg only) was mounted on a forwarder base and could cut the logs directly into the berces. The productivities observed in the forest were between 15 to 20 m³/hour, while about 30 m³/hour on wood yards of mills. But, above all, these grapples revealed too much fragile in forest conditions, particularly the AFICOR one with the hydraulic hoses. Hence this solution has been abandoned.

**A special head to process large trees on a whole – Solution 📈**

One of the target of the on-going European project “forstINNO”, leaded by the German manufacturer HSM and in which AFOCEL takes part, is to build a single-grip harvesting head able to take a maximum of the value of the wood from trees between 0.4 and 1.2m³, both in the main stem and in the largest branches of the crown (diameter > 10cm). This is a very challenging target for 2008.

### 5. CONCLUSION & PERSPECTIVES

In the medium term, shortage of chainsaw operators in hardwoods in France could become a real bottleneck for the supply of raw material to hardwood industry, especially to pulp mills and sawmills specialized in small logs. A realistic hypothesis is that 30% of the hardwood
harvest (which is of 14 million cubic meters) should be mechanized in the middle term in order to counteract the lack of motor-manual workforce. This rate of mechanization may be reached with about 300 machines, in broadleaved stands on favorable terrain conditions and with trees not too much branched or twisted (poplar plantations, young high forests, coppices).

However, the fleet in hardwoods has been remaining for several years around 30 full-time equivalent harvesters only. Current technical solutions proposed by manufacturers are not cost effective in too many types of broadleaved stands commonly found in France. Loggers are in expectation for alternatives: it is up to the researchers and forest machine manufacturers to find real innovations, satisfying from both a technical and economic point of view.

6. LITERATURE CITED

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