OPTIMISING THE CHAIN FROM THE PLANT TO THE PLANK, TAKING INTO ACCOUNT CONSIDERATIONS RELATED TO SUSTAINABLE MANAGEMENT. NEW RESULTS ON SESSILE OAK SILVICULTURE*

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ABSTRACT

Since the 4th IUFRO WP 5.01.04 Workshop held in Canada in 2002, our research team, the LERFoB, in co-operation with two other French organisations, CTBA and ONF, has made a new advance on a long-term project aiming to optimise the chain from the plant to the plank in sessile oak (*Quercus petraea* Liebl.) taking into account considerations related to sustainable management. The method used in this project is typical of the method in use at the LERFoB — that is, a method based on joint modelling of growth and wood quality as well as simulation software. There are nine elements in our chain of models and software. These are now available to perform detailed simulations of the effect of contrasted silvicultural schedules — in a context of pure and even-aged stands naturally or artificially regenerated — on products delivered, environmental considerations, economical considerations, and employment.

Keywords: silvicultural schedule; forest–wood chain; sustainable management; multicriteria evaluation; optimisation; simulation software; *Quercus petraea*.

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INTRODUCTION

The presentation described new advances gained since the 4th IUFRO WP 5.01.04 Workshop in Canada in 2002 on a long-term project to optimise the chain from the plant to the plank in sessile oak, taking into account considerations related to sustainable management (Nepveu *et al.* 2004).

"Considerations related to sustainable management" means considerations other than those related to material aspects such as volume production, quality, and monetary benefits, so that is considerations related to employment, energy balance (from renewable/non-renewable sources), sequestred carbon (in the forest and in the resulting wood products), as well as the amount of mineral nutrients lost due to harvesting.

The five authors belong to three organisations :

- Gérard Nepveu, Gilles Le Moguédec, and Frédéric Mothe work at the LERFoB, the Laboratoire d'Etude des Ressources Forêt-Bois. The LERFoB is a joint public research laboratory (begun in the year 2000) between INRA institute and Higher Forest School (ENGREF). The task force of the LERFoB comprises 10 PhD students + 49 permanent staff of whom 25 are researchers or teacher-researchers (growth and yield modellers, wood quality modellers, forest ecologists);
- Emmanuel Bucket belongs to CTBA, the Centre Technique du Bois et de l'Ameublement. The CTBA is in charge of the R&D for the wood industry;
- Myriam Legay works at the R&D department of ONF, the Office National des Forêts. The ONF is in charge of the management of the French public forests.

The method used in the project described here is typical of the method in use at the LERFoB and is based on joint modelling of growth and wood quality as well as on simulation software.

The presentation is organised in five parts :

(1) General introduction of our chain of models and software;

(2) Our state-of-art at the 4th IUFRO WP 5.01.04 Workshop, Canada, 2002;

(3) New developments since the 4th IUFRO WP 5.01.04 Workshop;

(4) Examples of uni- and multi-criteria evaluation of 36 silvicultural schedules through our chain of models and software;

(5) Conclusion, and next steps; the Optichêne project.

INTRODUCTION OF OUR CHAIN OF MODELS AND SOFTWARE

Briefly, our chain of models and software includes nine elements. This chain allows us to simulate jointly the "material considerations" and "sustainability considerations" of the outputs of a given silvicultural schedule.

Element 1: The Growth and Yield Simulator "Fagacées"

The growth and yield simulator "Fagacées" (Dhôte 1998; Dhôte & Le Moguédec 2004) is fed by an individual tree growth model independent of distance. Up to now Fagacées has run for pure and even-aged stands of beech (*Fagus sylvatica* L.) and sessile oak naturally or artificially regenerated. The inputs for Fagacées are the fertility class and the silvicultural schedule.

As part of the French software platform called "CAPSIS" (De Coligny *et al.* 2004), Fagacées is for free use.

The outputs delivered by Fagacées for each simulated tree at each stage of its life are summarised in Fig. 1.

Two comments have to be made about the simulations of Fagacées :

- Fagacées accepts several simplifications in tree simulation in which the pith is centred and perfectly vertical, the tree section is perfectly circular, the stem is perfectly straight, and there are no branches below the crown;
- The allometric relationships included allow Fagacées to simulate the volume of branches in the crown.

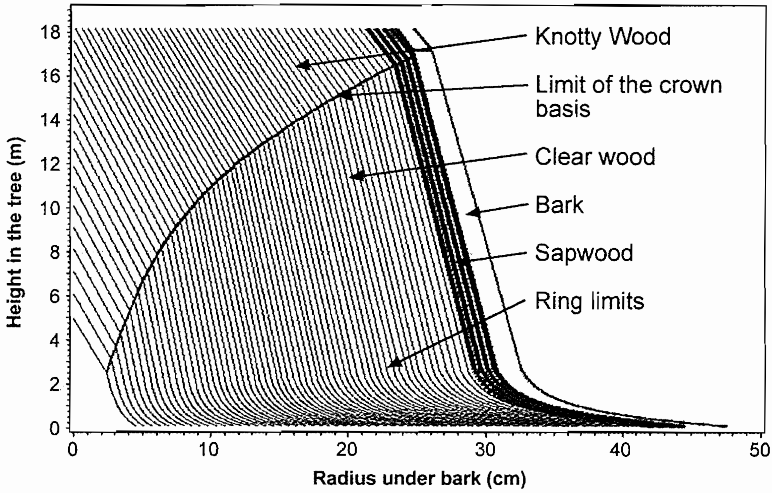

FIG. 1–Outputs delivered by the growth and yield simulator Fagacées for each simulated tree at each stage of its life.

Element 2: A Wood Density Model

The wood density model built in our LERFoB is a mixed-model that takes into account the intra- and inter-tree variability (Guilley 2000).

From Fagacées outputs, our wood density model allows us to estimate the ovendry matter content (and carbon content) in all above-ground parts of the simulated tree and related simulated products/by-products/firewood.

For example, a silvicultural schedule corresponding to a "heavy thinning" (*see below*) would produce the pattern illustrated in Fig. 2 which shows the above-ground sequestred carbon in living and dead trees as well as in resulting simulated products/by-products/firewood that may be obtained during the life of a forest stand through combination of Elements 1 and 2 (and following Elements 3, 4, 5, and 7 as well) of our chain of models and software.

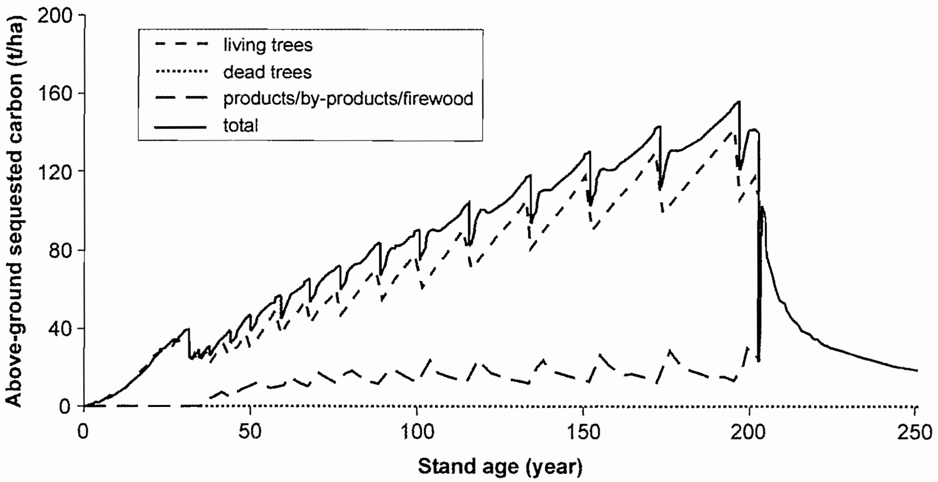

FIG. 2–Above-ground sequestred carbon all through the stand life in living and dead trees as well as in resulting simulated products/by-products/firewood in a silvicultural schedule corresponding to "heavy thinning" (after Bucket *et al.* 2005, *see* details in the text).

Element 3: A Model for Decomposition Time of Dead Trees

Our model for decomposition time of dead trees in the forest presently accepts that each year a given dead tree loses 2.5 cm of its radius along its stem. As for all the parameters put in our chain of models and software, this one can be changed to perform sensitivity analyses (Le Moguédec 2004).

From Fagacées outputs (Element 1) and the wood density model (Element 2), Element 3 enables the carbon sequestred above-ground in the dead trees to be computed.

Element 4: Data on Carbon, Nitrogen, Phosphorus, Potassium, Calcium, and Magnesium Content in Wood and Bark

Data on carbon, nitrogen, phosphorus, potassium, calcium, and magnesium in wood and bark have been included in our chain. These data were gained from wood and bark samples collected at breast height on 20 sessile oak trees aged 100 years.

From Fagacées outputs (Element 1) and the wood density model (Element 2), Element 4 allows us to compute the export of nutrients from the forest when harvesting.

Element 5: Cross-cutting and Log Allocation Decision Model

From Fagacées outputs (Element 1) regarding external dimensions and internal characteristics (namely bark and sapwood thickness as well as diameter of knotty heartwood), a cross-cutting and log allocation decision model (Element 5) allows us to allocate the various parts of each simulated tree into:

- Log(s) for sliced veneers (if any);
- Log(s) for making barrel staves (if any);
- Log(s) for furniture and indoor joinery (if any);
- Log(s) for industrial sawing (if any);
- Log(s) for making LVL veneer (if any);
- Log(s) for making particleboard (if any);
- Firewood.

Element 6: Price Model for Logs

A price model for logs (felled sale) has been established by Cavaignac *et al.* (2005) and included in our chain. This Element 6 is based on statistical modelling from the observed sale prices for several hundreds of log sets.

In the model, the price depends on allocation of the log (*see* Element 5) and mid-diameter of the log (except for firewood).

Element 7: Log Processing Models

From the outputs of Element 1 (Fagacées) and Element 2 (wood density model), log-processing models (Element 6) established for each log type (Element 5) and based mainly on external dimensions and internal characteristics (bark and sapwood width, knotty core diameter) compute the quantity of end-products (area of sliced veneer sheets, etc.) as well as volume and ovendry mass of by-products.

Ways to (virtually) process the logs and to compute the quantities of wood products/by-products for sliced veneers, barrel staves, sawn goods for furniture and indoor joinery, sawn goods for industrial sawing, and LVL veneers are exemplified in Fig. 3.

Element 8: Data from the Silvicultural Part of the Forest-wood Chain

Element 8 consists of a set of data collected from the forest manager (Office National des Forêts) regarding the silvicultural and harvesting costs as well as employment in the forest sector.

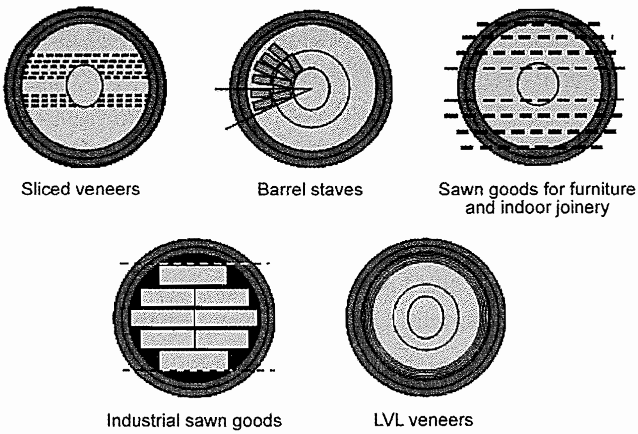

FIG. 3–Scheme of the virtual processing of the simulated logs (coming from Element 5 of the chain) for sliced veneers, barrel staves, sawn goods for furniture and indoor joinery, industrial sawn goods, and LVL veneers.

Element 9: Data from the Industrial Part of the Forest-wood Chain

Element 9 consists of a set of data collected from the forest industry regarding energy costs (from renewable and fossil sources), lifetime of the various end-products generated, employment, and sale prices of end-products, as well as haulage distances between the forests and relevant wood industries.

For details on Elements 4, 6, 7, 8, and 9, please refer to Bucket (2004) and Bucket *et al.* (2005).

OUR STATE-OF-ART AT THE 4TH IUFRO WP WORKSHOP, CANADA, 2002

At the 4th IUFRO WP 5.01.04 Workshop, only Elements 1, 2, and 3 of our chain of models and software were presented. Simulations of the effects of silvicultural schedules on sessile oak were therefore crude (Nepveu *et al.* 2004).

They took into consideration the following four outputs: (i) the volume, dry-matter, and carbon sequestred above-ground at a given time in the forest; (ii) the carbon sequestred in the related products; (iii) the volume of bark exported from the forest when harvesting (considered as an indicator of the mineral nutrient export); (iv) the revenue for the forest manager due to (standing) sale of trees.

NEW DEVELOPMENTS SINCE THE 4TH IUFRO WP 5.01.04 WORKSHOP

At present, Elements 1 to 9 allow detailed simulations of the effect of contrasting silvicultural schedules on products delivered, environmental considerations, economical considerations, and employment.

As examples, results of several simulations done through our chain for three thinning regimes (very heavy thinning, heavy thinning, no thinning) applied to sessile oak are presented in this section. They are related to: carbon sequestred in the forest and products, amount of mineral nutrients lost due to harvesting, renewable and fossil energy used, revenue for the forest manager, and revenue for the wood industry.

The silvicultural conditions taken into consideration for our three virtual forests (one forest managed with "very heavy thinning", one with "heavy thinning", one with "no thinning") were as follows:

- Pure and even-aged stands;
- Naturally regenerated forests;
- Fertility class: dominant height 24.4 m at age 100 years (the same for the three forests);
- Final cutting at age 202 years;
- 202 stands of same area in each forest;
- Fully balanced forests (one stand aged 1, one stand aged 2, ..., one stand aged 202);
- The three silvicultural schedules correspond to the same RDI (Relative Density Index) maintained from age 31 to 202: RDI = 40 for the forest "very heavy thinning"; RDI = 65 for the forest "heavy thinning"; RDI = 100 for the forest "no thinning".

The reason why we used virtual forests in place of normal (real) forests is explained in the last section of the paper.

The results of the simulations are shown in Tables 1–4 and Fig. 4.

What these Tables and Figure mean is that :

- The silvicultural schedule dramatically affects the amount of carbon sequestred in trees and products/by-products (144 t/ha for "no thinning" compared to 100 t/ha for "very heavy thinning" — Table 1);

TABLE 1–Carbon sequestred in living and dead trees (above-ground) as well as in resulting products/by-products/firewood *versus* silviculture (t/ha and % of the total) (after Bucket *et al.* 2005, *see* details in the text).

	Very heavy thinning	Heavy thinning	No thinning
In living trees	75 (75%)	96 (74%)	123 (86%)
In dead trees	< 1 (< 1%)	< 1 (< 1%)	5 (3%)
In products/by-products/firewood	24 (24%)	32 (25%)	16 (11%)
Total	100 (100%)	129 (100%)	144 (100%)

- Carbon in the living trees represents a prominent part of the total carbon sequestred (74% to 86% depending on the schedule — Table 1);
- Minimal carbon is sequestred in dead trees (Table 1);
- The higher the amount of sequestred carbon, the smaller the quantity of mineral nutrients lost due to harvesting (Tables 1 and 2);
- The heavy thinning silvicultural schedule uses the greatest amount of energy through harvesting, transportation, and log processing (*see* Fig. 4);

TABLE 2–Quantity of mineral nutrients lost due to harvesting *versus* silviculture (kg/ha/year) (after Bucket *et al.* 2005, *see* details in the text)

	Very heavy thinning	Heavy thinning	No thinning
Nitrogen	4.45	5.02	3.20
Phosphorus	0.19	0.21	0.13
Potassium	2.36	2.54	1.63
Calcium	15.2	19.8	12.4
Magnesium	0.22	0.26	0.17

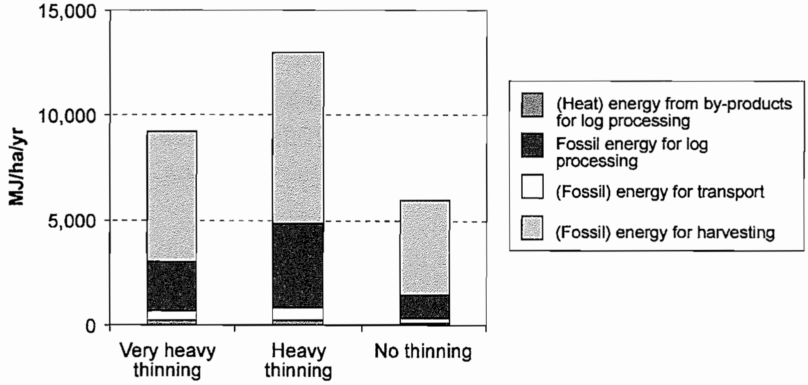

FIG. 4–Renewable and fossil energy used for harvesting, transport, and log processing *versus* silviculture (MJ/ha/year) (after Bucket *et al.* 2005, *see* details in the text)

- A great deal of the energy needed can be provided from by-products produced during log processing (Fig. 4);
- Energy for transport and harvesting represents a small part of the energy budget (Fig. 4);
- Revenue of the forest manager in "very heavy thinning" and "heavy thinning" is of approximately same value (1,423 *versus* 1,441 Euros/ha/year), "no thinning" being less (991 Euros/ha/year — Table 3);
- For the three schedules, total sale provided by logs for sliced veneers, barrel staves, furniture, and indoor joinery represents around 80% of the revenue of the forest manager (Table 3);

TABLE 3–Revenue of the forest manager (according to the log type delivered) *versus* silviculture (% of the total revenue and Euros/ha/year) (after Bucket *et al.* 2005, *see* details in the text)

	Very heavy thinning	Heavy thinning	No thinning
Logs for sliced veneer	38%	29%	30%
Logs for barrel staves	23%	21%	23%
Logs for furniture and indoor joinery	28%	31%	27%
Logs for industrial sawing	9%	16%	19%
Logs for LVL	1%	1%	0%
Logs for particleboard	1%	1%	0%
Firewood	<1%	<1%	<1%
Total	100%	100%	100%
Euros/ha/year	1,423	1,441	991

- The schedule "heavy thinning" provides the best revenue for the wood industry based on 1 ha of forest (2,377 Euros/ha/year compared to 2,018 and 2,006 Euros/ha/year for "very heavy thinning" and "no thinning" respectively — Table 4);
- As for the forest manager, sales of sliced veneers, barrels, and sawn timber for furniture and indoor joinery represent a prominent part of the total revenue of the wood industry (80% to 88% for "heavy thinning" and "very heavy thinning" respectively — Table 4).

EXAMPLES OF UNI- AND MULTI-CRITERIA EVALUATION OF 36 SILVICULTURAL SCHEDULES THROUGH OUR CHAIN OF MODELS AND SOFTWARE

Thanks to our present chain of models and software we are now able to compare a lot of silvicultural schedules for a number of types of outputs and taking into consideration alternative conditions (e.g., changing the rules of bucking and log allocation, different types of end-products, a dramatic increase in fossil energy costs).

For example, we run our chain of models and software to :

- Compare 36 contrasted silvicultural schedules for different inputs;
- Illustrate the relationships, at silvicultural schedule level, between outputs of the same type at forest and industry levels;
- Evaluate the possible antagonism between some functions of the forest.

As the results presented here are just examples which illustrate some of the large number of outputs that we are able to simulate with our chain, we will not comment on them in detail.

TABLE 4–Revenue of the industry (according to the type of wood product delivered) *versus* silviculture (% of the total revenue and Euros/ha/year) (after Bucket *et al.* 2005, *see* details in the text)

	Very heavy thinning	Heavy thinning	No thinning
Sliced veneer sheets	39%	36%	37%
Barrels	32%	23%	33%
Sawn timber for furniture and indoor joinery	17%	21%	15%
Industrial sawn timber	8%	14%	14%
Veneer sheets for LVL	2%	4%	0%
Particleboard	2%	2%	<1%
Total	100%	100%	100%
Euros/ha/year	2,018	2,377	2,006

Comparison of 36 Contrasted Silvicultural Schedules for Several Outputs

The 36 contrasted silvicultural schedules compared here correspond to those presented by Nepveu *et al.* (2004). In addition to the conditions already mentioned in the previous sections of this paper, the 36 schedules simulated are obtained by combining six initial (age 31) thinning intensities (from very heavy thinning (RDI = 5) to no thinning (RDI = 100)) with six final thinning intensities (very heavy thinning (RDI = 5) to no thinning (RDI = 100)). The change from the initial to the final RDI is done progressively.

The 36 simulated schedules are compared in Fig. 5 to 7 with respect to the volume of the end-products delivered by the relevant forests (sliced veneer sheets + barrels + sawn timber for furniture and indoor joinery + industrial sawn timber + veneer sheets for LVL + particleboard); the fossil energy needed to manufacture 1 m^3 of end-products; and the renewable energy generated when manufacturing 1 m^3 of end-products, respectively.

The information provided in Fig. 5 to 7 can be summarised as follows. Once again, these are only a few examples of the type of information that we are able to deliver through our chain of models and software :

- The volume of the end-products provided each year by 1 ha of forest is highly influenced by the schedule. From this point of view, a high initial-density combined with an average final Relative Density Index seems to be the preferred schedule (Fig. 5);
- The fossil energy needed to manufacture 1 m^3 of end-products (in addition to the heat energy provided by the by-products, generated in the course of the processing) seems to be independent of the schedule (Fig. 6);

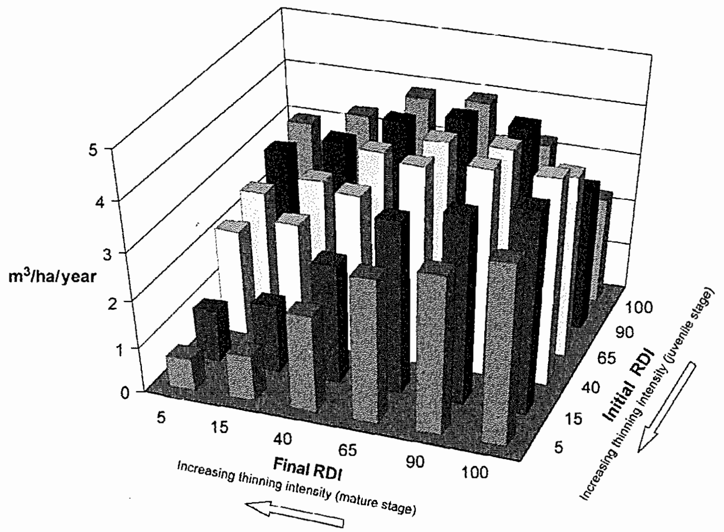

FIG. 5–Volume of the end-products delivered by the forest (m^3/ha/year) depending on the silvicultural schedule (*see* details in the text).

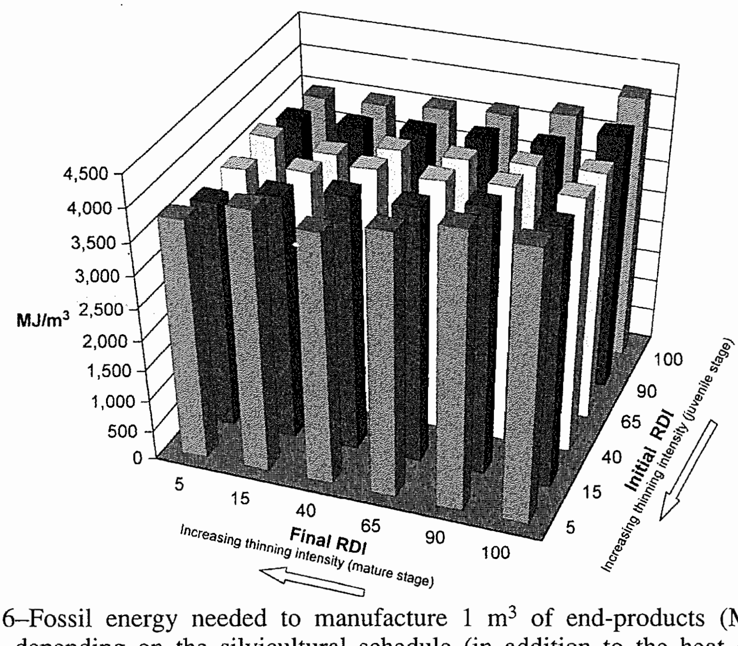

FIG. 6–Fossil energy needed to manufacture 1 m^3 of end-products (MJ/m^3) depending on the silvicultural schedule (in addition to the heat energy provided by the by-products) (*see* details in the text).

- Contrary to the previous example, the renewable energy (firewood + by-products), which is generated when manufacturing 1 m^3 of end-products, depends significantly on the schedule: this energy is clearly higher for denser initial stands and, in this context, slightly higher for denser final stands (Fig. 7).

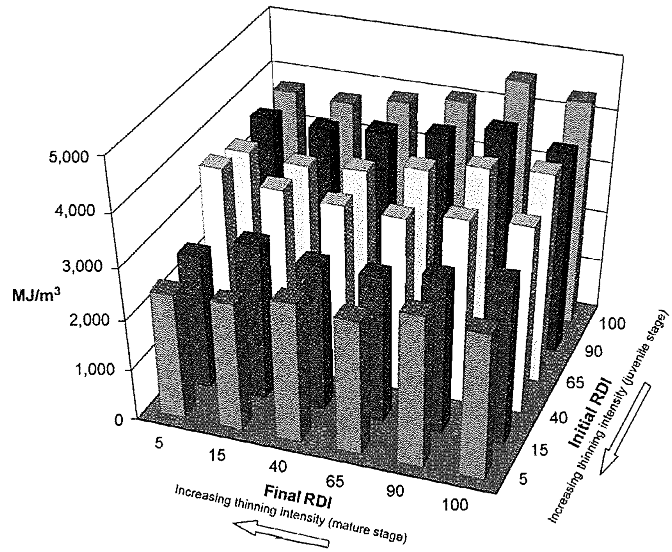

FIG. 7–Renewable energy (firewood + by-products) generated when manufacturing 1 m^3 of end-products (MJ/m^3), depending on the silvicultural schedule (*see* details in the text).

Relationships at Silvicultural Schedule Level Between Outputs of the Same Type at Forest and Industry Levels

The relationship at silvicultural schedule level between two outputs of the same type simulated for the forestry and industry parts of the chain is illustrated for profit in Fig. 8 and for employment in Fig. 9.

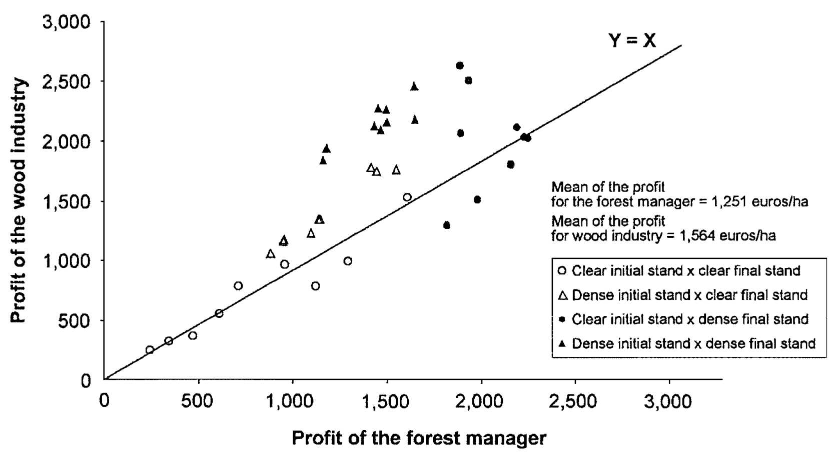

FIG. 8–Profit of the wood industry *versus* profit of the forest manager (Euros/ha/ year). Each point corresponds to one of the 36 silvicultural schedules simulated (*see* details in the text).

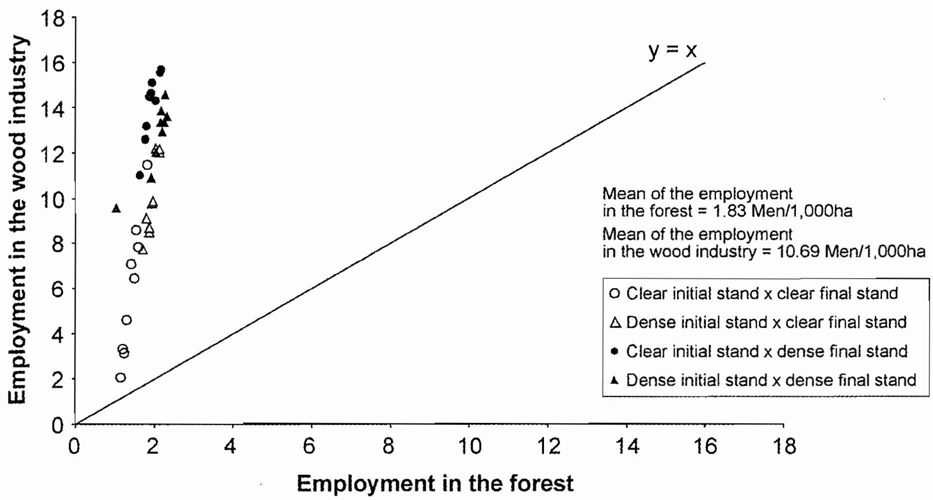

FIG. 9–Employment in the wood industry *versus* employment in the forest (men/1000 ha of forest). Each point corresponds to one of the 36 silvicultural schedules simulated (*see* details in the text).

In these Figures, each of the 36 points corresponds to one of the 36 silvicultural schedules mentioned above. These 36 points were categorised into four groups of nine silvicultural schedules each, that is:

- Clear initial stand × clear final stand (initial and final RDI ≤ 40);
- Dense initial stand × clear final stand (initial RDI ≥ 65; final RDI ≤ 40);
- Clear initial stand × dense final stand (intial RDI ≤ 40; final RDI ≥ 65);
- Dense initial stand × dense final stand (initial and final RDI ≥ 65).

The profits were computed as follows :

- Profit of the forest manager = log and firewood (felled) sale revenue – silvicultural costs – harvesting costs
- Profit of the wood industry = end-products sale revenue – log buying costs – energy costs – log transport costs.

At the silvicultural schedule level, the correlation between the profit of the wood industry and the profit of the forest manager is highly positive (Fig. 8). It also appears that, in schedules combining high initial and final levels of stand density, the profit of the wood industry is significantly higher than the profit of the forest manager.

Even if positively correlated, the employment provided by 1 ha of forest is poorly influenced by the silviculture (Fig. 9). This is contrary to employment in the wood industry which is much better in dense final stands.

Evaluation of the Possible Antagonism Between some Functions of the Forest

As examples of outputs that our chain of models and software enables us to simulate, we present in Fig. 10 to 15 the relationships between four functions of the forest. The results are based on the 36 silvicultural schedules mentioned above. The functions of the forests analysed were:

- Material consideration: the volume of end-products generated each year by 1 ha of our virtual oak forest;
- Economic consideration: the sum of the profits made by the forest manager and the wood industry per year and per hectare of forest;
- Human consideration: the sum of employment in the forest and wood industry per 1000 ha of forest;
- Environmental consideration: the fossil energy needed to manufacture 1 m^3 of end-products.

Looking at Fig. 10 to 15, it appears that:

- There is no antagonism at all between the production of goods, employment, and profit, and they are highly and positively correlated at the silvicultural schedule level (Fig. 10 to 12) ;

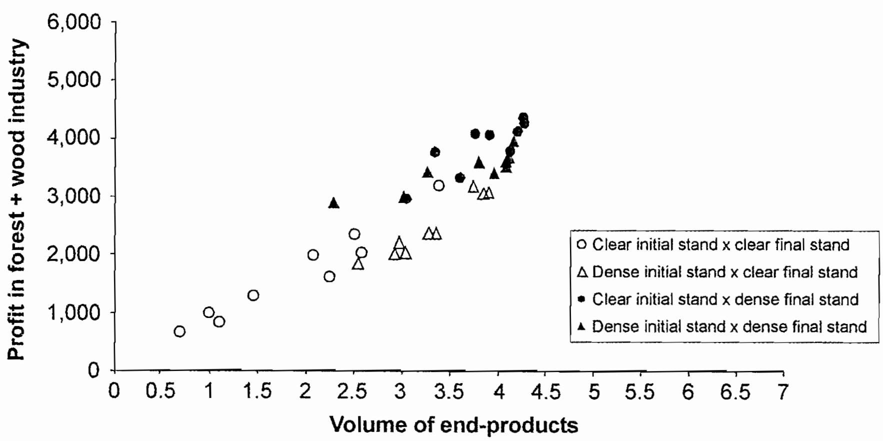

FIG. 10–Sum of employment in the forest and wood industry per 1000 ha of forest (men/1000 ha) *versus* volume of end-products generated each year by 1 ha of forest (m^3/ha/year). Each point corresponds to one of the 36 silvicultural schedules simulated (*see* details in the text).

- When choosing to increase the production of goods, employment, and profit through silviculture, the fossil energy needed to manufacture 1 m^3 of end-products does not appear affected (Fig. 13 to 15).

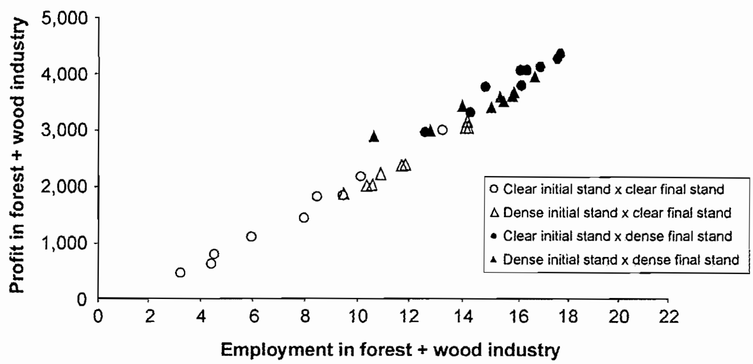

FIG. 11–Sum of the profits of the forest manager and the wood industry per year and per hectare of forest (Euros/ha/year) *versus* volume of end-products generated each year by 1 ha of forest (m^3/ha/year). Each point corresponds to one of the 36 silvicultural schedules simulated (*see* details in the text).

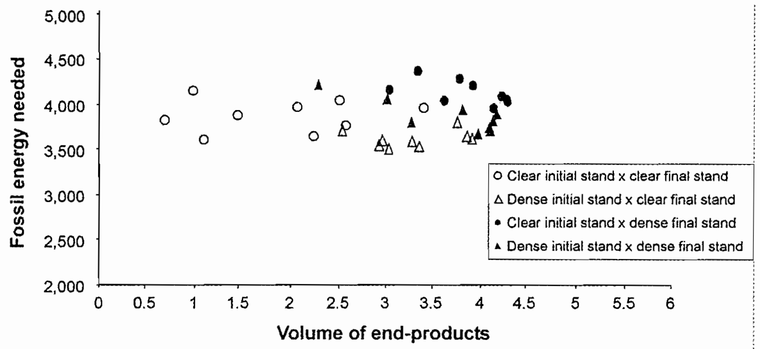

FIG. 12–Sum of the profits of the forest managers and wood industry per year and per hectare of forest (Euros/ha/year) *versus* sum of employment in forest and wood industry per 1000 ha of forest (men/1000 ha). Each point corresponds to one of the 36 silvicultural schedules simulated (*see* details in the text).

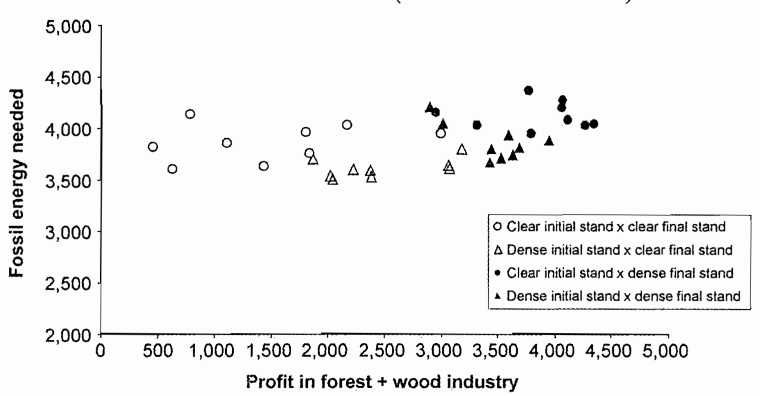

FIG. 13–Fossil energy needed to manufacture 1 m^3 of end-products (MJ/m^3) *versus* volume of end-products generated each year by 1 ha of forest (m^3/ha/year). Each point corresponds to one of the 36 silvicultural schedules simulated (*see* details in the text).

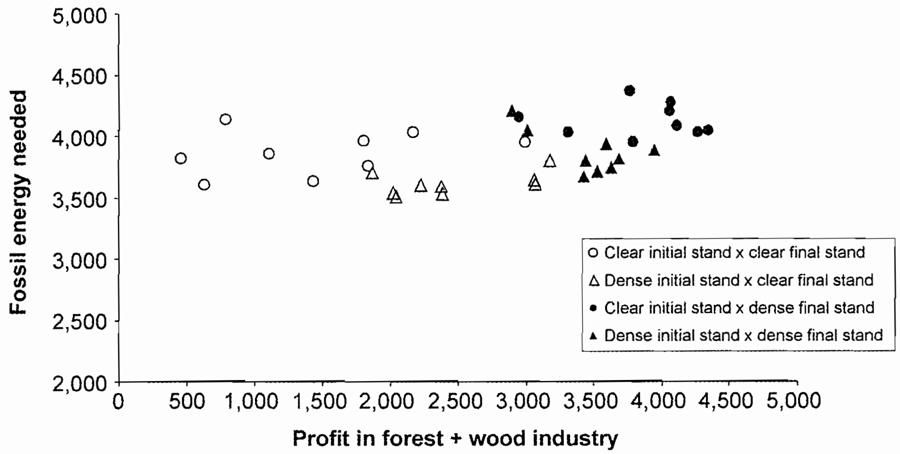

FIG. 14–Fossil energy needed to manufacture 1 m^3 of end-products (MJ/m^3) *versus* sum of the profits of the forest manager and wood industry per year and per 1 ha of forest (Euros/ha/year). Each point corresponds to one of the 36 silvicultural schedules simulated (*see* details in the text).

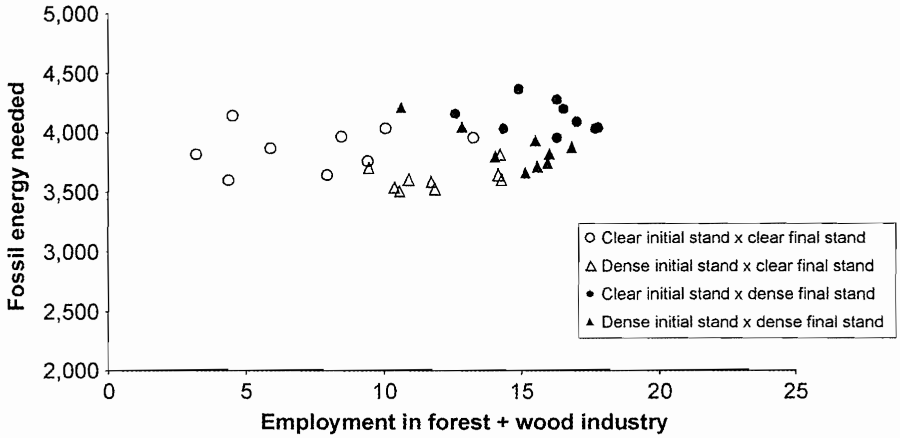

FIG. 15–Fossil energy needed to manufacture 1 m^3 of end-products (MJ/m^3) *versus* sum of employment in forest and wood industry per 1000 ha of forest (men/1000 ha). Each point corresponds to one of the 36 silvicultural schedules simulated (*see* details in the text).

CONCLUSION AND NEXT STEPS

Thanks to our chain of models and software, we are now able to simulate a very large number of material, economic, environmental, and human outputs for a given silvicultural schedule applied to sessile oak, including both the forest and industrial parts of the forest-wood chain. The examples given above demonstrate a very limited number of potential uses of the tool developed at the LERFoB laboratory in co-operation with ONF and CTBA. For this reason, we have not commented on them in detail.

It is important to mention that, at present time, elementary models attached to elements 1 to 9 of our chain have been evaluated satisfactorily. However, the evaluation of the whole chain remains to be done.

In spite of the originality and usefulness of this chain of models and software, we are aware of its present limits. The most important ones are its ability to simulate only a virtual and fully balanced sessile oak forest which is made up of even-aged and mono-specific stands. This is somewhat far from the present situation in the French oak forests. As a result, if we consider that the tool developed represents a significant advance in the field of the quantitative simulation of the benefits that the forest can provide to society, additional work must be done. Our aim is to make the tool completely adapted to the needs of the forest manager, the wood industry, and the people in charge of the policy of the forest-wood chain in France.

For this reason our LERFoB considers the results presented here to be a first contribution to a big project to be carried out during the next few years. This project is called "Optichêne" — "Opti" for "Optimisation" and "chêne" for "oak".

The Optichêne Project: Goal and Steps

The goal of Optichêne is to predict for the future (short-term, long-term) the quantities and qualities of the French oak wood resource which is of economic significance (*Quercus petraea* and *Q. robur*), taking into account (i) the present standing resource (remember the very long rotation time for oak); (ii) possible changes in land use; (iii) possible changes in the type of end-products to deliver; (iv) the environmental constraints that could be enforced. In summary, we intend to define in a multi-criteria way the most appropriate ways to manage the present standing oak wood resource at the stand, forest, and country levels.

The five steps of Optichêne that we have in mind at present (some of them have already been started) are as follows.

Step 1

To include our chain of models and software in the French software platform CAPSIS for free use (De Coligny *et al.* 2004) and to complete what we are already able to do in a simple silvicultural context (mono-specific, even-aged, and fully balanced forest) with respect to outputs which cannot yet be simulated by our chain: 3D shape of the stem, pith eccentricity, branches under current crown basis. As a result we will be in a position to simulate the quality of our virtual products more accurately.

Step 2

To introduce into the above-mentioned simple and balanced virtual system elements of risk (storm, drastic energy use, and/or cost changes) and of imbalance (spatial considerations, unbalanced distribution of the age classes in the forest) but still considering even-aged and pure *Q. petraea* stands.

Step 3

To build software aimed at simulating the distribution of the quality traits of the products (sawn boards, veneer sheets) coming from a present standing resource of oak trees, which is described by inventory data such as total height, diameter at breast height, and age. The software would be similar to the WinEPIFN© software developed by Jean-Michel Leban in our LERFoB (Leban *et al.* 1997; Saint-André *et al.* 1997).

Step 4

Using the spatialised data of the French National Inventory Board (IFN) which is available for even-aged and pure stands of *Q. petraea*, we will estimate the interior of the trees (cf Step 3) and then, using our chain of models and software, we intend to grow the corresponding trees. As a result, we should be able to predict the quantities and qualities of the products for the future taking into account possible evolutions of the context (change in silviculture, climatic change, new wood products).

Step 5

To start from the relatively simple silvicultural context taken into consideration for Steps 1 to 4 in order to extend Optichêne to irregular stands including sessile and/or pedunculate oaks (these stands represent large parts of our resource).

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