Economics of silvoarable systems using LER approach

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Introduction

During the fourth year, Thomas Borrell and Fabien Liagre, in collaboration with Christian Dupraz - INRA, have realised all the technical and economical simulations for the French context. APCA participated to the redaction of the French chapter for the deliverable 7.2 - Plot economics of European silvoarable systems report – leaded by the partner Chavet.

Face to the late we observed in the results we should have received from yield-safe, it was decided to go on our simulations using the Ler-Safe data to feed Farm-Safe.

All the results of our simulations have been presented to all the Chambers of Agriculture which have provided the economical data in the 3 regional meetings we named before.
1 The LER approach

**LER-biomass and LER-product**

The Land Equivalent Ratio indicates the area of monocultures needed to produce as much as one intercropped hectare (Vandermeer, 1989). It is calculated as the sum of relative areas (RA), i.e. productions ratios: for each product, the intercrop production divided by the monoculture production. In most of the agroforestry cases, there are 2 RAs: the crop RA and the tree RA. For instance, a tree RA of 0.7 means that an agroforestry plot produces as much timber as a forestry plot of 0.7 ha. A LER of 1.3 thus indicates than intercropping produces 30% more than monocropping.

However, it can be calculated either with total biomass or only with commercial products, particularly in the case of timber production: the higher rate of thinning in forestry than in agroforestry implies different tree relative yields whether it is calculated with or without thinned trees.

This distinction leads to two different indicators: the LER-products, calculated with the commercial products (bole of timber of the felled trees, grain of the cereals, etc.), and the LER-biomass, calculated with the total biomass produced on the plot (for their detailed way of calculation, see Dupraz *et al.*, 2005). Although the likely range of values for the LER-products is still to be defined with experimental plots and models, we already know that the expected values of LER-biomass are likely to be comprised between 1 and 1.4. Indeed, a value below 1 is biologically unrealistic considering that if one of the intercrops dominates too much the other, it shall perform as in a monoculture plot and thus produce as much biomass of the same area of monoculture production. A value above 1.4 seems too much optimistic with regards to present experimental results and bibliographical documentation (Dupraz *et al.*, 2005).

**The LER-based generator**

For this study, we used a constrained generator of data: forest, arable and agroforest time-series are generated in accordance with an expected LER-biomass (see Annex 1: Detailed description of the LER-based-Generator).

The tree RA-biomass is defined according to the densities in forestry and agroforestry and to the expected increase in tree growth rate at low density. The crop RA-biomass is then deduced in order to reach the predetermined LER-biomass. The LER is only divided in a crop component and a tree component (timber); it is thus impossible to generate data-sets for a third component (fruits for example), such as for a traditional orchard or double purpose walnuts.

The arable and forest reference data and the values of these two RAs permit to generate all the time-series under constraint:

- the arable time-series is the repetition of the reference yields in accordance with the rotation;
- the forest time-series is generated in function of the reference volume of timber per ha at felling;
- the two agroforest times-series (one for the intercrop, one for the trees) are generated so that the constraint fixed by the RAs is respected (sum of productions for the intercrop, volume of timber per ha at felling for the trees).
Amongst the hypothesis made in this generator, we assume that:

- the agroforest trees are felled at the same time as the forest trees, but their higher growth induces bigger individual pieces of timber; in any case, the unit volume in agroforestry doesn’t exceed 20% of the forestry volume one.

- there is no difference in the partition of biomass for the intercrop and a classical arable crop: the crop RA-products is thus equal to the crop RA-biomass, which shall both be called “crop RA”; 

- the intercrops cannot offer higher yields than the arable crops without any tree (consequently the value of the crop RA cannot be superior to the maximum intercropping area: 1 – the proportion of area occupied by the tree strips); we made therefore the hypothesis that the trees don’t affect positively the crop yield which could be discuss on a long term period (soil erosion and fertility, wind effect, etc.).

- the width of the intercropped alley can be reduced by successive steps when the yield decreases (less productive areas are given up), in order to preserve economically acceptable yields as long as possible. When it cannot be reduced anymore (at a minimum width), the intercrop is suppressed when it is no more profitable (profitability threshold yield).

**A wise hypothesis for the agroforest tree growth**

In most of the cases, agroforest designs are at lower density than forest designs. As a consequence, trees grow quicker. We assume that the growth rate increases when the density decreases, until to reach a critical final density where the genetic potential is fully expressed. Below this density, we assume that trees don’t grow more, even if they are completely isolated.

At this critical density, we assume that trees grow at a rate driven by a coefficient: the **individual tree timber volume growth acceleration in low density AF conditions**, or Tree Growth Acceleration (TGA). At critical density, the volume of an agroforest individual piece of timber at felling, $V_{AF}$, is thus calculated as:

$$V_{max_{AF}} = TGA \times V_F$$

where $V_F = \text{volume of a forest individual piece of timber at felling}$

(in the forestry reference data which is used).

$V_{max_{AF}}$ is thus the maximum volume of an individual piece of timber.

Unfortunately, the critical densities and the likely range of values for TGA are not well documented. Thus these parameters had to be fixed by expert knowledge.

In order to realise wise simulations, we assumed a quite low value of TGA: 1,2 for the three species (Table I).
Species | Final density in forestry | $V_F$ | TGA | Critical density | $V_{\text{max,AF}}$
---|---|---|---|---|---
Walnut 100 trees/ha | 1 m³/tree | 1,2 | 50 trees/ha | 1,2 m³/tree
Wild cherry 150 trees/ha | 0,8 m³/tree | 1,2 | 60 trees/ha | 0,96 m³/tree
Poplar 200 trees/ha | 1,5 m³/tree | 1,2 | 100 trees/ha | 1,8 m³/tree

$V_F$ is the volume of timber of an individual forest tree. TGA is individual Tree timber volume Growth Acceleration in agroforestry at densities lower or equal to the critical density. The critical density is the highest density at which the maximum volume of an individual piece of timber is reached. $V_{\text{max,AF}}$ is the maximum timber volume of an agroforest tree, reached at densities lower or equal to the critical density.

Table I: reference values in forestry and values of TGA, the critical density and $V_{\text{max,AF}}$ for each of three tree species

Nevertheless, some unpublished experimental results are in favour of higher values for TGA: at M. Jollet’s farm (Les Eduts, Charentes Maritimes, France), INRA’s measurements of the forest and agroforest trees at the middle of the revolution indicate a TGA of 2 for black walnuts, at 80 trees/ha (Gavaland, pers. com.). But another thinning will soon accelerate the growth of the forest trees, and then this estimated TGA is likely to decrease.

There is thus an important difference between our hypothesis and what we could expect (Figure 1).

![Figure 1: Volume of the individual walnut timber volume in function of the final density and of the value of TGA.](image)

As an economic consequence of such a wise hypothesis, the volume of timber at felling is less important, thus the revenue of the tree component might be under-estimated.
**Maximum expectable LER in function of species and final density**

As the production of agroforest timber is determined in accordance with the densities, the critical density and TGA, the tree RA-products and the tree RA-biomass are fixed: it is impossible to tune them without modifying one of these previous parameters. Then the range of variation of the LER (biomass or products) corresponds to the crop RA:

- As a LER-biomass inferior to 1 is biologically unrealistic, the minimum value of the crop RA is equal to $1 - \text{tree RA-biomass}$.

- As we assume lower or equal yields, the maximum value of the crop RA must be inferior or equal to the maximum intercropping area. In our optimistic assumptions, at highest densities (tree lines every 10 m), we assumed a crop RY at $\frac{3}{4}$ of the maximum intercropping area.

- A likely value would be the mean of these two extreme values.

As the proportion of land required by the trees strips rises with the density, the maximum crop RA decreases when the density gets higher. A first conclusion is that we obtain acceptable RA with densities which correspond to distances between the tree lines included between 24 to 40 m.

![Figure 2: Range of values of the crop RA with walnut, wild cherry and poplar, according the distance of the tree lines and depending on how optimistic the dynamic of the LER is.](image)

In forestry, the realisation of many thinnings means that a lot of biomass is synthesised in addition of the trees which shall be conserved until the last fall. As we assume that the volume of the agroforest trees is maximum 20% bigger than the one of the forest trees, the production of woody biomass is small compared to the one of a forestry plot. Thus the ratio of woody biomass, i.e. the tree RA-biomass, is low. At low density, even an optimistic value of the crop RA is insufficient to compensate such a low tree RA. Consequently, high LER-biomass cannot be reached for all densities, in particular for species with a high rate of thinning in forestry such as wild cherry (Figure 3).
However, very satisfactory LER-products can be reached even with these species.

![Figure 3: Expectable LER-products for walnut, cherry and poplar, depending on how optimistic the dynamic of the intercrop is](image)

**Impact of the TGA on the LER results**

In our simulations, we used a TGA of 1.20. We were cautious in our predictions if we consider some experimental plots (such in Restinclières in France) or private site (Farm of Claude Jollet in Charente Maritime) where we observed some TGA which reach 2. If we had taken this value of 2, the tree RA would have increased between 15 to 30 % in comparison with what we obtained with 1.20.

![Figure 4: Influence of the Tree Growth Acceleration on the tree RA (biomass and products), according to the tree density.](image)
2 Data references and main hypothesis

The forestry references

The revolution duration, timber production and production techniques (initial density, prunings, thinnings, sward maintenance, and final density) were determined by expert knowledge, in accordance with available documentation.

The densities correspond to the schedule of conditions of the French circular “Forêts de production” and to forestry organisms’ advises.

<table>
<thead>
<tr>
<th>Individual piece of timber at felling (m³/tree)</th>
<th>Density (trees/ha)</th>
<th>Volume at felling (m³/ha)</th>
<th>Revolution duration (years)</th>
<th>Mean annual production (m³/ha/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>initial</td>
<td>final</td>
<td>Good land unit</td>
<td>Land unit medium</td>
</tr>
<tr>
<td>Walnut</td>
<td>1</td>
<td>200</td>
<td>100</td>
<td>46</td>
</tr>
<tr>
<td>Wild cherry</td>
<td>0.8</td>
<td>800</td>
<td>150</td>
<td>50</td>
</tr>
<tr>
<td>Poplar</td>
<td>1.5</td>
<td>200</td>
<td>300</td>
<td>19</td>
</tr>
</tbody>
</table>

Table 1: Densities, revolution duration and mean annual and total productions for walnut, wild cherry and poplar. With walnut, 2 thinnings of 50 trees/ha are realised at 1/3 and 2/3 of the revolution; with wild cherry, 3 thinnings are realised at 1/3 (400 trees/ha), half (200 trees/ha) and 2/3 (50 trees/ha) of the revolution.

Supports for afforestation on agricultural land vary in function of the region and of the tree species: as the poplar revolution is shorter, the Compensation Payment for Agricultural Loss (PCPR) is available for 7 years instead of 10.

<table>
<thead>
<tr>
<th>Type of farm (region)</th>
<th>Hy-Lc (Centre)</th>
<th>Ly-Lc (Poitou-Charentes)</th>
<th>Hy-Hc (Franche-Comté)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walnut and wild cherry Establishment grant (4 first years) PCPR farmer (10 first years)</td>
<td>50% of the costs 240 €/ha</td>
<td>50% of the costs 300 €/ha</td>
<td>0</td>
</tr>
<tr>
<td>Poplar Establishment grant (4 first years) PCPR farmer (7 first years)</td>
<td>50% of the costs 240 €/ha</td>
<td>50% of the costs 300 €/ha</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 2: Regional supports for afforestation on agricultural land for walnut, wild cherry and poplar (year 2003). The PCPR is the Compensation Payment for the loss of agricultural income.

Franche-Comté is a particular region. More than 50% of the area are already woodlands, thus afforestation is not encouraged: there is no support available for new forestry plantation.

Everywhere in France, newly afforested plots benefit from an exemption from land tax: for 10 years with poplar, 50 years with walnut and wild cherry. In our simulations, this land tax is comprised between 30 €/ha (Centre) and 39 €/ha (Poitou-Charentes).

Reference data in agriculture

All arable data come from the Farm observatory ROSACE, a tool produced by APCA. Thanks to this typology of farms made by the regional Chamber of Agriculture, several types of farms are defined and described, each one corresponding to the mean of 5 to 10 farms selected by the Chambers experts. Each year, the economical inputs are re-calculated (yield, net margin, farm costs, labour and CAP payment). In addition, all the technical orientations and strategies of the farm are also described.
We selected 3 types of farm, which we shall now designate with 4 initials:

- Hy-Lc: High yields and Low fixed costs
- Hy-Hc: High yields but High fixed costs
- Ly-Lc: Low yields and Low fixed costs

For each of them, the ROSACE typology indicates:

- The cropping area of the farm, distinguishing tenant farming and property;
- The crop rotation in function of the quality of the soil (up to 3 Land Units: best, medium, worst);
- The mean yields, attributed to the medium Land Unit (for the best and worst Land Units, we respectively assumed an increase and a decrease of 10% of the mean yields);
- The variable costs, assignable fixed costs and fixed costs and labour.
- The prices of the products and sub-products (straws of the wheat) and the CAP payments of the farm Single Farm Payment, SFP).

To elaborate the selection of each type of farms, various partners from the Chambers of Agriculture have participated: Camille Laborie, who is in charge of ROSACE in APCA, Anne-Marie Meudre (Franche Comté), Catherine Micheluzzi (Poitou-Charentes) and Benoît Tassin (Centre).
The Net Margin is equal to the Gross Margin minus the fixed assignable costs (land tax and machinery costs). The Total Net Margin is equal to the Net Margin minus the fixed costs (rent of land, amortisation and maintenance of the buildings, social contributions, banking costs). Labour costs are not taken into account.

**The profitability threshold yield**

With the development of the trees, the crop yield decreases progressively. Below a certain level, the crop is not more profitable, above all near the tree area. For each crop of the three types of farm, the threshold yield was first determined according to the price of the product, the CAP payment and the variable costs, assignable fixed costs and a part of the fixed costs. As the results, in proportion of the mean yield of each crop, were roughly the same in the three farms, we fixed this proportion in order to facilitate the extrapolation to other types of farm.

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1. If the crop is abandoned on a part of the cropping area, we assume that the fixed costs should decrease a little; thus they must be taken into account in the calculation of this threshold yield.
Table 4: Profitability threshold yield in proportion of the mean yield in the farm and example for the farm Hy-Hc

<table>
<thead>
<tr>
<th>crop</th>
<th>Mean yield in the farm</th>
<th>Profitability threshold yield</th>
<th>Mean yield in Hy-Hc</th>
<th>Profitability threshold yield in Hy-Hc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winter wheat</td>
<td>100 %</td>
<td>50 %</td>
<td>6.7 t/ha</td>
<td>3.35 t/ha</td>
</tr>
<tr>
<td>Maize</td>
<td>100 %</td>
<td>70 %</td>
<td>7.5 t/ha</td>
<td>5.25 t/ha</td>
</tr>
<tr>
<td>Oilseed rape</td>
<td>100 %</td>
<td>60 %</td>
<td>3.5 t/ha</td>
<td>2.1 t/ha</td>
</tr>
</tbody>
</table>

The threshold yield is the same in every farm, whatever the land unit is. Thus it shall be reached more quickly in the worst land unit than in the best land unit.

**Main management features of the agroforestry systems**

For each type of farm, we simulated the introduction of 2 agroforestry designs in the 3 land units (best, medium, and worst):

- Plantation at 50 trees/ha, on 40 m spaced tree-lines;
- Plantation at 120 trees/ha, on 22 m spaced tree-lines.

The tree strip is 2 m wide. The width of the intercropped alley is respectively of 38 m and 20 m, thus the maximum crop area represents 95% of the initial area at 50 trees/ha and 91% at 113 trees/ha.

With walnut and wild cherry, an early thinning is realised when the timber volume reaches 0.1 m³ (around the years 10-13), therefore the final densities are different from the poplars’ one (see Table 5).

<table>
<thead>
<tr>
<th>Agroforestry</th>
<th>Density (trees/ha) initial</th>
<th>Timber volume (m³/tree)</th>
<th>Productio (m³/ha) initial</th>
<th>Forestry</th>
<th>Density (trees/ha) initial</th>
<th>Timber volume (m³/tree)</th>
<th>Productio (m³/ha) initial</th>
<th>Tree RA-biomass</th>
<th>Tree RA-products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walnut</td>
<td>50</td>
<td>40</td>
<td>1.2</td>
<td>48</td>
<td>200</td>
<td>100</td>
<td>1</td>
<td>100</td>
<td>0.36</td>
</tr>
<tr>
<td></td>
<td>120</td>
<td>80</td>
<td>1.08</td>
<td>86</td>
<td>800</td>
<td>150</td>
<td>0.8</td>
<td>120</td>
<td>0.66</td>
</tr>
<tr>
<td>Wild cherry</td>
<td>50</td>
<td>40</td>
<td>0.96</td>
<td>38</td>
<td>800</td>
<td>150</td>
<td>0.8</td>
<td>120</td>
<td>0.22</td>
</tr>
<tr>
<td></td>
<td>120</td>
<td>80</td>
<td>0.92</td>
<td>74</td>
<td>800</td>
<td>150</td>
<td>0.8</td>
<td>120</td>
<td>0.42</td>
</tr>
<tr>
<td>Poplar</td>
<td>50</td>
<td>50</td>
<td>1.8</td>
<td>90</td>
<td>200</td>
<td>200</td>
<td>1.5</td>
<td>300</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>120</td>
<td>113</td>
<td>1.76</td>
<td>199</td>
<td>200</td>
<td>200</td>
<td>1.5</td>
<td>300</td>
<td>0.66</td>
</tr>
</tbody>
</table>

Table 5: Initial and final densities, volume of an individual piece of timber and production in forestry and in the simulated agroforestry systems; tree Relative Area (RA)-biomass and tree RA-products

The crops Relative Areas (RA) have been fixed for 3 hypothesis: optimistic, probable and pessimistic.

The pessimistic hypothesis means that the LER-biomass is equal to 1. Therefore, the crop RA is equal to: \((1 - \text{tree RA-biomass})\).

The optimistic crop RA is determined according to 2 constraints:

- The crop RA must be inferior to the maximum intercropping area
We also assumed to fix a ceiling for the LER-biomass of 1.4. Thus the crop RA is equal to: \((1.4 – \text{tree RA-biomass})\). This ceiling of 1.4 was reached with walnut and poplar at 120 trees/ha, so the crop RA seems quite low with regards to the maximum intercropping area.

We assumed a probable crop RA as the arithmetic average of the 2 previous values (pessimistic and optimistic) (see Table 6 and Table 7).

<table>
<thead>
<tr>
<th>Initial density (trees/ha)</th>
<th>Width between tree lines (m)</th>
<th>Width of the intercropped alley (m)</th>
<th>Maximum intercropping area</th>
<th>Pessimistic crop RA</th>
<th>Probable crop RA</th>
<th>Optimistic crop RA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walnut</td>
<td>50</td>
<td>40</td>
<td>38</td>
<td>0.95</td>
<td>0.64</td>
<td>0.79</td>
</tr>
<tr>
<td></td>
<td>120</td>
<td>22</td>
<td>20</td>
<td>0.91</td>
<td>0.34</td>
<td>0.54</td>
</tr>
<tr>
<td>Wild cherry</td>
<td>50</td>
<td>40</td>
<td>38</td>
<td>0.95</td>
<td>0.78</td>
<td>0.85</td>
</tr>
<tr>
<td></td>
<td>120</td>
<td>22</td>
<td>20</td>
<td>0.91</td>
<td>0.57</td>
<td>0.72</td>
</tr>
<tr>
<td>Poplar</td>
<td>50</td>
<td>40</td>
<td>38</td>
<td>0.95</td>
<td>0.70</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td>120</td>
<td>22</td>
<td>20</td>
<td>0.91</td>
<td>0.34</td>
<td>0.54</td>
</tr>
</tbody>
</table>

Table 6: Crop RA in function of the tree species, density and optimism level. Bold values are those which depend on the ceiling of 1.4 for the LER-biomass.

<table>
<thead>
<tr>
<th>Initial density (trees/ha)</th>
<th>Width between tree lines (m)</th>
<th>Width of the intercropped alley (m)</th>
<th>LER-biomass reached with the</th>
<th>LER-products reached with the</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Pessim. crop RA</td>
<td>probabl crop RA</td>
</tr>
<tr>
<td>Walnut</td>
<td>50</td>
<td>40</td>
<td>38</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>120</td>
<td>22</td>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td>Wild cherry</td>
<td>50</td>
<td>40</td>
<td>38</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>120</td>
<td>22</td>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td>Poplar</td>
<td>50</td>
<td>40</td>
<td>38</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>120</td>
<td>22</td>
<td>20</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 7: LER-biomass and LER-products in function of the tree species, density and hypothesis of optimism for the intercrop bold values are those which depend on the ceiling of 1.4 for the LER-biomass.

**Economic hypothesis**

**CAP payments**

In agriculture, the crops area benefits from the Single Farm Payment (SFP): it was calculated on the basis of the historical references of each farm, in accordance with the way France decided to implement the new CAP in 2006.

In the basic scenario, we assumed that the intercrops are eligible to the SFP proportionally to the area of the plot that they occupy. It is the present situation in France. The rights corresponding to the tree area could be transferable to another eligible area which doesn’t benefit from a payment right. In our simulations, we did not attribute them to new plots, considering therefore that these rights were lost for the farmer.

**Tree grants**

In our basic scenario, agroforest trees benefit from the same establishment payments as the forest trees: 50% of the costs of the 4 first years in Poitou-Charentes and Centre. It corresponds to the present situation, permitted by the circular “Forêts de protection” which
relies on the line i of the French National Rural Development Programme. However an agroforest plot cannot benefit from neither the PCPR nor the exemption of land tax.

In France, an agro-environmental measure called “agroforest habitats” can be contracted under certain conditions, but it still faces administrative difficulties and is not available in most of the departments, thus it was not taken into account in our simulations.

Costs and prices
Some key points have to be underlined:

- The cost of sward maintenance is higher in forestry than in agroforestry. In forestry, at the beginning of the revolution, sward maintenance is realised thanks to two grindings instead of one for the maintenance of the tree strip in agroforestry.

- The farmer makes all operations himself, except the marking out and plantation of the young trees. Both of these operations are charged 15 €/h. The timber prices correspond to standing trees, thus neither the harvesting cost is taken into account.

- In a cash flow approach, the basic scenario doesn’t include the labour cost for the farmer. While in a farming management scenario, we consider an hourly cost of 7.62 €/h (minimum salary in France). In this last approach, it’s therefore possible to evaluate the efficiency of the farmer labour.

As it seems impossible to anticipate the future evolution of prices and costs, we assumed constant values. For instance, a rise or a drop of timber value would respectively increase or decrease the tree revenue.
3 Main results

Labour impact for one silvoarable hectare

An essential condition for adopting agroforestry from the farmers’ point of view is that they don’t want to devote more time to a new system. If the farmer planted more trees (case 1), he would need 1 to 1.5 days each year to maintain the trees. But in the second half of the rotation, the labour decreases progressively due to the fact that trees don’t need more special maintenance and that the intercrop activity is reduced. If he plants fewer trees, the impact during the first years is poor. With the small density, the intercrop activity is longer, because the crop yield is not so affected by the trees. The labour requested in the second half of the rotation is therefore lower but very near from the initial scenario.

Prediction of yield evolution

Crop yield evolution

Predicting the crop yield during the second half of the rotation is a perilous venture. If we know the behaviour of the intercrop during the first half thanks to experimental measures on existing plots, we asked the bio-economics model to predict the yield evolution. In our simulation, as we said, we used the LER-Safe prediction. We made the essential hypothesis that the LER must be include between 1 and 1.4. This condition helps us to determine a possible range of crop yield evolution, from the pessimist one to the optimist one (see Figure 6).
Figure 6: Evolution of the relative intercrop yield according to optimist or pessimist view about the tree competition. Case of one ha of wild cherry with an initial density of 120 trees/ha for a final density of 80 trees/ha.

In this example of a plantation of wild cherry at 80 trees/ha (final density), which means a distance between the trees rows of 25m, the crop yield represent more than 90% during the first half of the tree rotation. According to the interaction level, the crop yield varies between 30 and 75 % of the pure crop yield of reference the year before harvesting the trees.

The crop yield depends on different parameters:

- The parameters due to some initial choices: the crop nature (a sunflower will be more affected by the shadow of the adult trees than a cereal), the density of the plantation and the distance between the lines, choice of the land unit (a deeper soil will be more adapted), ...

- The parameters depending on the capacity of the farmer: well pruned trees, tree root maintenance (root cutting), ...

In our economical scenarios, we have tested the different level of interaction.

**Tree yield evolution**

As for the crop yield estimation, we put forward the hypothesis of different level of timber productivity. But for our simulations, we only use one prediction of timber production. To validate our approach, we use a very cautious estimation of production (see Figure 7). Our results can therefore be considered as the minimum result we can get from our hypothesis.
Figure 7: Range of timber volume evolution for an initial plantation of 120 wild cherry. The figure indicates of the cautious hypothesis of standing volume we used for our simulations (77 m$^3$ for 80 final trees).

**Cash flow impact**

To evaluate the impact of the project on the cash flow, we must distinguish first the investment cost and then the evolution of the annual cash flow depending of the crop yield evolution and the possible over cost to crop between the trees in comparison with a pure crop system.

**Initial investment**

The poor number of trees to plant in an agroforestry system reduces considerably the investment cost if we compare with a current afforestation cost on agricultural land. The tree cost is nonetheless higher. The owner will choose a better quality of the trees and will have to protect each one with a strong protection: each tree has a possible future value and demands a special attention.

The total cost of a plantation (without subsidy) varies between 500 and 1000 euros/ha according to the tree specie (the walnut plantation being the most expensive). This cost represents between 20 to 60 % of the average cost in the case of common land afforestation (see Figure 8).

![Figure 8: Comparison of the investment in agroforestry and forestry scenario, WITHOUT subsidy.](image-url)
In France, it’s current to get a subsidy of 40 to 70% to cover the investment cost and the maintenance cost of the trees during the 4 first years (except in Franche Comté).

Since 2004, the French Government decided to suspend all economic aids to the land afforestation, excepted for agroforestry. In our simulations, we decided to conserve this aid, to be able to compare between the two options (see Figure 9).

![Cash Flow Evolution Diagram](image)

**Cash flow evolution**

**Evolution of the cash flow at the plot scale**

The cash flow evolution will depend of the crop yield evolution and the LER level we have selected and the final density. For example, in the Figure 10, we’ve illustrated the cash evolution for two different densities but for a medium LER level.

![Annual Cash Flow Diagram](image)

**Figure 9: Comparison of the investment in agroforestry and forestry scenario, WITH subsidy.**

**Figure 10: Evolution of the annual cash flow for a probable scenario with wild cherry (LER=1.07 for a density of 50 trees/ha and 1.15 for a density of 120 trees).**
Being cautious in our forecast, we notice nonetheless that at half of the rotation, the gross margin still represent 80 to 90% of the agricultural gross margin. We must underline that in our simulations, we've considered that the crop payment area is reduced progressively by the tree area. In case of the silvoarable area was eligible in its totality, the impact on the cash would be sensible, above all in some regions where man get poor crop yield and where the crop payment is essential in the gross margin calculation (Franche Comté for example).

Let’s also underline the fact that in the INRA experimental plots, the LER reaches more 1.3 than 1.15 that we have chosen in our simulation with an initial density of 120 trees/ha.

**Influence of the CAP payment policy**

Inside the first pillar policy, the situation of the agroforestry plots could be different depending of each country member. In fact, at a European level, the agroforestry plot could be eligible to the Compensatory Payment. We compare here the possibility to get the payment on the whole area (Request of the Safe consortium) or only on the intercrop area (French situation).

The impact of the eligibility given to the whole surface on the profitability is not so important. In all our simulations, the profitability increases by 3% in the best option for agroforestry. The impact is more at a cash flow level, when the crop gross margin is low. That’s typically the case for the farms where:

- The crop component is lower than the payment component in the gross margin calculation (Mediterranean area or farm with high cost of production)
- The yield is decreasing faster in the silvoarable scenario (high density of plantation or strong impact of the trees on the crop RA) (see Figure 11)

![Figure 11: Influence of the different CAP payment policies in agroforestry on the annual cash flow evolution.](image)

**Evolution of the cash flow at the farm scale**

At the farm scale, one of the first questions of the farmer is about the importance of the area to plant. Does he have to plant on a big area? In several plots or in a single plot? There is no only one answer. According to the strategy of the farmer, a large range of scenarios is available. The choice will depend to the cash flow context and to know if the farmer can support a strong investment or not, and above all if he aims to decrease progressively his
crop activity or not. The labour availability is also a strong parameter to decide which area to plant. According to our simulation and experimental experience, we often recommend not planting more than 10 % of the cropping area. In that case, the impact on the farm gross margin is less than 3 % in average on the first half of the tree rotation. A gradual plantation will allow a reduction of the cash flow impact (see Figure 12).

![Graph showing cash flow evolution for two scenarios: single plantation and gradual plantation.](image)

a. Case of a single plantation  
b. Case of a gradual plantation

Figure 12: Comparison of the cash flow evolution when the farmer plants 8 % of his cropping area (50/50 Walnut/Wild cherry). We compare the option where the farmer would plant the silvoarable area in once time or if he decides to plant 2 % every 5 years during 20 years.

A gradual plantation will also allow a soft distribution of the timber income in the time from the moment where the owner begins to harvest the first mature trees (case b). From this moment, the timber income is regular. In our example, he can harvest the trees every 5 years. In this context, the farm gross margin increase by 15 %. According to the importance of the plantation and of the species he planted, a farmer could increase his farm income between 10 to 100%. Of course, it can suppose a long term to wait for the farmer before the first tree harvest…

**Profitability of a silvoarable investment**

**Comparing a silvoarable scenario with agricultural scenario**

For our simulations, we have selected 3 kinds of farms:

- Farm with good crop yields and few fixed costs.
- Farm with medium crop yields with few fixed costs.
- Farm with medium crop yields and high fixed costs.

For each farm, corresponding to each region of the LTS of the WP8, we have run different scenarios according to:

- the tree density: 120 versus 50 for the initial density which corresponds to a final density of 80/40.
- the LER level: optimist, probable and pessimist
- the land unit: good/medium
- the 3 tree species: poplar, walnut and wild cherry
108 scenarios have been run in total (36 scenarios / LTS). The Figure 13 shows a synthesis of the Agricultural Values for all these scenarios we have calculated for each specie according to the level of LER.

Figure 13: Profitability of the silvoarable scenarios according to the tree specie and the LER level.

A first interesting result is that the silvoarable scenarios are at least as profitable as the agricultural scenario.

Walnut timber is actually the most expensive timber on the market. For a same duration of rotation, the best results have been logically obtained with the walnut than the wild cherry. The period of harvesting time is a key parameter in the profitability calculation (see Figure 14).

Figure 14: Influence of the maintenance quality on the profitability.
A late in the pruning dates can put the harvesting date back by 10 or 20 years, above all for some sensitive specie such as the hybrid walnut. In this example, a late of 20 years means a reduction of 60% of the profitability in comparison of the agricultural profitability.

**Influence of the TGA on the Agricultural Value**

The value of the Tree Growth Acceleration has a strong impact on the profitability of the silvoarable scenarios. This impact is stronger for the scenario with higher densities of plantation. In the following figure, we noticed that the scenario with a density of 120 ha react much quicker than a scenario with 50 trees.

Again, in our simulations, we used a TGA of 1.20 which could be considered as a pessimist approach with what we observe in the reality. For example, in the Jollet's case, the agricultural value would have been increased by 10 to 15 % (see Figure 15).

![Figure 15: Influence of the TGA on the Agricultural Value](image)

**Which density to plant to get the best profitability?**

A common question from the farmers is about the number of trees to plant. The farmers often want to maintain a correct crop yield during the whole rotation but trying in the same time to get the best investment for timber. Other decides to plant more trees with the aim to decrease the agricultural activity, even till to suppress the intercrop. We didn’t take this case in this study.

For each specie, Walnut, Wild cherry and Poplar, according to our production hypothesis, we simulated the impact of the density to the LER but also to the Agricultural Value (see Figure 16).
Figure 16: Influence of the tree density on the LER value and the Agricultural value for wild cherry, walnut and poplar.
We observe that for each specie, the best density to get the optimum LER is higher than the best density to get the optimum Agricultural Value. For the species with a poor Tree RA (Walnut and wild cherry), the range of density are similar (see Table 8). The best density would vary between 80 to 120 trees/ha to get the highest LER, while the farmer will get the best profitability with a density included between 60 and 90 trees/ha. Of course, with a higher TGA, this range would increase.

<table>
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<td>130 - 200</td>
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<tr>
<td>Agricultural Value</td>
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<td>60 - 90</td>
<td>100 - 130</td>
</tr>
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</table>

Table 8: Range of density to get the optimum LER and Agricultural Value results for each specie (trees/ha – final density).

For the poplar, the optimum densities are higher than for the 2 others species. This result is due to the fact that the biomass produced by the silvoarable poplar is similar to the biomass produced by the forestry poplar. The Tree RA is therefore higher for a given density compared to other species which demand more important fellings.

What could influence these results? As we already said, the TGA level could strongly influence these results, giving priority to higher densities. The policy schedule and the price level of the crop and tree component will be therefore the most important parameters. In the case of the walnut, the choice of a density of 75 trees/ha is a wise option. Below, the farm doesn’t want to take any risk at a long term period, above he bets more on the trees.

Comparing a silvoarable scenario with a forestry scenario

We compare also the case where the farmer was hesitating between a forestry investment rather than a silvoarable investment from a profitability point of view (see Figure 17).

![Figure 17: Comparison of the profitability of the silvoarable and afforestation scenario with the agricultural scenario. Silvoarable plantation of 120 wild cherry by ha characterized by a LER of 1,15.](image)

In this example, we explore the case of a probable LER of 1.15 in the silvoarable option. In almost all our simulations, the silvoarable options are more profitable than the forestry option.
The forestry option may be more profitable in the case where the crop margin is very poor, above all if it’s possible to plant some valuable species such as walnut for example.

It’s also interesting to notice that for the poplar, the silvoarable option could be a possibility to stimulate the poplar market. In France, the poplar area is currently decreasing because of the price fall of the timber (less than 45 €/m3). Agroforestry could therefore be a possible strategy to reduce the market risks.

**Property holdings evaluation in agroforestry**

According to his age, a land owner who plants trees, will not necessarily benefit from the harvest... But, as a farmer told us, a farmer has three possibilities of income: the sale of his products, the stock variation and the possibility to make a capital gain. In this last option, a silvoarable plot is a capital which could be evaluated if necessary (inheritance, expropriation, etc). The land evaluation in agroforestry is the combination of the agricultural land evaluation and the future value of the trees (see Figure 18).

![Figure 18: Evolution of the monetary value of the silvoarable land according to the age of the trees. In agroforestry, this value is the sum of the agricultural value plus the timber future value. If the young trees could have a future value, for example at 10 years old, they don’t necessary have a commercial value in the sense that the landowner can not expect some income if he cut them.]

In this example of a wild cherry plantation, the capital evaluation may represent between twice and four time the agricultural land value according to the age of the trees. In the case of a walnut plantation, it may represent till 7 times this value 10 years before the tree harvesting.
Photo 1: In this plot of 4 ha, the wild cherries are 30 years old. The value of the standing volume is estimated to 4 000 €/ha, which represents the same value of the agricultural land. But the future value of this plantation is much higher and overpass the 10 000 €/ha.

**Main conclusions**

To invest in agroforestry represents a light investment in money and labour comparing with some new systems of diversification. In our simulations, the profitability reaches 10 to 50 % with walnut, and -5 to +15 % with wild cherry and poplar, comparing with the agricultural scenario.

A regular calendar of plantation on a few surfaces is a good option for the farmer (labour and cash flow impact). 10 % represents between 2 and 3 % of reduction of the farm gross margin. But in the balanced period, the income increases by more than 15% (mixed plantation of walnut and wild cherry trees). The gross margin could double if the farmer plants progressively his whole cropping area. But in that case, it means a stronger impact on the initial cash flow and demands a consequent labour...

If the best bio-physical option is to plant between 80 to 120 trees by hectare (130 to 200 for the poplars), the best economical option is to plant a lower density around 60 to 90 trees by hectare (100 to 130 for the poplar). This means a distance between the trees lines varying between 24 to 36 m.

All our simulations haven’t taken into account the environmental benefits such the carbon sequestration, or the impact on the nitrogen pollution. These aspects could be calculated and to be summed to the whole profitability of the silvoarable systems.
4 Bibliography


5 Annex

**Annex 1: Detailed description of the LERbased-Generator**

**Principle**

Farm-SAFE does not have any biophysical module, the time-series must be generated independently: pure crop and intercrop yields, timber production in forestry and agroforestry. We used a generator constrained by the LER-biomass: depending on a previously fixed value and on a quite low number of parameters, these times-series are produced. The starting and final points are known, the evolution between them is drawn thanks to a logistic equation.

A key characteristic is that the climatic variability is not taken into account. It would have necessitate to define the impact of variables (temperature, water, light, etc...) which are not implicated in this type of constrained prediction. Nevertheless, we assume that except in very particular cases, this variability does not have any impact on the economic results: on a whole revolution (20 to 60 years), “bad weather” years are compensated by “good weather” ones, as we are not interested in year-by-year results but final profitability and global evolution of financial results. Because of discounting, climate would only have a strong effect if “bad weather” years were concentrated in a specific part of the revolution, which is very unlikely to happen.

**Notations**

We use the words “forestry” and “forest trees” for all types of pure trees plantation, even when the initial density is very low, such as for walnut.

A distinction is made, in forestry and agroforestry, between the trees which are cut at thinnings and the trees which are maintained until last felling: the firsts are called “thinned trees”, the others “felled trees”.

We call “timber” the bole of the tree, which has the highest commercial value. The same word is used for the thinned trees, even if the bole is often too small to be sold as good timber.

\[ V_F \] is the individual forest tree timber volume at forestry reference density.

\[ V_{AF} \] is the individual agroforest tree timber volume, depending on the density.

\[ V_{max,AF} \] is the maximum individual agroforest tree timber volume.

**Parameters**

- Parameters per tree species
  - \( D_C \), the critical agroforestry density, i.e. the density at which the tree growth potential is attained: the individual agroforest tree timber volume is equal to \( V_{max,AF} \), the trees cannot be bigger, even at lower densities.
  - \( TGA \), the coefficient of individual Tree timber volume Growth Acceleration in low density AF conditions, or Tree Growth Acceleration; e.g. 1.2 indicates that the individual agroforest tree timber volume at a lower or equal density than \( D_C \) will be 20 % bigger than the one of a forest tree, due to the positive impact of both low
density and intercropping (exceeds of nitrogen, less competition than the perennial vegetation classically established between forest trees, etc…).

- Timber To Biomass in forestry, e.g. the timber contribution to the total biomass of a young forest tree (TTB\textsubscript{young-F}) and of a felled forest tree (TTB\textsubscript{fell-F});
- Timber To Biomass of a felled agroforest tree (TTB\textsubscript{fell-AF});
- maximum value for the forestry ratio: biomass of all the thinned trees/biomass of all the felled trees;
- individual tree timber volume of the agroforest tree at thinning.

- Parameters of the logistic curves
  - curvature and inflexion for the individual forest tree timber volume, for the individual agroforest tree timber volume;
  - curvature and inflexion for the height of the forest trees, of the agroforest trees;
  - curvature for the intercrop yields.

- Parameters used only as Farm-SAFE entries\textsuperscript{2}
  - final tree height (same in forestry and agroforestry);
  - maximum bole height (same in forestry and agroforestry);
  - fixed value of the ratio: firewood volume/timber volume in forestry, in agroforestry.

**Entries**

- arable rotation, reference yield and threshold yield for profitability for every crop;
- tree species, revolution duration (60 years maximum);
- forestry: reference production, initial density, years of thinnings (maximum 5) and numbers of thinned trees;
- agroforestry: initial density, number of trees cut in the unique thinning, plot design (distance between tree lines, initial width of the intercropped alley, width of the intercropped alley reduction step);
- LER-biomass aimed.

---

\textsuperscript{2} These three parameters are not used in the generation of tree production data-sets (timber), but they are needed as entries for Farm-SAFE (tree height and production of firewood).
The generation of data-sets

- The first step is the generation of the time-series of the monocropping systems:

The time-series of pure agricultural yields are produced simply by repeating the reference yields as many times as necessary to last the duration of the revolution.

The time series of the timber production of the felled trees are generated with the following logistic equation:

\[
Y_t = \frac{Y_{\text{initial}} - Y_{\text{final}}}{1 + \left(\frac{t}{T_{\text{inflexion}}}\right)^{\text{courbure}}} + Y_{\text{final}}
\]

where \( Y_t \) is the value of \( Y \) at year ;
\( Y_{\text{initial}} \) and \( Y_{\text{final}} \) are the initial and final values of \( Y \);
\( T_{\text{inflexion}} \) is the inflexion date (end of linear growth).

\( Y_{\text{initial}} \) is equal to zero and \( Y_{\text{final}} \) to any value, as the curve is then distended in order to go through a point \( (X';Y') \): \( X' \) is the date of fell of the trees and \( Y' \) is the reference production (in m3/ha of timber at felling).

For forestry, 3 other time series are generated:

- The timber production of the thinned trees\(^3\), as it is considered that they can be smaller than the felled trees. The same logistic equation is used, with an \( Y' \) calculated in function of 2 constraints:
  
  (i) thinned tree timber volume \( \leq \) felled tree timber volume.

  (ii) the parameter "maximum value for the ratio: biomass of all the thinned trees/biomass of all the felled trees"

- The biomass of both the felled and the thinned trees, thanks to the ratio Timber To Biomass. We assume that if \( TTB_F \) may vary with time \( t \), it is a linear variation:

\[
TTB_F(t) = \frac{TTB_{\text{fell}} - TTB_{\text{young}}}{T} \times t + TTB_{\text{young}}
\]

where \( T \) is the revolution duration.

The biomass of the felled trees and of the thinned trees is thus calculated by dividing their respective timber time series by \( TTB_F(t) \).

---

\(^3\) There is only one time series for all the thinnings: late-thinned trees have the same rate of growth as early-thinned trees.
• The Relative Areas calculated in function of the Tree Growth Acceleration:

The coefficient of individual Tree timber volume Growth Acceleration in low density AF conditions, or Tree Growth Acceleration (TGA), permits the calculation of the agroforest tree timber volume:

- At $D \leq D_C$, $V_{AF} = V_{maxAF}$
- At $D = D_F$, $V_{AF} = V_F$
- $D > D_F$ is not possible
- At $D_C < D < D_F$, $V_{AF} = V_F + D \times \frac{V_F - V_{maxAF}}{D_F - D_C} - D_F \times \frac{V_{maxAF} - V_F}{D_F - D_C}$

Where: $D$, $D_C$ and $D_F$ are the actual density, the critical density and the forest density

$V_{AF}$, $V_F$ and $V_{maxAF}$ are the actual agroforest tree timber volume, the forest tree timber volume and the maximum agroforest tree timber volume, with $V_{maxAF} = TGA \times V_F$

On the basis of the final densities in forestry and agroforestry, the forestry RA-products can then be deduced.

With $TTB_{fell-AF}$, we easily know the agroforest trees biomass at felling.

With regards to the low initial density in agroforestry, we assume that the thinned trees grow as well as the felled trees: the thinning is early enough to avoid a strong effect of competition, thus the individual thinned tree timber volume is the same as the one of a felled tree at that time. And as the number of thinned trees is low and the thinning quite early, the volume of thinned biomass is poor enough to permit us to consider a fixed $TTBAF$ in time. Thus the volume of thinned biomass in agroforestry is calculated by dividing the thinned timber production by $TTB_{fell-AF}$.

The forestry RA-biomass can then be calculated.

The arable RA-biomass is deduced in function of the aimed LER-biomass. It is equal to the arable RA-products, as we assume that the proportion of grain in the biomass of the crop is the same in agriculture and in agroforestry.

• The generation of the agroforestry data-sets:

The agroforestry timber time-series are generated with the same logistic equation: $Y'$ is then the forestry reference production multiplied by the forestry RA-products.

Until the thinning, the volume of timber of the thinned trees is taken into account simply by adding the equivalent number of trees with the same individual tree timber volume.

The intercrop time-series are also generated with this logistic equation, with an $Y_{final}$ equal to 0: one time-series per crop of the rotation (maize, wheat, oilseed, etc...). For each crop, the curve is adjusted in function of the threshold yield and the width of the intercropped alley reduction step: as the yield per total ha decreases with time due to tree growth and increasing light competition, we assume that the cropped area is reduced by successive steps (see Figure 19). A reduction of the width of the intercropped alley happens every time
the yield per cropped ha passes under an economically defined threshold. The last reduction corresponds to the suppression of the intercrop.

Figure 19: chronological schema of the intercropped area in the alley in function of tree growth.

The width of the intercropped strip (w) is reduced at t1 and t2 in order to increase the mean yield per cropped ha. Its next reduction at t3 corresponds to the suppression of the intercrop. In the generator, up to 6 reductions can be made.

The intercrop curves are adjusted by modifying their inflexion date so that the sum of the intercrop productions is equal to the crop reference yield multiplied by the arable RA-products.

The intercrop time-series are then mixed according to the arable rotation to obtain a single time-series.

- The same tree height curve time series in forestry and agroforestry

A last time-series is generated for both forest and agroforest trees: their height growth. It is not used in the timber volume calculation, but this time-series is needed in Farm-SAFE for its “autoprune” function.

We use the Boltzmann logistic equation:

\[
Y(t) = \frac{Y_{\text{initial}} - Y_{\text{final}}}{1 + e^{\left(\frac{t - T_{\text{initial}}}{t_{\text{final}} - t_{\text{initial}}}\right)}} + Y_{\text{final}} - Y(t = 0)
\]
As for the timber time-series, $Y_{initial}$ is equal to zero and $Y_{final}$ to any value, as the curve is distended in order to go through a point $(X'; Y')$: $X'$ is the date of fell of the trees and $Y'$ is the aimed height.
## Annex 2: Labour, revenues and costs in the 3 types of farms

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<td>102,10 (straw 30 €/t)</td>
<td>328</td>
<td>278</td>
<td>315</td>
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<td>348</td>
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<td>348</td>
<td>434</td>
<td>315</td>
</tr>
<tr>
<td>set aside</td>
<td>1,5</td>
<td>–</td>
<td>328</td>
<td>15</td>
<td>315</td>
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</table>
Annex 3: Economic data relative to monocropped or intercropped walnut, wild cherry and poplar in the 3 farms

Tree timber standing value

<table>
<thead>
<tr>
<th>Tree timber volume (m³/tree)</th>
<th>Walnut</th>
<th>Wild cherry</th>
<th>Poplar</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>thinned trees</td>
<td>felled trees</td>
<td>thinned trees</td>
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<tr>
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<tr>
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<tr>
<td>0.05</td>
<td>10</td>
<td>10</td>
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</tr>
<tr>
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<td>60</td>
<td>10</td>
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<tr>
<td>0.12</td>
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<td>80</td>
<td>10</td>
</tr>
<tr>
<td>0.13</td>
<td>10</td>
<td>100</td>
<td>10</td>
</tr>
<tr>
<td>0.14</td>
<td>10</td>
<td>126</td>
<td>10</td>
</tr>
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<td>20</td>
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<td>10</td>
</tr>
<tr>
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<td>20</td>
<td>144</td>
<td>10</td>
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<tr>
<td>0.17</td>
<td>20</td>
<td>153</td>
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</tr>
<tr>
<td>0.18</td>
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<td>162</td>
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</tr>
<tr>
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<td>20</td>
<td>171</td>
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<td>720</td>
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<td>810</td>
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<tr>
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<tr>
<td>1.8</td>
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<tr>
<td>1.9</td>
<td>1000</td>
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</tr>
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<td>1100</td>
<td>1100</td>
<td>175</td>
</tr>
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<tr>
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</table>
## Establishment costs

<table>
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<tr>
<th></th>
<th>Cost of plant (€/tree)</th>
<th>Cost of individual tree protection (€/tree)</th>
<th>Labour for ground preparation (h/ha)</th>
<th>Labour for full weeding (h/ha)</th>
<th>Labour for marking out (min/tree)</th>
<th>Labour for planting trees (min/tree)</th>
<th>Labour for tree protection (min/tree)</th>
<th>Labour for localised weeding (min/tree)</th>
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</thead>
<tbody>
<tr>
<td>agroforest walnut</td>
<td>6.00</td>
<td>1.50</td>
<td>4.00</td>
<td>0.50</td>
<td>7</td>
<td>2</td>
<td>2</td>
<td>0.50</td>
</tr>
<tr>
<td>forest walnut</td>
<td>4.00</td>
<td>0.50</td>
<td>6.50</td>
<td>1.50</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>0.50</td>
</tr>
<tr>
<td>agroforest wild cherry</td>
<td>1.00</td>
<td>1.50</td>
<td>4.00</td>
<td>0.50</td>
<td>7</td>
<td>2</td>
<td>2</td>
<td>0.53</td>
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<tr>
<td>forest wild cherry</td>
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<td>0.50</td>
<td>6.50</td>
<td>1.50</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>0.53</td>
</tr>
<tr>
<td>agroforest poplar</td>
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<td>12.00</td>
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## Maintenance and pruning costs

<table>
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<tr>
<th></th>
<th>Weeding period (years)</th>
<th>Annual labour for weeding (min/tree)</th>
<th>Annual cost of herbicide for weeding (€/tree)</th>
<th>Labour for annual grass sward maintenance (h/ha)</th>
<th>Materials for annual grass sward maintenance (€/tree)</th>
<th>Height at first prune (m)</th>
<th>Minutes per tree at first prune (min/tree)</th>
<th>Height at last prune (m)</th>
<th>Minutes per tree at last prune (min/tree)</th>
<th>Removal of pruning (min/tree)</th>
</tr>
</thead>
<tbody>
<tr>
<td>agroforest walnut</td>
<td>1 - 3</td>
<td>0.50</td>
<td>0.14</td>
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<td>1.00</td>
<td>1.00</td>
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<td>1 - 3</td>
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<td>1 - 3</td>
<td>0.50</td>
<td>0.14</td>
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<tr>
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<td>1.00</td>
<td>8</td>
<td>8.00</td>
<td>10.00</td>
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<tr>
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<td>0.14</td>
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<td>8</td>
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</table>

## Labour for thinning and felling

<table>
<thead>
<tr>
<th></th>
<th>Marking up &amp; labour (min/tree)</th>
<th>Removal of tree (min/tree)</th>
<th>Labour (min/tree)</th>
<th>Removal of tree (min/tree)</th>
</tr>
</thead>
<tbody>
<tr>
<td>agroforest walnut</td>
<td>7</td>
<td>5</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>forest walnut</td>
<td>7</td>
<td>5</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>agroforest wild cherry</td>
<td>7</td>
<td>5</td>
<td>4</td>
<td>2</td>
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<tr>
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<td>4</td>
<td>2</td>
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<td>4</td>
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<td>7</td>
<td>5</td>
<td>4</td>
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</tbody>
</table>

## Administrative costs

In agroforestry, the land tax is the same as in an agricultural plot. It was thus applied to the tree strips.

<table>
<thead>
<tr>
<th></th>
<th>Land tax (€/ha)</th>
<th>Insurance (€/ha)</th>
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</thead>
<tbody>
<tr>
<td>Hy-Lc (Centre)</td>
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<td>20</td>
</tr>
<tr>
<td>Hy-Hc (Franche-Comté)</td>
<td>52</td>
<td>20</td>
</tr>
<tr>
<td>Ly-Lc (Poitou-Charentes)</td>
<td>58</td>
<td>20</td>
</tr>
</tbody>
</table>