Alley coppice: an evaluation of integrating short rotation coppice and timber trees

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Abstract: This paper summarises the main results from a recent research project focused on an innovative Alley Coppice (AC) land use system. We report on an AC system comprising standard trees for the production of valuable wood and the alley intercropping of short rotation coppice trees (SRC) for the production of bioenergy. Much of this work was carried out within the European project AgroCop (2012-2014) that combined field experimentation with bio-economic modelling. Two experimental plantations are located in Italy and France. The first plantation (9 years old) was used to study the intercropping of *Pyrus* spp. and *Sorbus* spp., as standard trees, with poplar SRC. Current measurements do not show any difference in stem height between intercropped standard trees and trees in pure plantation forestry. This was probably due to shading by the SRC canopy on standard trees. Nevertheless, this light competition has improved the stem form of standard trees, with a main bole almost straight and free of defects. In France, the poplar SRC crop was established into the alleys of a hybrid walnut tree plantation (18 years old) in a system we term: delayed alley coppice. Poplar growth was strongly limited by the shade of the walnut trees, although some microclimatic mitigation of water stress was observed on poplar shoots during the peak of summer heat. Biophysical modelling was conducted with the calculation tool YDEAL, comparing AC (hybrid walnut intercropped with poplar SRC) vs SRC monoculture vs walnut forestry monoculture. Simulations were performed on a 60 years rotation cycle of AC (harvesting cycle for the standard trees), and three cycles of 20 years for the poplar SRC, with triennial coppicing. Three growth condition scenarios were studied, namely poor, medium and optimum site conditions, mostly according to average yield data of poplar SRC (6, 10 and 15 t dry matter ha^{-1} $year^{-1}$, respectively). The financial analysis was performed using a calculation tool named FinAC. The AC system could be as profitable as the forestry monoculture, in the best financial and environmental scenarios, with the wood price determining absolute system profitability. AC can provide a landowner with a periodical annual income during the growth of standard trees. The feasibility of AC is partly limited by wood market uncertainty, the use of farmland for a medium-long period with the same culture, and the current difficulty in estimating AC profitability. AC could be used as a temporary system (10-15 years) to improve the stem form and wood quality of standard trees.

Keywords: AgroCop project, alley coppice, agroforestry, biomass, LER, NPV

1. Introduction

A bio-based economy, which produces sources of renewable energy and raw materials, requires land use systems, which combine the production of food, feed and wood with environmental safeguards to mitigate global warming and greenhouse gas (GHG) concentration in the atmosphere. The use of wood, as timber but also as a source of energy, provides one option to help reduce the use of fossil fuels. Yet, current trends indicate that the demand for woody biomass will exceed its supply. Therefore there is interest in Europe in new land use concepts that will facilitate both timber and biomass production in a sustainable and economically viable way. Agroforestry and short rotation coppice (SRC), for timber and bioenergy wood production, are two such systems.

Agroforestry is the deliberate combination of agricultural activities (crops and/or livestock) with trees. It can be used as an alternative to plantation forestry for timber production, using tree species which can produce valuable hardwood timber such as walnut (*Juglans* spp.) and cherry (*Prunus avium*) (Graves et al., 2007; Palma et al., 2007). Agroforestry can increase land productivity by the complementary capture of light, water and nutrients by the different tree and crop components. One way to measuring the improvement in land productivity is to use the Land Equivalent Ratio (LER) (Mead and Willey, 1980). LER compares the yields from growing two or more crops together with the yield obtainable from growing the same crops in monocultures or pure stands. When the LER is higher than one, the intercropping is more productive than monocultures because of beneficial interactions. For agroforestry systems combining timber trees and crops in Europe, LER simulations varied between 1.0 and 1.4 (Graves et al., 2007).

Short rotation coppice (SRC) can produce wood biomass within short cycles (2-5 years) using densely-planted fast-growing trees (e.g. poplars, willows, eucalypts (*Eucalyptus* spp.), robinia (*Robinia pseudoacacia*)) with coppicing ability. Cultural operations, from planting to wood harvesting are all mechanized (Vanbeveren et al., 2015), with minimum requirement of manual labour, similar to herbaceous crops (Morhart, 2013; Paris et al., 2011; 2015). The coppicing cycles of 2-5 years vary according to site conditions and species (Facciotto et al., 2015). A new tree-based intercropping system (Figure 1) using an agroforestry approach with SRC, called alley coppice (AC) (Morhart et al., 2014), was investigated in the European research project AgroCop (www.agrocop.com).

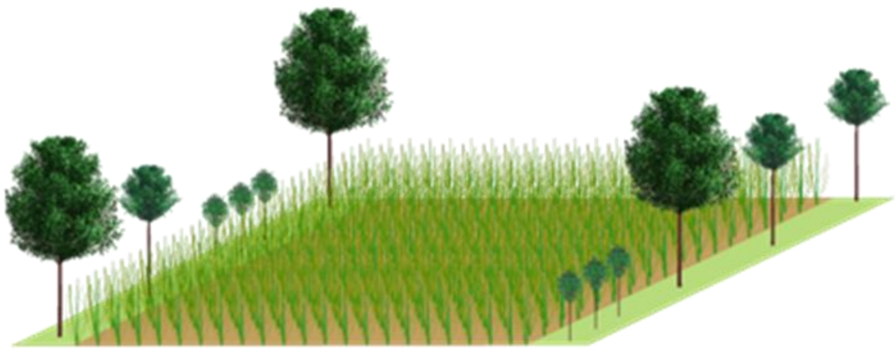

Figure 1. Alley coppice plot, combining timber trees, planted at a regular wide pattern, with short rotation woody crop (SRC) of densely panted fast growing trees in wide alleys with coppice management (from Morhart et al., 2014).

We started from the hypothesis that AC has important potential advantages including: i) a regular income guaranteed from the SRC component; ii) a land equivalent ratio (LER) potentially greater than 1.0; iii) improved stem form of timber trees due to little competition between the species and intensive tree management; vi) reduced costs because timber trees can be planted at their final spacing, avoiding expensive thinning operations; v) reduced wind/storm damage to young timber trees because the SRC component protects young timber trees, and vi) positive impacts on biodiversity and reduced soil erosion. The aim of this paper is to present an updated synthesis of the main results obtained from the research activity carried out in Europe regarding alley coppice, combining data from experimental plots, and biophysical and financial modelling.

2. Experimental plots and results

New AC systems were established in France, Germany, Italy, and Ireland in the last decade. In this document, we report some of the results that were obtained from two sites, where we assessed different planting scenarios, beginning with two different establishment methods: 1) Simultaneous planting (SP) where valuable timber trees and SRC were planted at the same time (site in Italy), and 2) Delayed planting (DP) where SRC was planted between already existing rows of valuable timber trees. On these experimental sites, the growth and yield of timber and SRC trees were studied, and competitive interactions for light and water resources were monitored using hemispherical photography and measurements of plant water potentials.

2.1 Simultaneous planting

In Italy, the study site was located near the city of *Casale Monferrato* (45°08' N; 8°30" E, 102 m a.s.l.) in Northern Italy. The SP experimental field, with a total area of 1.5 ha, was established by CRA-PLF in 2007 on flat agricultural field with alluvial soil. The climate of the area, according to Köppen-Geiger world climate classification, is warm, temperate, fully humid, with hot/warm summers. The soil texture is sand and sandy loam. Experimental plots were established for comparing pure plantations of *Sorbus domestica* L. and *Pyrus comunis* L. (3 clones) with a mixture of the same trees and poplar clones under biennial SRC harvests in an AC system, using a randomized block design with two replications. Poplars were planted using 120 cm long unrooted stem cuttings, placed horizontally on the soil surface with an inter-row distance of 2 m. Timber trees were planted at 8 m x 8 m spacing. The distance between the trees and the poplar SRC is 3 m. Since the establishment year, tree growth and yield have been recorded.

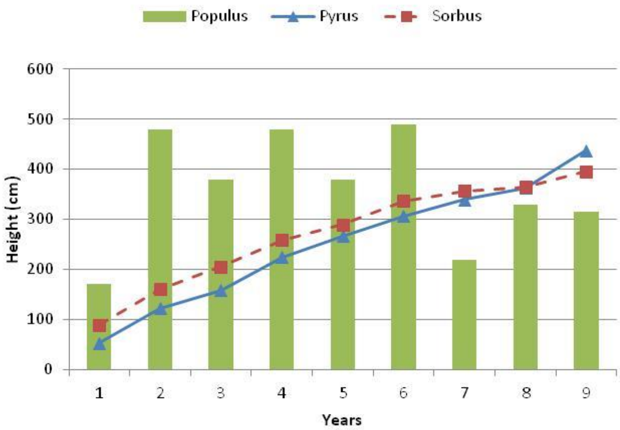

Figure 2. Simultaneous AC system. Total height of high-value timber trees (*Sorbus* and *Pyrus*) and SRC poplar, in the alley coppice experimental field, with biennial coppicing rotation (harvests in years 2, 4, 6, 8) for the first nine years since establishment (Casale M., Italy) (Facciotto et al., 2016).

The timber tree species in alley coppice stands showed a steady growth, reaching a mean height of 438 and 395 cm for *Pyrus* and *Sorbus* respectively (Figure 2), while the maximum height which was obtained in the pure stands was 523 cm for *Pyrus* and 453 cm for *Sorbus* , (data not shown). Timber trees in the AC treatment suffered light competition (see Paris et al., 2014) from the SRC poplar whose height was cyclically dominating the timber trees during the first 6 years, with 3 biennial harvests by coppicing. On the other hand, light competition positively affected the wood quality, as demonstrated by the value of the index of wood quality (*Q*) (Paris et al., 2014), measured at the end of the seventh growing season, which was higher for plants grown in combination with SRC poplar (55) than for those grown in pure stands (32). The competition improved the stem shape and forced the high-value timber trees to grow with a straight stem and thinner branches (Paris et al., 2014). From the seventh season, the height of the timber trees was greater than the poplar SRC that should minimise further light competition from the SRC.

2.2 Delayed planting

The DP site was located close to Montpellier (43°43’07’”N; 3°54’29’E, 117 m a.s.l.) in Southern France. It had a total area of 1.5 ha. The climate of the area is temperate, Mediterranean with dry and hot summers (Köppen-Geiger). The soil is alluvial, its texture is loamy clay sand. Hybrid walnut (*Juglans regia x nigra* L.) timber trees were planted in 1995, in an alley cropping system design with a 13 m x 8 m spacing. Winter cereals were the principal crops in the initial years. Poplar cuttings (variety Monviso) were planted in 2012 in double rows (10000 trees ha^{-1}) between the 18-year-old timber tree lines at a distance of 2 m from them. A SRC control without timber trees was also planted. A randomised block design with three replicates was used. Tree growth, yields, understory illumination, and poplar water status (via mid-day and pre-dawn leaf water potential, Ψ_{md} and Ψ_{pd}, respectively) conditions were studied during the year 2013.

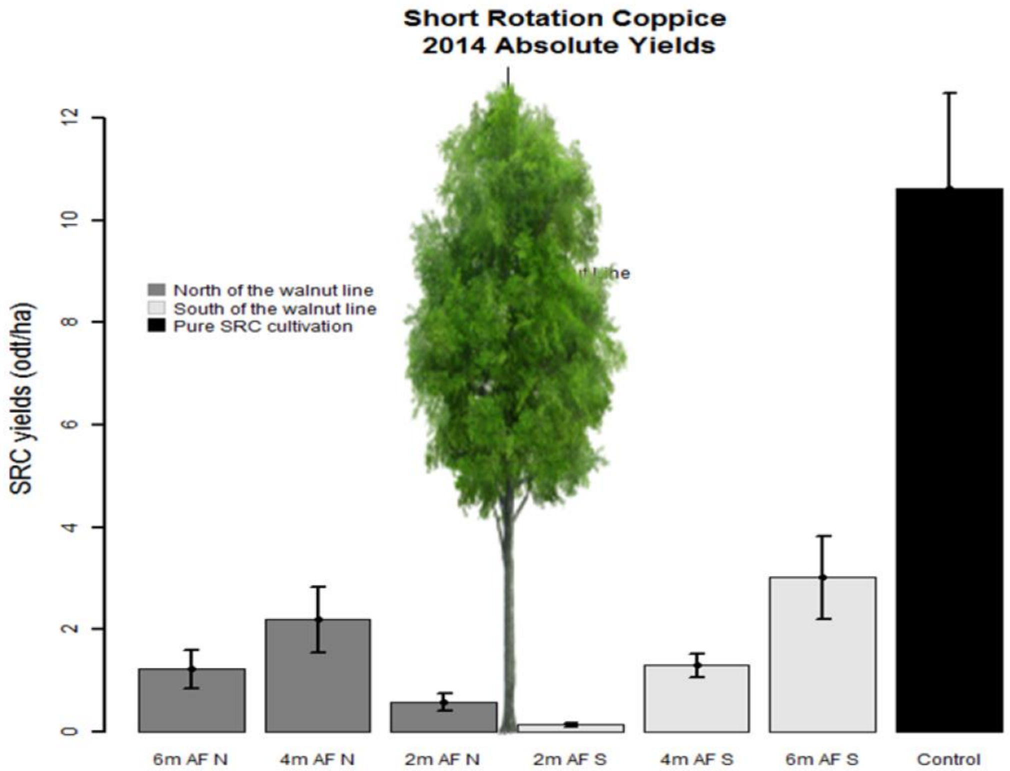

Figure 3. SRC yields in a Delayed Alley Coppice System. SRC poplar yields depending on sun exposure (south (S) and north (N) sides) and distance from timber tree line (2, 4 and 6 m) (Montpellier, France) (André et al., 2015) and yields from pure SRC without hardwood trees.

The first coppicing rotation gave a very low yield both in the pure SRC system (without hardwood trees) and in AC, 1.0 and 0.3 Mg dry matter ha^{-1} year^{-1}, respectively. In 2014, the

SRC yields in the AC were less than 40% of that in the pure SRC (Figure 3). There was a strong competition gradient from the timber tree line to the center of the intercrop alley, with yields at 2 m being significantly less than those at 6 m. A significantly higher water stress on poplar was measured in the presence of timber trees, with water stress on poplar shoots increasing the closer they were to the walnut row. However, this competition for water was mitigated by the microclimatic effect of timber trees. Indeed, we observed a protection effect by walnut shade on SRC, by measuring differences between Ψ_{md} and Ψ_{pd} in control and AC. This may explain the yield difference between north and south SRC exposure (André et al., 2015).

3. Biophysical modeling

Within the AgroCop project, a calculation tool was developed for assessing the biophysical behavior of AC systems. This tool, called YDEAL (Yield Dynamics Estimation for Alley Coppice), describes the yield dynamics for AC systems under defined conditions or scenarios, based on a meta-analysis of available literature data and on data measured directly on the project's field sites. We assessed different scenarios, beginning with the two different establishment methods, *simultaneous planting* and *delayed planting*. In the simulations, we considered hybrid walnut as the timber tree and hybrid poplar for the SRC crop. The two AC methods were applied for three different growth scenarios, namely poor, average, optimum growth conditions (by meta-analysis). In the poor scenario, for sub-marginal site conditions, we assumed for the SRC a potential yield of 6 t ha^{-1} $year^{-1}$ of dry woody biomass (or dry matter, dm) and 1.6 m^3 of timber per tree for walnut. In the average scenario, the SRC has a yield of 10 t dm ha^{-1} $year^{-1}$ and walnut has a timber yield of 1.1 m^3 $tree^{-1}$. In the optimum scenario, SRC has a yield of 15 t dm ha^{-1} $year^{-1}$ and walnut has a yield of 1.6 m^3 $tree^{-1}$. Major details on the biophysical modelling are reported in André et al. (2015). Output examples of YDEAL simulations are shown in Figure 4.

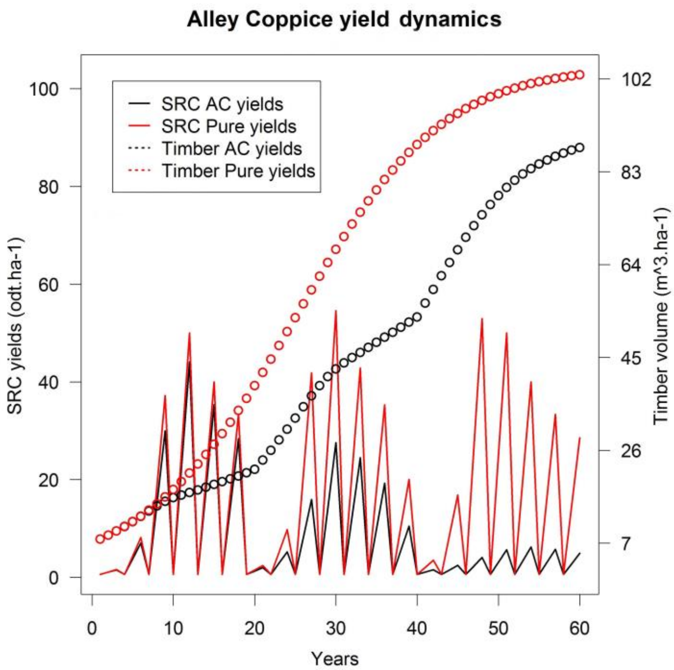

Figure 4. Output examples of the biophysical model YDEAL developed in the AgroCop project for Alley Coppice (AC) systems, with simultaneous planting method, under the scenario of optimum growth conditions (fertile alluvial soil of Central-western Europe), with hybrid walnut as timber tree, and hybrid poplars as SRC species

In the simultaneous AC scenario, the growth of timber trees in the AC system was less than in the pure timber system during the first 20 years due to light and water competition. In the following two SRC cycles of 20 years, the timber trees became more competitive for light and perhaps soil water resources. In the delayed planting methods (not shown), during the first 20 years, the growth of timber trees is unaffected, because there is no competing intercrop. In the following two SRC cycles of 20 years, both the timber trees and SRC crop have reduced yields in comparison to their respective monocultures. The simulations shown in Figure 4 for the optimum scenarios were also run for the poor and average scenarios (data not shown), obtaining yield data for all the studied scenarios. These data were used to calculate the LER of AC in the different scenarios (Table 1), which was always higher than one.

Table 1. Modelled values of LER (Land Equivalent Ratio) of Alley Coppice systems (AC) under different growth scenarios and establishment methods (simultaneous and delayed planting).

	Growth scenarios		
	Poor	Average	Optimum
Simultaneous planting of SRC	1.10	1.13	1.22
Delayed planting of SRC	1.05	1.07	1.13

4. Financial modeling

To determine the financial profitability of AC systems for farmers and landowners, a specific calculation tool (FinAC; Tosi, 2015) was developed, with a specific database containing all the costs of cultural operations and cultural inputs for timber plantation forestry and for SRC. These data were derived by using information from the countries involved in the AgroCop project (Germany, Ireland, Italy and France). These costs were then standardised, in order to find a modeling condition with representative values of average conditions of Western Europe. Market values of wood biomass for energy and timber were standardised to average values of 70 € (t dm)$^{-1}$ and 500 € m^{-3}, respectively, although these values can be strongly variable in time and on local or regional markets. A discount rate of 3.5% (year 1-30) and 3.0% (year 31-60) was assumed. Financial simulations were then run using the yield outputs of YDEAL, for the above mentioned growth scenarios.

Under the poor scenario, the NPV values are very low, equivalent to 630 € ha^{-1} for the poplar SRC and 290 € ha^{-1} for the simultaneous Alley Coppice (Figure 5). Forestry gave a NPV of 3,700 € ha^{-1}. For the Alley Coppice, both lagged and simultaneous, in the last 20 years of the cycle it would not be possible to cultivate SRC poplars because of strong competition, mostly for light, of the adult walnut trees. Given the low productivity of the SRC, the NPV of the delayed AC (1,680 € ha^{-1}) was higher than the simultaneous planting because of the reduced costs for plant material, establishment and management during the first 20 years.

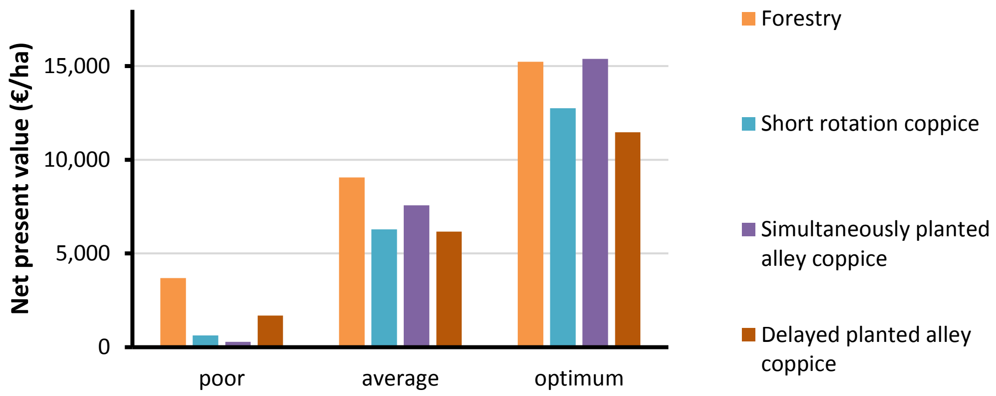

Figure 5 Output example of the economic model (FinAC) developed in AgroCop, displaying the Net Present Value (NPV) (€/ha) of alley coppice systems grown in different scenarios with average, poor, and optimum growth conditions. For the simulation, we assumed a 60 years plantation with replacement of SRC trees each 20 years. The harvesting cycle of SRC is triennial. We selected walnut as the timber tree and poplar as SRC woody crop.

In the average scenario, the highest NPV was again achieved from forestry (9,057 € ha^{-1}), although the alley coppice systems increased in relative profitability. In the optimum scenario, the best NPVs were achieved by forestry (15,240 € ha^{-1}) and the simultaneous alley coppice system (15,380 € ha^{-1}) (Figure 5). In conclusion, the forestry system was generally more profitable at the end of the 60 years cycle in comparison to AC and pure SRC. However forestry has only a final return after 60 years, without any intermediate income, except to the final sale of the valuable timber (except for the small income coming from thinning operations). Under the optimum and average scenarios, simultaneous AC provided a higher NPV than SRC culture. Hence, in comparison to the more profitable Forestry, AC guarantees an income every three years thanks to the harvest and selling of biomass from intercropped SRC; in comparison to SRC monoculture, alley coppice guarantees a slighter higher profitability, with the final income from the timber harvest and selling.

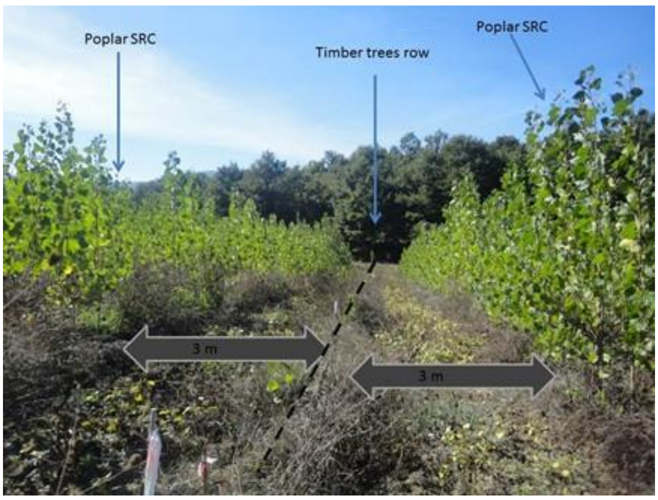

Figure 6. La Valletta, Italy (42°40'55"N; 12°23'26''E). A 10 ha commercial poplar SRC plantation where few rows of poplar were removed after one year, and planted with wild cherry (*Prunus avium*) seedlings in spring 2013. This activity was carried out within the Agrocop project. Planting some timber tree lines when establishing an SRC plantation can be a feasible way of integrating timber and bioenergy production. Once the timber trees have reached a good size, it may be possible to remove the SRC stools (approx. after 10-15 years) so that the alleys can be intercropped with annual crops.

4. Discussion and conclusions

The study indicates that the Alley Coppice system represents an interesting opportunity to integrate timber and bioenergy production, with synergic benefits in terms of stem form of timber trees and a LER > 1.0. However the financial analysis suggests that AC shows the highest relative and absolute profitability under favourable growth conditions. In general the walnut monoculture for timber production gave the highest profit. These results should be used with caution because of the limitations of the modeling approach and because the productivity and quality of forestry based on monocultures can be very variable. For example, in the last 25 years in Italy have seen many failed attempts to convert marginal agricultural lands to monoculture hardwood plantations for timber production using European grants (Facciotto et al. 2015). Our models (YDEAL (André et al. 2015); FinAC (Tosi, 2015)) are based on a preliminary and a relatively small data set. It is desirable to collect more field data to generate a more reliable database to improve our prediction of the biophysical and economic behavior of alley coppice systems. The achievement of high yields of high quality timber depends on the appropriate choice of planting materials and tree management experience, and the returns are very sensitive to unreliable timber prices.

The agroforestry system is an alternative method to establish valuable broadleaved species for timber production on good fertile soils whilst producing other crops within the tree rotation. In Europe, the Common Agricultural Policy (CAP) offers the potential for national governments to support the establishment of agroforestry systems and SRC plantations. Depending on the initial assumptions, AC systems might be more profitable than SRC monocultures in medium and good site conditions. Therefore, we recommend that for new SRC plantations, consideration should be given to planting several rows of timber trees in combination with wide alleys (at least 25-30 m) of SRC crops (Figure 6). The experimental work suggests that alley coppice systems can also improve the stem form and thereby the potential timber quality of valuable tree species like walnut and wild cherry (Loewe et al. 2013; Mohni et al. 2009).

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