Innovative Alley coppice Systems-mixing timber and bioenergy woody crops: 7 years growth and ecophysiological results in experimental plots in northern Italy, Po Valley

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Abstract: Land use competition between food/feed and energy crops could exclude the establishment of Short Rotation Coppice (SRC) plantations, as bioenergy woody crop, on productive agricultural land. A solution could be the cultivation of multipurpose plantations producing biomass and logs for industry, as an innovative alley coppice system. This is a mixture between high value timber trees and SRC of poplars and willows. The advantages of this cultural model could be that: i) the farmers can receive payments for biomass every 2-5 years during juvenile phase of the high value timber trees, ii) the timber trees can be planted at final spacing, avoiding plantation thinning, iii) the SRC, with a rapid canopy closure, has a positive environmental impact, reducing soil erosion and increasing biodiversity, iv) the SRC can protect the timber trees from wind and storm, v) a modulated light competition of SRC towards the timber trees causes the correct growth of their stem, reducing pruning intensity. This paper refers preliminary results obtained during the first 7 years in experimental plots, in northern Italy, comparing alley coppice of poplar SRC with *Sorbus* and *Pyrus* trees and sole timber trees without any mixture. Data reported concern on tree growth and stem form, along with some preliminary observation on light competition. The timber trees in the alley coppice treatment reached satisfactory stem dimensions, associated with improved wood quality in comparison to the sole timber trees. Although the timber trees in the alley coppice plots were dominated by the poplar SRC shoots, the light competition was not so intensive for inhibiting the growth of the *Sorbus* and *Pyrus* trees. Research funded by Moprolegno Project (2006-'09) and "AgroCop" Project"-WoodWisdom-Net - ERA-NET Bioenergy (2012-'15).

Keywords: Sorbus, Pyrus, poplar; agroforestry; SRC; light competition; timber quality

Introduction

Energy and valuable timber are two commodities strongly in shortage in Europe. Bioenergy plantations, such as Short Rotation Coppices (SRC), can be established on agricultural land, with rotation cycles of 2-5 years, using fast growing tree species (e.g. *Populus spp.*, *Salix spp.*, *Eucalyptus spp.*, *Robinia pseudoacacia*), with coppicing ability and able to support very high planting density (ca. 6000-10000 plants ha^{-1}) (Bergante and Facciotto, 2011; Paris et al., 2011). In Europe SRC is gaining attention for producing biomass for energy conversion (heat, electricity) in alternative to imported fossil fuels, and for reducing emission of greenhouse gases. SRC can be more attractive than traditional forms of plantation forestry for the short length of rotation cycles, and because cultivation practices are fully mechanized from planting to harvesting (El Kasmioui, Ceulemans, 2012; Faasch, Patenaude, 2012; Manzone et al. 2009).

In Europe there is also a large commercial flux of high quality timber that is mostly imported from developing countries, mostly as tropical hardwoods. In the last two decades many attempts have been done in Europe for encouraging farmers to establish valuable timber plantations with endemic/naturalized tree species, like cherry (*Prunus avium*), walnut (*Juglans* spp.), oaks (*Quercus spp.*), ashes (*Fraxinus spp.*) (Fady et al., 2003; Magagnotti et al., 2010). Unfortunately those attempts have not always been very successful, because timber tree species require soils with medium-high fertility (Lauteri et al., 2006; Mohni et al., 2009). Furthermore the length of the rotation cycle (30-50 years) is scarcely attractive for farmers/landowners (Palma et al., 2007) and the cultural practices for improving stem form and wood quality, such as pruning and thinning, are expensive and un-profitable (Bisoffi et al., 2009).

A solution to these problems can be mixing timber trees with SRC in alley coppice system, as innovative land use management addressing important productive and environmental issues. The main advantages of alley coppice system could be that: i) the farmers can receive payments for biomass from SRC every 2-5 years for 10 or more years when high value timber trees are in the juvenile phase, ii) the high value timber trees can be planted at definitive spacing, so that plantation thinning could be avoided, reducing production cost, iii) the SRC, with a rapid canopy closure, have a positive environmental impact reducing soil erosion and increasing biodiversity (soil fauna, birds and little mammals), iv) the SRC can protect the high value timber trees from wind and storms, v) light competition of SRC towards the high value timber trees causes the correct growth of their stem and the formation of a smaller number of thin branches, in comparison to traditional mono-cultural model of plantation forestry, reducing pruning intensity.

The average duration of a SRC plantation is 10-15 years, with dramatic yield depression after this limit (Dillen et al., 2013; Geyer, 2006). The soil occupied by the SRC therefore needs to be uprooted and used for another crop or for the establishment of a new SRC plantation. Thus, alley coppice system is a specific form of agroforestry system in which the long lasting element is the timber trees population.

In order to achieve the desiderated benefits in alley coppice system, the tree species mixture and the layout of the plantation need to be carefully designed for avoiding competitive interaction for site resources (soil moisture and nutrients, light) between slow growing timber trees and fast growing SRC woody crops. In fact, most of tree species suitable for SRC are well known for their high water and nutrients uptake (Guidi et al., 2008; Lars, 2002; Morhart et al., 2013; Pistocchi et al., 2009). Furthermore, the fast growth along with the high planting density of SRC should rapidly reduce the solar radiation available for companion timber trees in an alley coppice mixture.

A transnational European project named AgroCop (WoodWisdom-Net – ERA-NET Bioenergy - 2012-2015; http://www.agrocop.com) is currently investigating alley coppice system in Europe, and a network of experimental sites was set up for studying the correct assumption of the benefits of the studied system. The AgroCop network included an experimental plantation that was established in northern Italy, Po Valley, in 2006 within an Italian local project (Moprolegno, 2006-2009), for comparing alley coppice plots and pure timber plots.

Materials and Methods

The experimental site

The experimental field, with a total area of 1.5 ha, was established at Mezzi Farm (45°08'11" N; 8° 30" 50" E, 102 m a.s.l.), located near Casale Monferrato (AL, northern Italy), on a flat agricultural field with alluvial soil. Mezzi is the experimental farm of CRA-PLF research Institute. The climate of the area, according to Köppen-Greiger world climate classification (Kottek *et al*., 2006), is warm, temperate, fully humid, with an hot/warm summer. Average temperatures are 12.9, 24.4 and 0.5 °C, as annual, maximum and minimum averages of the hottest and coldest months, respectively. Average yearly precipitation is 745 mm, with almost 400 mm distributed during the growing season from April to September (Bergante and Facciotto, 2011). The soil texture is sandy and sandy loam. Experimental plots were established for comparing pure plantation of *Sorbus domestica L.* and *Pyrus spp*. with the mixture of these noble hardwoods with poplar clones under SRC management as alley coppice system, using a randomized block design with two replications for each of the two treatments (pure timber trees and alley coppice) Three micro-propagated clones of *Sorbus domestica* were used: TOSCA 3, TOSCA 10/15, TOSCA 10/16); and one clone for *Pyrus* spp. L. (PVC 74-15-53). One year rooted plantlets, selected and provided by University of Milan (Prof. C. Piagnani and D., Bassi – Piagnani et al., 2009; Facciotto et al, 2009), were used as planting material. Timber trees were planted at a spacing of 8 x 8 m. Three clones of poplar were used for the experiment: Lux and Oglio (*Populous deltoids* Bartr.); Triplo (*P. x canadensis* Mönch). The distance between poplar and noble hardwood trees was 3 m. Poplar was planted as un-rooted stem cuttings, 120 cm long, placed horizontally, 5 cm below the soil surface with an inter-row distance of 2 m. Before the establishment of the plantation, the soil was ploughed to a depth of 40 cm, and then arrowed before planting. Ryegrass (*Lollium perenne* L.) was sown as cover-crop and organic mulch was used on timber tree rows for weed control. During the summer of the first year, three harrowings were carried out between the SRC rows. During the second and following years, the cultural practices were reduced: weed control by disc harrowing was done only once in late spring. Sprinkler irrigation was applied once or twice per year in late July-August, depending of the current precipitation. One or two treatments against leaf beetles *Chrysomela populi* L. were applied in spring and summer. Poplar rows in the alley coppice plots were harvested mechanically at the end of the 2nd, 4th, and 6th year since plantation establishment.

Measurements

At the end of each vegetative season, tree survival, stem diameter at breast height (mm), and total stem height (cm) were recorded both on timber trees and poplars. The total fresh weight of poplar stems and branches were measured on a sample of 10-30 trees per clone at the end of each rotation cycle, for the estimation of poplar yield with allometric regressions between stem diameter and total shoot weight. In 2013, new eco-physiological measurements were carried out in order to study the inter-relationships between timber and poplar trees. The percentage total light transmittance (PTLT, %) was estimated with hemispherical photos (HPs), using a digital camera (Nikon Coolpix 995), equipped with an hemispherical lens (Nikon fisheye converter FC-E8 0.21x). Two sets of hemispherical photos were performed. A first one, on April 29th, for estimating PTTL for timber trees in mixture with SRC, just before the third biennial poplar harvesting, when poplar trees were already in full budburst. The HPs were carried out according to standard procedures: after sunset, with diffusive radiation, levelling the camera and orienting it to the magnetic north. The camera was set at midway between each pairs of timber trees, along the row, to an height of 1.5 m above the ground surface, imitating the light conditions in the mid-canopy of the timber trees. A second set of HPs were recorded on August, 7th, on the canopy top of poplar-timber mixture, for measuring PTLT of poplar shoots, after almost 2 months of growth since coppicing. On each measurement session, 5 HPs were taken for each treatment and block. Digital photos were then analysed with the Gap Light Analyser software (Frazer et al., 2000), using correct data input for sun and sky parameters of the region. Percentage TLT calculations were made for the period between April 1 and October 30, covering approximately the entire growing season for timber and poplar trees, from budburst to leaf shedding.

Finally on December 2013, measurements were carried out to detect positive effect of the mixture with poplar SRC on the wood quality of timber trees .

The following equation was used (VVAA, 2000):

$$Q = 3H - (E + F + DI + DF + DM + CF + Kn + EB) \quad \text{[eq. 1]},$$

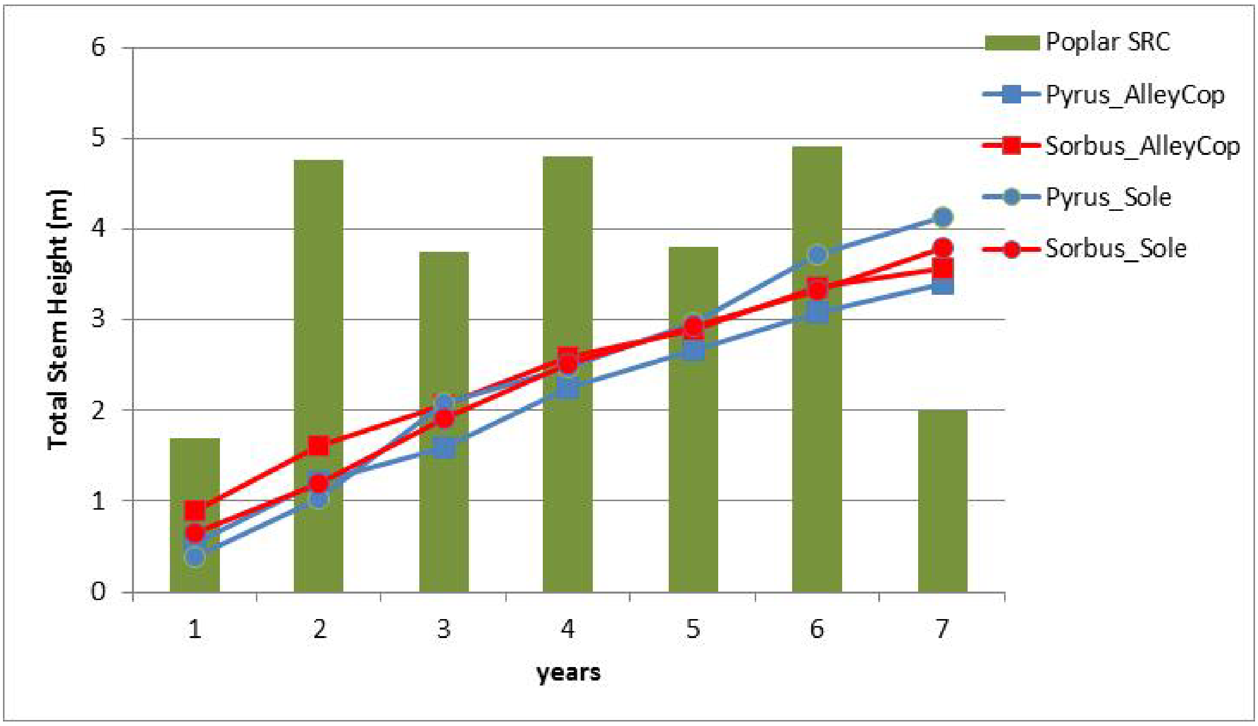
with: Q= index of wood quality; H= log value, as function of log length and straightness index of log axis; E = log eccentricity; F= fiber orientation; DI = absence/presence of insects damages; DF = absence/presence of bacteria/fungi damages; DM= absence/presence of mechanical damages; CF = presence/absence of critical fork; Kn = presence/absence of knots with a diameter ≥ 2 cm; EB= presence/absence of epicormic branches.

In this paper just a part of all observations and measurements are presented and discussed. This with the aim of giving a first picture of the alley coppice functioning in the studied experimental plots. A more complete set of data and information will be presented in further publications.

Results and Discussion

In Figure 1 are reported the growth rates in total stem height (H) for the tree species during the first seven years, since the plantation establishment. Poplar SRC was managed with a biennial coppicing rotation, therefore its values of H reflect the cyclical regrowth after coppicing in the years 3, 5 and 7. The growth rates of poplar SRC in the studied plantation, with biennial rotation, are lower in comparison with the average growth rates of the cultivation in northern Italy (Bergante et al, 2010). The average height of 5 m of poplar shoots in our plantation, in the second year of each biennial rotation, are more similar to the values of the cultivation with annual coppicing, probably due to the twin row planting lay out we used in this experiment. This planting lay out, with very high stem density (>10000 stems ha^{-1}), may have depressed the shoot growth for very high intraspecific competition (Mareschi, 2008). The timber tree species had a continuous growth, reaching a total H at the end of the seventh growing season of 4.1 and 3.8 m for pure *Sorbus* and *Pyrus*, respectively, while the same species reaching an H of 3.4 and 3.6 m, respectively, in the alley coppice mixture. The analysis of variance did not show any significant difference between the treatments for H of timber trees after seven year of growth.

Figure 1: Total height of timber trees (*Sorbus* and *Pyrus*) and poplar SRC, with biennial coppicing rotation, for the first seven years since establishment in the alley coppice experimental field. AlleyCop= mixture of timber trees with poplar SRC; Sole= pure timber tree stand.



The lower growth rates of timber trees in mixture with poplar SRC, in comparison with pure timber tree stands can be explained with the light competition of poplar, as shown by the low percentage total light transmittance (PTTL, %) measured for the timber trees in the alley coppice treatment, at the beginning of the seventh growing season (Table 1). At that moment the timber trees were completely dominated by poplar shoots, whose H was on average 5 m, i.e. 2.5 m higher than the associated timber trees. On the contrary, any shading effect of timber trees was observed on poplar shoots during the middle of seventh growing season (Table 1, August measurement), when the poplar shoots were almost 2 m high. At that moment the timber trees were 1.5 higher than the associated poplar shoots, but the crown of the timber trees was not enough developed for shading poplar.

Table 1: Total light transmittance, in percentage to full sun condition (PTLT), estimated with hemispherical photos, and available for timber trees and poplar SRC, on two dates of the 7th growing season in the alley coppice exp. field. Values in parenthesis are the standard error of means (± sem).

Treatments	Camera Position (and date)	Along timber tree row (29 **Apr.** 2013)	Poplar top canopy (7 **Aug.** 2013)
		Total light transmittance (%)	
Alley Coppice		66.05 (2.35)	98.52 (0.15)
Sole timber		99.45 (1.3)	-

The light competition of poplar towards the associated timber trees seems positively affecting timber wood quality, as shown by the wood quality index (Q), measured at the end of seventh growing season (Table 2). Light competition has indeed improved the stem form of timber trees, forcing them to grow with a straight log and with thinner branches, in comparison to sole timber trees. This result is in full agreement with other experiments on mixed timber plantations, demonstrating the positive effect of trees mixture on timber wood quality (Loewe et al., 2013; Mohni et al, 2009).

Table 2: Total index of wood quality (Q total) for 7 years old *Sorbus* and *Pyrus* timber trees as affected by mixture with poplar SRC (alley coppice) in the exp. field.

Treatments	**Q total**
Alley Coppice	55
Sole timber	32

Conclusions

The preliminary results presented in this paper show that the hypothesized beneficial effects of alley coppice mixture can be achieved throughout a balanced mixture between slow growing timber trees and fast growing poplar trees under short rotation coppice management. After seven growing seasons, the timber trees in the alley coppice treatment reached satisfactory stem dimensions, in association with improved stem form and wood quality in comparison to sole timber. We used a distance of 3 m between the timber trees and poplar rows. This distance seems to leave enough room to the timber trees for growing without a too strong, detrimental competition with the adjacent poplar trees. We detected a light competition of poplar shoots towards the timber trees, but so far it has not been so intensive to inhibit the growth of *Sorbus* and *Pyrus* trees.

Mixed timber trees plantations, although strongly recommended for their productive and environmental advantages, are rarely applied at commercial level because their technical management is more complex in comparison to mono-specific timber plantations (Kelty, 2006). Alley coppice design could be an innovative mixture in relation to its management simplicity, especially concerning the mechanization of cultural operations and marketability of final and intermediate products.

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