TREE FARMING, AGROFORESTRY AND THE NEW GREEN REVOLUTION. A NECESSARY ALLIANCE

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In Italy, as in the rest of Europe, tree farming and agroforestry systems can contribute significantly to domestic wood production, for industrial usage and energy conversion, combining productive activities with ecosystem services. This has been demonstrated in the last few years by many research studies carried out at national and international levels. Trees outside forest can have positive effects on adjacent cropping areas in terms of biodiversity, landscape, carbon cycle and soil protection, in full agreement with the latest guidelines on the EU's "greening" of the new Common Agricultural Policy (CAP). The uncertainty of the international wood market has led to a dramatic crisis of private investments on traditional plantation forestry for timber production, although poplar plantations are still intensively managed and constantly innovated throughout research activity. Alternative solutions relay on flexible cultural models, able to quickly adapt to wood market uncertainty, throughout the implementation of cropping systems providing various sized and quality wood assortments for energy and round wood at different time steps. This can be achieved by applying: i) polycyclic arboriculture, i.e. combining tree species with different rotation lengths; ii) Short Rotation plantations with 2-3 and 5-6 yr. rotation coppicing cycle, producing assortments for multiple industrial uses; ii) new agroforestry systems with a modern complementarity between trees outside forest and agricultural activities, balancing food and wood security with environmental preservation. These opportunities offered by the new cultural models need a more coordinated political and industrial organization of the domestic wood sector.

Keywords: tree farming, agroforestry, food security, marginal lands, wood market, greening, CAP.
Parole chiave: arboricoltura da legno, sistemi agroforestali, sicurezza alimentare, terreni marginali, mercato del legno, *greening*, PAC.

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1. Introduction

The primary sector is undergoing a profound reorganization in order to address the social, economic and ethical issues emerging at a global scale. Terms such as "New Green Revolution" and "Bioeconomy" indicate the urgent need to adopt innovative approaches to the agricultural and forestry sectors in order to increase the production of raw materials for food, energy and other industrial purposes. In addition, various ecological services need to be guaranteed through the sustainable use of natural resources. Both tree farming and agro-forestry systems can contribute significantly to the increasing importance of wood as a renewable raw material and the variety and multi-functionality of the applicable crop models. According to the latest FAO data (FAO, 2010), the world's forest plantations amount to about 264 M ha, with a rate of new plantations of 4.3 Mha y^{-1}from1990 to 2010 and an expected area of 300 Mha in 2020. Representing only 5% of the global forest area, in 2000 these plantations provided about 35% of the total round wood produced in the world (FAO, 2001). In Italy, wood production outside the forest mainly includes the following crop models: a) poplar plantations for peeler logs (traditional poplar plantations); b) energy plantations with poplar and other fast-growing tree species (short-rotation-coppices, SRC); c) valuable hardwood plantations for veneer logs; d) agro forestry systems. Innovative solutions provide a combination of two or more of the above-mentioned crop models resulting in mixed plantations with multi-layered structures, as well as a great potential in terms of both wood production and environmental advantages.

2. Traditional poplar plantations

In Italy the area of traditional poplar cultivation based on ten-year cycles, for the production of the plywood, is continuing to decrease. Currently it has reached its historical minimum: 69,500 ha (FAO, 2012), of which only 39,000 ha is on farm land (General Census Agriculture, 2010). The industrial wood annually obtainable from poplar stands accounted on average for 1.1 million $m^3$from 2000 to 2010, and only 800,000 m^3 in 2010 (ISTAT, 2012), while the total domestic requirement is over 2 million m^3 per year. This deficit in domestic production is covered by massive imports of round wood from other European countries and particularly from Eastern Europe (FAO, 2012).

There are several reasons for the above situation including: a) an internal closed market controlled by a few buyers that maintain a low price of poplar wood (40-52 € per m^3 in stand); b) the choice of only one clone, the "I-214", as the preferred raw material for the industry and a consequent lack of market for the wood from other more productive poplar clones that are resistant to pest and diseases; c) a lack of awareness in terms of the environmental role of poplar.

Another negative aspect concerns the many environment-oriented laws and regulations that have banned poplar cultivation from lands that are the most appropriate for poplar growing, such as floodplains and river beds: particularly: ZPS - Special Protection Zone, SIC - Site of Community Importance and Parks.

As a consequence there has been a gradual reduction in the number of operators in the poplar sector (Nervo *et al.*, 2011). Furthermore in recent years, farmers have increased the distance between poplar plants, reaching a density of around 280 plants per hectare instead of the 300-330 previously used. The greater surface available per plant produces trunks of a higher quality and leads to greater flexibility in the length of the cycle.

Recently, two forest certification standard schemes for traditional poplar stands have been implemented: the Forest Stewardship Certification (FSC, www.fsc.org) and the Programme for the Endorsement of Forest Certification (PEFC, www.pefc.org), both based on internationally-recognized requirements. Sustainable poplar plantation management consists mainly of a management plan and the implementation of an environmental monitoring system i.e. clonal diversification, measures to mitigate negative impacts of chemical applications (pests and disease control, nutrient supply), safe harvesting methods, water-course protecttion, and irrigation water management and control.

All this has resulted in a reduction in cultivation practices and costs without affecting the quality of the wood (Vietto *et al.*, 2011). These certification systems involve an evaluation of individual companies (each forest company is inspected by a certifier on at least an annual basis). However in order to provide cost-effective certifications to private smallholders, group certification has also been developed (Coaloa and Vietto, 2008). At the end of 2012, a total of 4,393 hectares had been certified through certification groups of smallholders, in Piedmont, Friuli Venezia Giulia and Lombardy, on about 140 farms: 3,578 ha were certified with the PEFC scheme, the remaining 815 ha with the FSC scheme (Coaloa, 2014). Certification can help to improve the social perception of poplar cultivation, as well its environmental role.

In order to reduce the environmental impact of poplar cultivation, CRA-PLF have performed extensive studies and research to select clones that are resistant to the main biotic adversities and to improve cultivation techniques, thus reducing the need for treatment with pesticides and chemical fertilizers. The new poplar clones, recently placed on the market, are characterized by fast growth, high wood production as well as adaptability to different environments and soil conditions, resistance to diseases, and wood quality (Vietto *et al.*, 2012; Facciotto *et al.*, 2014).

As regards cultivation techniques, the amount of nitrogen recommended by CRA-PLF and distributed into poplar stands is totally absorbed by trees. On the other hand, the abundant fertilizers applied to other crops, particularly nitrogen, remains unused and, leached throughout the soil, thus polluting the water table. Poplar stands have a lower environmental impact than food crops in terms of phytosanitary treatment, particularly compared with fruit orchards. The lower impact has been confirmed by surveys with bioindicators (*Carabidae* and soil *Arthropoda*), thus demonstrating that poplar stands are more similar to natural forests than to crops (Chiarabaglio *et al.*, 2014a). The absorption of GHG in poplar stands is quite high. In an average year of rotation length, it ranges from 13 t CO_2 $ha^{-1}yr^{-1}$ of stand grown with a low input to 19 t CO_2 $ha^{-1}yr^{-1}$ of stand grown with a high input (Seufert, 2010).

Poplar cultivation is likely to undergo a differentiation process towards a number of different cultural models, each specific to a group of products or environmental services (e.g. phytoremediation, especially in combination with SRF, and landscape restoration). The features of the main models are shown in Table 1. In the short term, the demand for poplar wood by new OSB panels, packaging, paper and energy industries is likely to increase. This demand will no longer be satisfied by the by-products of traditional poplar cultivation alone, therefore dedicated cultivations will become necessary.

Various high density plantation models, such as short rotation coppice, have been adopted in order to meet the new requirements of the above mentioned specific sectors. The growing demand for lignocellulosic feedstock for the production of second-generation biofuels can be met with the strong expansion of the areas planted with the new cultivation models (Coaloa and Facciotto, 2014). The production of second generation bioethanol, which was recently started in Crescentino (Piedmont, Italy) is particularly interesting. LCA modeling indicated that E100 (100% bioethanol) and E85 (85% bioethanol,15% petrol) fuels derived from poplar from various locations in the EU have a10% to 90% lower environmental impact than petrol in terms of global warming, abiotic depletion, ozone depletion and photochemical oxidation depending on the exact poplar supply chain and conversion technology models (Guo *et al.*, 2014). The development of crops for biomass production is relatively recent, and was first encouraged by government incentives for the conversion of agri-

cultural land to energy crops, in line with the National Action Plan for Renewable Energy in Italy.
This plan adopts the Renewable Energy Directive, and sets a target for the production of 4 Mt of dry matter (d.m.) per year by 2015 and 10 Mt by 2020 (Coaloa and Facciotto, 2014). Currently, however, the area dedicated to SRC is limited to about 10 000 ha, of which 7000 ha is with poplar. Several new poplar varieties such as 'Orion', 'Imola', 'Baldo' (selected by CRA-PLF) and 'Monviso', 'AF2', 'Sirio', 'Pegaso', 'AF8' and others (selected by a private company, Alasia Franco), characterized by a good growth rate, disease and pest tolerance and better sprouting after repeated coppicing, have led to an increase in biomass production, thus reducing the economic and energetic costs.
Site characteristics (soil fertility, climatic conditions) and water availability (precipitation and irrigation) are the main limiting factors to productivity (Bergante *et al*., 2010). The clones/provenances used in SRC trials have shown yields of up to 25 td.m. $ha^{-1}year^{-1}$. The yields in commercial plantations, where fertilization and irrigation are rarely applied by farmers, are lower (average ranging from 6 to12 td.m. $ha^{-1}year^{-1}$) (Paris *et al*., 2010; Facciotto *et al*., 2009). The coppice cycle in the "very high planting density" trials is generally short (2-3 years). The wood biomass produced is of a low quality owing to a high bark percentage (15-20%), and is mostly used as chips for bio-energy power plants or for co-firing in thermo-electric plants and incinerators.
In the case of "high planting density", the cycle is longer (5-6 years) and usually the yields obtained are within the range of 8 to 20t d.m. $ha^{-1}year^{-1}$.In this case, the raw material is of a good quality, with a lower bark percentage, and is best used for pellet production or other industrial uses, such as pulp for paper or packaging.

3. Short-rotation-coppices (SRC)

Short rotation coppices are a crop model especially developed for the production of energy wood. These crops have an energy balance generally favourable (NjakouDjomo *et al.*, 2015), and higher than traditional agricultural crops. In Europe SRC plantations cover an estimated area of 50,000-70,000 ha (Weitz, 2014), with about 12,000 in Sweden and 10,000 in Italy and Hungary, respectively. The species most frequently used are poplars and willows, followed by black locust (*Robinia pseudoacacia*) and eucalypts (*Eucalyptus* spp.) in Mediterranean areas. The development of these cropping systems is linked to the expected expansion in the share of energy from renewable sources. In the EU this share is expected to increase from 14% to 20% from 2010 to 2020, up to 27% in 2030 (Mantau *et al*., 2010). According to Mantau *et al*., in 2030 about 26 Mha of SRC plantations would be required to compensate for the deficit of energy-wood in the European Union.
Much research conducted in Italy and abroad has shown that the yield achievable with these crops varies with site conditions, growing techniques, and planting materials (NjakouDjomo *et al*., 2015, Di Matteo *et al*., 2012; Paris *et al*., 2011; Bergante, 2010; Bergante *et al*., 2010). In the Po valley, poplar and willow SRC plantations established in medium/high fertility arable soils with selected clones planted at a density of 5900 trees ha^{-1}, have shown yields frequently exceeding 10 t ha^{-1} y^{-1}d.m. up to 22-24 t $ha^{-1}y^{-1}$d.m. with a two-year rotation cycle (Paris *et al*., 2011). Yields around 10 t $ha^{-1}y^{-1}$d.m.have also been recorded in central Italy using poplar clones selected for biomass, with biennial or triennial rotation cycles and a planting density of 7140 trees ha^{-1} (Di Matteo *et al*., 2012). In addition black locust SRC plantations established in the Po valley have shown productivities of about 8-12 t $ha^{-1}y^{-1}$d.m. with a two-year rotation cycle (Bergante, 2010). Parallel research carried out in northern and central Italy has shown that SRC productivity depends mainly on the water availability expressed by annual or seasonal rainfall (Bergante *et al*., 2010).This suggests the likely effect of the undergoing climate change on the land suitability for these woody crops.
Poplar, willow and black locust SRC plantations, established with low planting densities of 1500-2000 trees ha^{-1} and a 5-7 year rotation cycle, are also under experimentation in the Po valley (Bergante, 2010) (Fig. 1). The aim of low density SRC is to achieve a great flexibility in the resulting assortments, producing energy-wood as well as small-sized logs for the packaging industry. Much research has clearly demonstrated that SRCs can also perform many ecological services when replacing traditional food crops. Increases in the storage of soil carbon (Garten, 2002; Bowman and Turnbull, 1997) and in animal biodiversity (Fry and Slater, 2009; Britt *et al*., 2007; Augustson *et al*., 2006; DTI, 2006; Burger *et al*., 2005) have been frequently emphasized. SRC woody crops are explicitly provided for in the new Common Agricultural Policy 2014-2020 as part of Ecological Focus Areas (EFAs). Poplar and willow SRC also have potential for removing heavy metals or other toxic substances from contaminated soils (Bianconi *et al*., 2011; Baum *et al*., 2009; Lewandowski *et al*., 2006; Berndes *et al*., 2004).
SRC plantations remove a relatively low amount of soil nutrients (Jug *et al*., 1999).However to promote the expansion of SRC crops in marginal areas, where competition with traditional food crops is low, the selection of species/genotypes with a high nutrient efficiency is mandatory. Italian alder (*Alnus cordata* L.), a fast growing, nitrogen fixing tree, endemic to restricted areas of the north Mediterranean Basin (southern Italy and Corsica island), has interesting potentialities for bioenergy plantations in marginal areas. Italian alder is considered the most drought adapted species amongst the *Alnus* genus. Although these potentialities, little is known about its suitability for SRC. Research are currently conducted on this species, with experimental plots for comparing its yield in comparison to other bioenergy woody species (hybrid poplars, robinia, eucalypts) (Scartazza *et al*., 2012), as well for studying the genetic of natural populations of *A. cordata* and *A. Glutinosa* in 16 sites in southern Italy. Within mixed alder populations,

natural hybrids between *A. cordata* and *A. glutinosa* were observed for the first time in 4 of 5 mixed populations (Villani *et al.*, 2013). These natural hybrids should be worthy of further investigation for their use in SRC.
In Italy, the spread of SRC plantations is also hampered by the low market value of the biomass, which discourages many farmers from undertaking this activity in the absence of government grants. Targeted policies are thus strongly needed to increase the attractiveness of these crops, by providing fair compensation to the owners.

4. Polycyclic plantations

In Italy, France and North America, mixed plantations with valuable broadleaved species and poplar clones have been implemented both in tree farming plantations (Buresti Lattes *et al*., 2008a; Vidal and Becquey, 2008; Zsuffa *et al*., 1977; Paquette *et al*., 2008) and in agro-forestry systems (Balandier and Dupraz, 1999; Rivest *et al*., 2010). In this type of tree farming plantations, called "polycyclic plantations", in Italy, the main crop trees, with different cultivation cycles, coexist in the same plantation area with: i) very short rotation trees for biomass production (SRCs); ii) short rotation trees for veneer production (poplar clones); iii) medium-long rotation trees for timber production (walnut and other valuable broadleaved species). The main crop trees are planted at a final harvesting distance, reaching the merchantable trunk size before the onset of strong intra-specific competition. The initial Italian experiences, carried out in typical poplar cultivation areas, have shown that poplar, due to its fast growing rates, slim shape and low shading crown, is able to actively support the growth of medium-long rotation crop trees. Minimum distances of at least 7 m, between poplar and medium-long rotation trees, are necessary to obtain a merchantable size before a significant diameter increment reduction will take place for the valuable broadleaves (Buresti Lattes *et al*., 2008b; Pelleri *et al*., 2013). For each medium-long crop tree, a variable surface of 100-144 m^2 is made (Buresti Lattes and Mori, 2012). Using this distance, the poplar is able to influence the valuable broadleaved tree stem form, inducing a conical crown, a light branching habit easy to prune, and a low canopy strata with living and active leaves, until harvest. The cultivation of trees with different rotation cycles has proved functional both from productive and environmental perspectives. In terms of timber production, the following results can be summarized.
- Very short rotation (SRCs): Plantations with different SRC surface investment levels were tested, using tree species suitable for mechanical harvesting aimed at chip production, and species for traditional harvesting, aimed at firewood production. Table 2 reports the 5-year production in a polycyclic plantation with seven species for biomass planted in double lines at a distance of 4 m from the other main crop trees. The double SRC line has a distance of 3 m between rows and 2 m along rows (Pelleri *et al*., 2014). Overall the SRC covers about 55% of the whole surface. The experience highlights the need to use different rotations according to the different growing rates.
- Short rotation (poplar clones): In traditional poplar plantations, generally a square planting design with a distance of 6 m is used, with a resulting stem density of 278 trees per ha. Poplar trees are usually harvested with a rotation of 10-12 years. In the polycyclic plantations, poplars are planted with wider spacing, with a square or rectangular planting design, and a resulting stem density of 90-142 trees per hectare. Poplar tree growth is therefore faster, reaching a merchantable size after 7-9 years. In an experimental polycyclic plantation, in Mantua in the north of Italy, some clones (Neva and Lena) reached an average dbh of 36 and 38 cm, respectively, after 9 years (Pelleri *et al*., 2013).
In polycyclic plantations, generally poplar stems have a larger dbh, higher volume, higher processing yield and lower processing costs in comparison to traditional poplar plantations (Castro *et al*., 2013).
- Medium-long rotation (valuable timber broadleaves). Experiments have focused on common walnut (*Juglans regia* L.). Species such as common oak (*Quercus robur* L.) have been used mainly in areas with a high naturalist and environmental value. In these special kinds of plantations, called permanent polycyclic, new tree lines can be planted in the space made available by the harvesting of trees with different delayed cycles. This is done in order to allow for continuous cultivation cycles in the same plantation area, thus maintaining a permanent tree cover (Buresti Lattes *et al*., 2014).
An experimental polycyclic plantation was established in Mantua, with 90 poplar trees (4 poplar clones: Lena, Neva, I214 and Villafranca) and 90 walnut trees (Common walnut and Hybrid walnut), planted with a rectangular overlapping design, with a distance of 7.4 m between poplar and walnut trees. Figure 2 reports the dbh trend, from 6 to 9 years after establishment, of 4 poplar clones and 2 walnut genotypes.
The most productive clones (Lena and Neva) reached a merchantable size after 7 years, while the less productive clones (I214 and Villafranca) reached it after 9 years (Pelleri *et al*., 2013).In the plots where poplar clones had already been harvested at 7 years, walnuts maintained a high growth rate with a dbh increase of 1.5-2.0 cm per year, with an average dbh of 33 cm at the age of 19.
Considering the ecological-environmental impact, polycyclic plantations have notable advantages over traditional poplar monoculture. Using nurse N-fixing trees and shrubs in this kind of mixed plantations has significantly reduced the overall cultivation practices (-61%), in particular a reduction in fertilization, irrigation and pesticides application (Pelleri *et al*., 2013). Recent research in Lombardy has shown a higher efficiency for carbon accumulation and a higher sustainability of mixed polycyclic plantations in comparison with traditional poplar plantations (Chiarabaglio *et al*. 2014b).
In summary, polycyclic plantations are more resistant to external disturbance and less demanding in terms of energetic input. This therefore makes them innovative, and more sustainable than poplar and walnut monocultures.

5. Agroforestry systems

Modern intensive agricultural practices, combined with predominant mono cropping farming systems, have contributed to the progressive and dangerous simplification of agro-ecosystems. This has led to serious environmental and productive consequences and to a dramatic impoverishment of many traditional rural scenarios, very often characterized by the strong interaction of forest trees with agricultural land use and practices (Eichhorn *et al*., 2006). The rapid development of the "Green Revolution" in modern agriculture has completely changed the traditional link between trees outside forest (TOF) and agricultural practices. In Italy, for example, in the mid 1940s, just before the rapid expansion of modern agriculture, TOF timber production was much higher than timber production from forest areas. Today, this balance has been completely reversed, and TOF timber production has completely declined.

Global environmental and productive emergencies, such as climate change and food security, have focused research and the interest of international institutions on the preservation and implementation of agroforestry systems, due to their intrinsic capacity to combine food and wood production with environmental preservation (Lasco *et al*., 2014). Traditional and innovative agro-forestry practices (Tab. 3) provide strategic opportunities for multifunctional systems, producing a variety of productive and environmental services towards a new smart agriculture (Scherr *et al.*, 2012).

The European Project SAFE (Silvoarable Agroforestry For Europe) demonstrated that agroforestry systems are compatible with modern agricultural techniques.

Biophysical and economic modelling has shown that introducing timber trees in arable fields and landscapes can often be more profitable for farmers and landowners (Graves *et al.*, 2007). Silvoarable systems can also efficiently address ecosystem services (Palma *et al.*, 2007), decreasing soil erosion and nitrogen leaching.

At the same time, these systems can increase carbon sequestration across areas dominated by intensive farming systems, without significantly hampering food production. Silvoarable systems, combining the inter-cropping of walnut (*Juglans* spp.) timber trees with arable and fodder crops (e.g. wheat, corn and clovers) are potentially some of the most profitable farming systems under the temperate conditions of western Europe (Graves *et al.*, 2007). Research on walnut silvoarable systems has been conducted in Italy since the early 1990s on the optimization of the system according to tree-crop interactions, planting tree seedlings in rows alternated with arable crops. The competition of crops with young trees was firstly studied, indicating that tree mulching is very effective in decreasing water compe-tition during summer drought periods (Paris *et al.*, 1994, 1998, 2005). The profitability of walnut silvoarable systems is strictly related to the duration of the inter-cropping period, with decreasing intercrop yields with increasing tree age. Therefore, it is of primary impor-tance to predict crop yield in relation to increasing tree size, according to simple tree parameters, such as tree basal area (G) (Nissen and Midmore, 2002), as a function of stem diameter and tree density. This hypothesis was tested in experimental walnut tree plots (*Juglans regia* L. and hybrid NG23xRA) (Perali *et al.*, 2009; Paris *et al*., 2013). Trees established in 1992 were intercropped with wheat (*Triticum aestivum*) in 2003, with clover (*Trifolium incarnatum* L.) in 2004, and finally with a natural meadow (2005-2010), comparing intercrop yields to the sole crop (crop reference yield, CRY). Hybrid walnut showed better growth rates in comparison to common walnut. At 18 years of intercropping, hybrid walnut trees reached a total height of 15 m, with an annual dbh increase of 1.3 cm. The hybrid walnut canopy was only slightly competitive with intercrops due to a late leaf development in spring.

The following regression equations between the CRY and G of hybrid walnut were developed for the three tested intercrops: i) wheat, CRY= -6.21G+100 (r=0.75***, G interval=0-5); clover, CRY= -0.04G+100 (r=0.07ns, G interval=0-6); pasture, CRY= -3.9G+100 (r=0.58*, G interval=0-14).

Using these regressions, silvoarable models can be simulated in relation to various planting densities and tree growth rate (Fig. 3). These data can be used to minimize competition between adult walnut trees and the intercrops up to the tree harvesting age. For example, with 50 tree ha^{-1} the CRY for wheat should decrease to less than 80% at a plantation age of around 23 years, representing two thirds of the harvesting cycle for hybrid walnut. With a density of 83 trees ha^{-1}, the wheat 80% CRY should start at a plantation age of 17 years.

Despite the emerging benefits of agroforestry systems, national and European policies are very inconsistent in terms agroforestry implementation in farming systems. Over the last 25 years, the Common Agricultural Policy (CAP) and the Rural Development Plants (RDPs) have practically ignored agroforestry systems, strongly sub-sidizing monocropping systems, both for food and timber production.

In Italy, over the last 25 years strong support has been offered to farmers and landowners planting timber trees on former agricultural land, but without establishing any sort of intercropping between trees and cash crops.

The main result has been that farmers often choose the worst soils for timber plantations, resulting in poor tree growth (Minotta and Paris, 2010). In 2005, the CAP recognized the positive impact of silvoarable systems on farming systems and the RDPs 2005-13 introduced the possibility of establishing, with public subsidies, such systems according to measure 2.2.2.

Unfortunately, this was largely unsuccessful (Pisanelli *et al.*, 2014), due to the lack of dissemination and poor financial support. The new RDPs (2014-20) are currently under evaluation, and hopefully a stronger support for agroforestry will be provided, both with direct measures for establishing new agroforestry systems, and also with the inclusion of agroforestry systems in the Ecological Focus Area of the Greening Measure.

The recently established European Federation of Agroforestry (EURAF, www.agroforestry.eu) plays an important role in supporting agroforestry in the CAP with intensive lobbying at European and national levels. In Italy, the working group on Agroforestry of S.I.S.E.F. (http://sisef.org/gdl/agroforestry/) and the AIAF (Associazione Italiana di Agroforestazione, www.agroforestry.it) refers to EURAF. A new project on agroforestry in Europe has been lunched (since January 2014) by the European Commission, AGFORWARD (AGroFORestry that Will Advance Rural Development, www.agforward.eu). It is a four-year project, developed by 23 organisations in 14 countries, with the goal of promoting appropriate agroforestry practices that advance sustainable rural development. From Italy, three organisations are involved in this project: CNR-IBAF of Porano; Veneto Agricoltura and CRA Olive culture of Spoleto. The project objectives are: i) to increase our understanding of existing, and new agroforestry systems in Europe; ii) to identify, develop and demonstrate innovations to improve the ecosystem service benefits and viability of agroforestry systems using participatory research; iii) to develop better adapted designs and practices for the different site conditions of Europe, and iv) to promote the wide adoption of sustainable agroforestry systems.

6. Conclusions

Many crop models are available to support an important and ecologically sound wood production outside the forest. This wide variety of tree farming and agroforestry systems is a basic prerequisite to match the wide environmental and structural diversity characterizing Italian farms, as well as the diversified needs of the domestic wood and energy industries, reducing at the same time the human pressure on the natural forests.
Key factors for the success of these plantations in Italy are the implementation of more efficient connections between wood producers and industrial users and targeted policies to increase the attractiveness of domestic wood for Italian industry. In conclusion, the Italian sector of tree farming and agroforestry systems is rich of resources that are just waiting for the right political and industrial organization for converting them in new opportunities for the wood-based sustainable domestic economy.

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Table 1. Main poplar cultivation models in Italy.
Tabella 1. Principali caratteristiche dei modelli colturali in cui si articola la moderna pioppicoltura in Italia.

Plantation model		*SRF*	*SRC*	*SRC*
Purpose		*plywood*	*OSB/biomass.*	*biomass*
Crop density	($p \cdot ha^{-1}$)	280	1100	5700
Rotation time	(years)	10	10	10
Harvesting cycle	(years)	10	5	2
Av. DBH at harvest.	(cm)	28-33	18	5-7
Av. Height at harvest	(m)	24	15	8
Growing stock at harvest	($f.t \cdot ha^{-1}$)	140-180	145	50
Sale price	($€ \cdot t^{-1}$)	75	20/40	20-55
Subsidies	(% of estab. cost)	60	40	40

Table 2. Experimental plantation of Meleti (Lodi-Italy). Production of 7 tree species for biomass, 5 years after plantation (Pelleri *et al*., 2014, modified).
Tabella 2. Impianto sperimentale di Meleti (LO). Produzione di biomassa ottenuta con 7 diverse specie arboree al quinto anno dopo l'impianto.

Type of SRC	*Surface*	*Rotation*	*Fresh tree*	*Dry tree*	*Wood*	*Wood*
	SRC		*weight*	*weight*	*moisture*	*Yield (dry weight)*
tree species	%	year	kg	kg	%	$Mg\ ha^{-1}$
Populus, clone AF2	55	3-4	158.5	66.8	57.9	55.3
Ulmus minor	55	3-4	67.5	38.2	43.4	31.6
Platanus hybrida	55	5-6	37.7	17.7	53.0	14.7
Corylus avellana	55	6-8	25.7	12.7	50.7	10.5
Fraxinus oxycarpa	55	6-8	16.7	10.8	35.2	8.9
Ostrya carpinifolia	55	6-8	18.3	10.5	42.6	8.7
Carpinus betulus	55	6-8	11.7	6.6	43.8	5.4

Table 3. Main agroforestry systems for timber and wood production in Italy.
Tabella 3. Principali sistemi agro-forestali in Italia per la produzione di legname pregiato e biomassa legnosa.

System	*Description*	*Main functions*
Tree edge-rows	Rows of trees and other woody species planted/growing along field borders	- Product diversification (timber, wood, bioenergy, fruits and berries,wild vegetables) - Biodiversity - Landscape/Aesthetic - Field fencing
Buffer strips	Perennial vegetation (grass, shrubs, trees) are planted in strips between arable land or pastures to enhance and protect aquatic resources (streams, lakes) from negative effects of agricultural practices	- Filtration of agricultural pollutants - Water filtration - Soil protection from water erosion
Wind shelters	Rows of trees are planted around farms and fields to protect crops, animals and soil from wind	- Wood and timber production - Protection from wind of crops livestock and buildings - Wind erosion control
Silvo-arable systems	Trees are planted in single or multiple rows with arable or horticultural crops between the rows	- Production diversification (timber, wood and crops) - High use efficiency of cultural inputs and natural resources - Soil protection
Silvo-pastoral systems	Trees are combined with forage and livestock production including high (forest or woodland grazing) and low density (open forest trees) stands and plantations	- Production diversification (timber, wood and livestock products) - Livestock wellness
Special applications	Use of agroforestry technologies, planting trees for specific requirements (eg.: filtration of waste waters, Phyto-remediation) and wood production	- Filtration and depuration of urban and rural waste waters - Decontamination of polluted soils; - Production of decontaminated timber and wood (with in-situ phyto-degradation of contaminants)

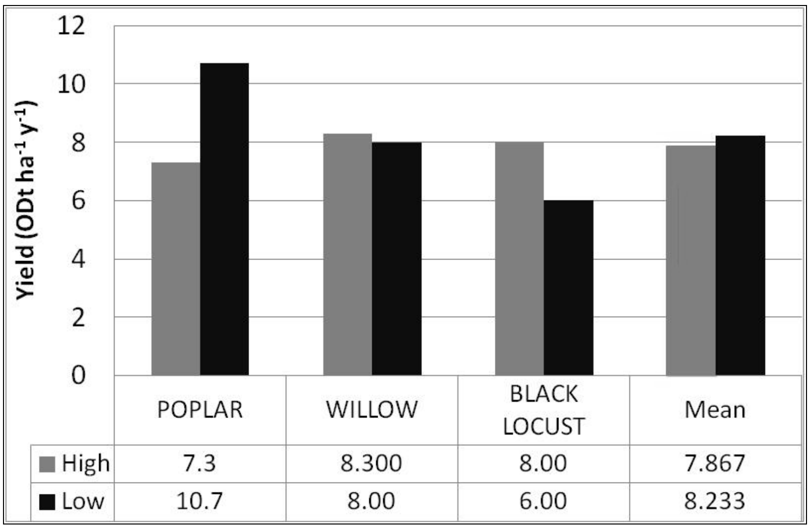

Figure 1. Yield of poplar, willow and black locust SRC energy crops planted at High (8333 trees ha^{-1}) and Low (1667 trees ha^{-1}) density in northwest Italy. Data collected at the end of the fourth season after planting (from Bergante, 2010).
Figura 1. Produttività delle SRC con pioppo, salice e robinia realizzate ad alta (8333 alberi ha^{-1}) e bassa (1667 alberi ha^{-1}) densità nell'Italia Nord-Occidentale. Dati riferiti al termine del quarto anno dopo l'impianto.

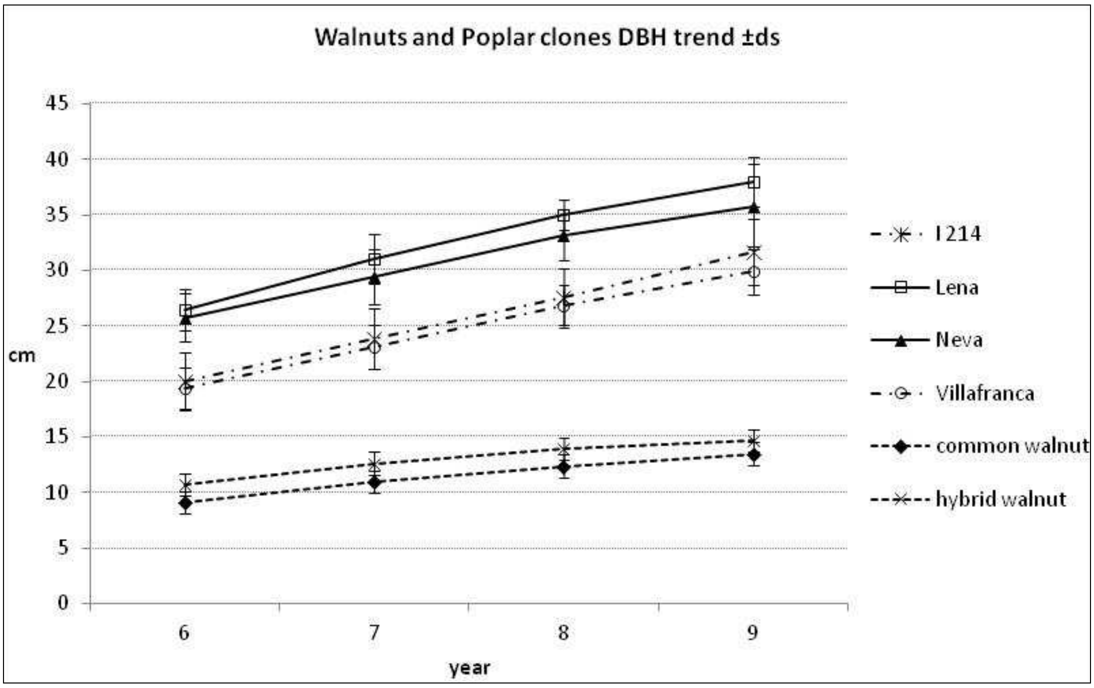

Figure 2. Experimental plantation at San Matteo delle Chiaviche (Mantova) on polycyclic plantations. Diameter growth (1.3 m above ground) of walnut genotypes and poplar clones using a distance of 7.4 m between the two species (Pelleri *et al*., 2013 modified).
Figura 2. Impianto sperimentale di San Matteo delle Chiaviche (MN): Andamento del diametro del fusto (ad 1,30 m di altezza) di piante di noce e di pioppo consociate in piantagione policiclica, e poste ad una distanza reciproca di 7,4 m.

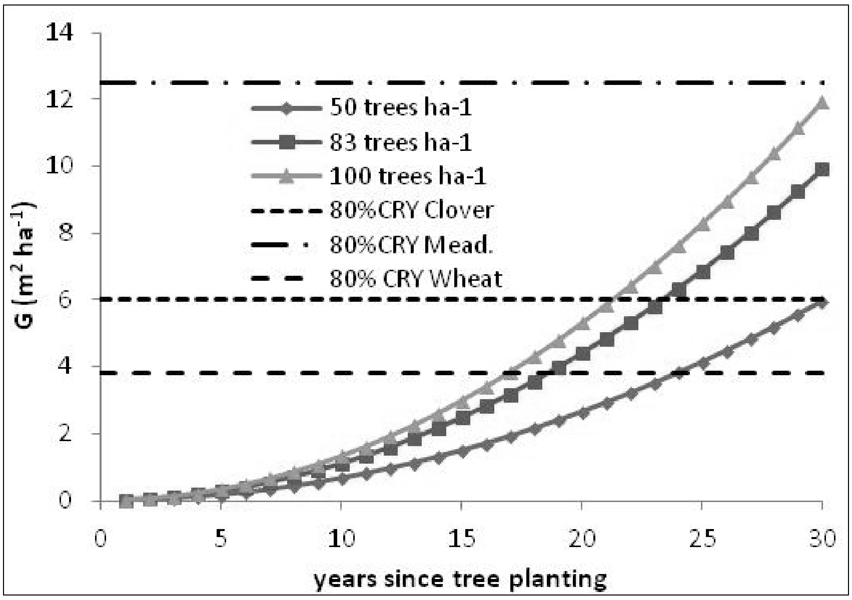

Figure 3. At what plantation age does intercrop yield start to decline in walnut silvo-arable systems? The three exponential curves indicate the time evolution of tree basal area (G) for three planting densities of walnut trees. The horizontal lines are the G value determining the intercrop yield which is 80% lower than the sole crop (Crop Reference Yield, CRY). Each intersection between the exponential and horizontal lines indicates at what age the CRY starts to be 80% (Perali *et al*., 2009, Paris *et al*., 2013).
Figura 3. Simulazione delle interazioni competitive tra alberi e colture consociate in sistemi silvoarabili di noce da legno. Le tre linee esponenziali rappresentano l'evoluzione dell'area basimetrica (G) del noce per tre densità di piantagione (50, 83 e 100 alberi ha^{-1}). Le tre linee orizzontali rappresentano i valori di G per cui le colture consociate hanno una produzione che declina al di sotto dell'80% della coltura non consociata (CRY). L'intersezione tra le linee orizzontali e quelle esponenziali indica a che età degli alberi la CRY del coltura assume valori uguali all'80%.

RIASSUNTO

Arboricoltura da legno ed agroforestry per un approvvigionamento sostenibile di legno da industria e da energia

L'arboricoltura da legno e l'agroforestry possono contribuire in maniera significativa all'approvvigionamento di legname da industria e da energia secondo modelli colturali polifunzionali ed a basso impatto ambientale. Le ricerche condotte in Italia ed all'estero evidenziano la possibilità di pervenire a produzioni legnose interessanti dal punto di vista quantitativo e/o qualitativo ed ecologicamente sostenibili, conseguendo contemporaneamente utilità di carattere ambientale. Nelle aree agricole le piantagioni da legno, se opportunamente progettate e gestite, possono avere ricadute positive anche sulla biodiversità, il paesaggio, il ciclo del carbonio e la protezione del suolo, secondo i più recenti orientamenti sul greening della nuova PAC. Tra i modelli colturali più adatti agli ambienti italiani, si citano la pioppicoltura tradizionale per la produzione di assortimenti da sfogliato; i cedui a corta rotazione per la produzione di legno da energia; gli impianti policiclici in grado di produrre sulla medesima superficie assortimenti di pregio di pioppo e di latifoglie nobili e legno da energia; i sistemi agro-forestali che consentono una complementarietà ottimale con le produzioni agricole alimentari ed una significativa diversificazione dei prodotti ottenibili sulla medesima unità di superficie. Altro fattore fondamentale per il successo delle produzioni legnose fuori foresta è la realizzazione di un più efficiente raccordo tra i produttori e gli utilizzatori industriali del legno. In particolare, sono necessarie politiche indirizzate ad aumentare l'appetibilità della produzione nazionale per l'industria italiana del comparto. L'ecocertificazione delle produzioni, come già attuato per il pioppo, potrebbe essere un passo interessante in questa direzione.

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