GUIDELINES FOR SUSTAINABLE POPLAR PLANTATIONS

Guidelines for sustainable poplar culture

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1. INTRODUCTION

Supply chains based on the use of poplar wood and its derivatives are important internationally. In particular, specialized poplar cultivation has contributed for decades to the development of important economic and productive sectors such as those of paper, wood-based panels and furniture, by providing high-quality raw materials – thanks in part to concentrated efforts in clonal selection and in dissemination of appropriate cultivation methods using smaller amounts of plant protection products and mineral fertilizers than are used in the main agricultural crops cultivated in the same geographical regions. Besides contributing to remove from the atmosphere some of the carbon (which in the form of carbon dioxide is among the causes of the *greenhouse effect*) by storing it in long-lived products for furnishing and construction, specialized poplar plantations also contribute to the pursuit of important objectives for society, such as climate change mitigation and environmental and landscape improvement in rural areas.

Even though the environmental impact of poplar cultivation is lower than that of the main agricultural crops practised in the same lowland environments, creators of public opinion and important sectors of public administrations responsible for defining environmental protection standards (for example, for the sites of the Natura 2000 network) and rules for access to financing for the establishment of new plantations (for example, the European Commission) frequently express doubts and request reassurance in this regard. Given this common lack of awareness of the real economic and environmental benefits of poplar cultivation, political and programmatic decisions at the national and European levels are fundamental to support correct business choices in the agro-industrial supply chains. To this end, these guidelines are intended as an updated analytical and reference document for use by those in technical and institutional settings, producer and user associations, standardization bodies and civil society movements concerned with environmental protection, for the elaboration of shared strategies aimed at a renewed valorization of production chains based on the use of poplar wood.

1.1. International situation

Worldwide, the area occupied by poplar appears to be progressively increasing. In 2015 the global poplar area was estimated at just under 92 million hectares, including natural and planted areas, specialized plantations and agroforestry systems (Table 1).

The area planted with poplar globally is estimated at approximately 31.4 million hectares, the largest part in Canada and China, which respectively account for 69% (21.8 million hectares, managed by semi-extensive methods) and 27% (8.5 million hectares) of the total. These are followed by France (200,000 hectares), Turkey, Iran, Spain and the United States (about 100,000 hectares each). More than half of the areas planted with poplar are under multifunctional management (58%), while smaller areas are primarily designated for environmental protection functions (9%) and biomass production for energy use (3%).

The global area of specialized plantations for the production of wood for industrial use is estimated at approximately 9.4 million hectares. Specialized plantations, which annually supply over 12 million cubic meters of wood, are particularly relevant in the production of wood-based panels, i.e. plywood, veneer, fibreboard and particleboard (FAO, 2016).

Table 1. Global estimates of the area occupied primarily by poplar.

	Area primarily under poplar (ha)	Area of specialized poplar plantations for the production of industrial wood (ha)
Europe	890,971	489,553
Africa	14,500	-
Asia and Russia	35,948,530	5,408,700
Americas	55,043,453	3,533,906
Total	91,917,454	9,432,159

1.2. Italian situation

The production of poplar wood has a particular importance in the Italian wood–furniture–paper sector. In the country more than 10,000 enterprises practise specialized poplar cultivation, almost all of which are direct growers.

Table 2. Area of specialized poplar plantations in Italy (estimates based on sampling, referring to poplar plantations equal to or greater than 5,000 m^2, excluding polycyclic plantations; reference year: 2017).

Region	Estimated area (ha)
Valle d'Aosta	0
Piemonte	12,475
Lombardia	19,850
Trentino Alto Adige	0
Veneto	2,650
Friuli Venezia Giulia	3,725
Liguria	0
Emilia Romagna	4,700
Toscana	1,350
Umbria	75
Marche	0
Lazio	450
Abruzzo	75
Molise	0
Campania	500
Puglia	25
Basilicata	25
Calabria	200
Sicilia	25
Sardegna	0

An inventory of forest tree crop plantations in Italy carried out by the Centro di ricerca Foreste e Legno (Research Centre for Forestry and Wood, CREA) estimated the area of specialized poplar cultivation at 46,125 hectares (Table 2), referring to high stands (i.e. coppiced excluded) the year 2017. Specialized poplar cultivation is concentrated in the Po Valley plain (94%), with 70% of the plantations located in the regions of Lombardia and Piemonte.

2. TECNICAL GUIDELINES

In plantations specialized for the production of veneer logs, rotations generally vary from 8 to 10 years in the lowlands to up to 15 years in the Piemonte foothills, while plantations specialized for production of logs for panels and pulp have rotations of 4 to 6 years. Planting and cultivation techniques obviously differ, as do the varietal choices, based on the wood properties required by end users.

Italian poplar cultivation is widely linked to the use of **clone 'I-214'**, which has ideal wood characteristics for the manufacture of plywood panels (light weight, colour) but presents challenges owing to its susceptibility to biotic threats (woolly aphid, rusts, *Marssonina* leaf spot). The preference of the Italian industrial sector for the quality of the wood produced by clone 'I-214' has significantly influenced the choice of plant material, limiting the dissemination of new clones and favouring widespread **monoclonal plantations**. On the other hand, the availability of clones offering **greater environmental sustainability** (*Maggiore Sostenibilità Ambientale*, thus referred to as **MSA clones**) characterized by better resistance to the main biotic adversities, makes it possible to develop semi-extensive cultivation models that, by minimizing cultural and pest-control interventions, permit more environmentally sustainable poplar culture. The process of peeling the wood of these clones is substantially identical to that for 'I-214', even if their technological inhomogeneity may require the industry to adjust its processing methods (for example, by separating logs of various clones in the yard and semi-finished products in the warehouse, differentiating drying regimes, etc.).

2.1. Requisite soil and climate conditions

The most suitable sites for the specialized cultivation of poplar are **floodplain areas** and **lowland areas** with soils characterized by **good fertility** and **water availability**. Conversely, soils with low water availability or hydromorphic or calcareous and/or saline soils are not recommended, as they reduce the effectiveness of cultural operations, including phytosanitary interventions, and the economic viability of wood production.

For the cultivation of poplar the most appropriate soils are deeper than 50 cm, are permeable, have good water availability (the level of the water table is considered optimal at 100-150 cm depth), are characterized by sandy-silty or sandy-clay texture, are not excessively loose or heavy, have a uniform profile and have a pH from subacid to moderately alkaline (Table 3). In these conditions it is possible to limit stresses caused by many primary pests and pathogens (including *Marssonina brunnea* and *Melampsora* spp.) and to prevent damages caused by opportunistic pests and pathogens (including *Discosporium populeum, Melanophila* spp., *Agrilus* spp.) or the appearance of disease (for example,' brown spots' physiologic disorder). As mentioned, soils with a high content of active calcium carbonate (above 10%) and saline soils are to be avoided: sodium chloride concentrations even of only one part per thousand are able to provoke phytotoxicity in most cultivated clones, especially during the phase when saplings are taking root (Frison and Facciotto, 1992).

Table 3. Soil characteristics limiting realization of specialized poplar plantations.

Soil characteristics (1)	Degree of importance (2)		Importance of the limitation		
			absent or very light (3)	**moderate (4)**	**severe (5)**
Texture (6)	***	medium to coarse	X		
		moderately fine to fine		X	
Depth available for roots (cm) (7)	**	> 50	X		
		< 50			X
Permeability (8)	***	good or moderate	X		
		imperfect		X	
		poor to very poor			X
Acidity (pH)	*	5.5 - 8.5	X		
		4.5 - 5.5		X	
		< 4.5 and > 8.5			X
Drought risk	*	absent to moderate	X		
		strong to very severe			X
Salinity (EC_5 mS/cm) (9)	***	< 0.15	X		
		0.15 - 0.4		X	
		> 0.4			X
Active calcium carbonate (%)	***	< 6	X		
		6-10		X	
		> 10			X
Flood risk (frequency)	*	none to frequent	X		
Flood risk (duration)	**	< 1 month	X		
		> 1 month		X	

(1) referring to the soil layer explored by the root system;
(2) * not very important, ** moderately important, *** very important;
(3) soils that ensure wood production that is generally not less than 80% of the maximum potential under the same bioclimatic conditions without particular cultural interventions;
(4) soils in this class may reduce production by as much as 60% of the maximum potential under the same bioclimatic conditions and/or may require particular cultural practices;
(5) soils not amenable to poplar cultivation;
(6) medium: sandy loam, loam, silt loam, silt
coarse: sandy, sandy loam
moderately fine: clay loam, sandy clay loam, silty clay loam
fine: clay, sandy clay, silty clay
(7) depth of layers limiting the root system (e.g. hardened horizons, horizons of carbonate accumulation, impermeable clay horizons).
(8) good: water drains quickly; moderate: water drains slowly in some periods and soil is wet for only a short time during the growing season; imperfect: water drains slowly and soil is wet for long periods during the growing season; poor to very poor: soil is saturated periodically or for most of the growing season.
(9) electrical conductivity of the soil extract 1:5.

The most widely cultivated poplar species are heliophilous and hygrophilous; as a rule, they require average annual rainfall of not less than 700 mm or supplemental irrigation during the summer. Black poplar (*Populus nigra*) and white poplar (*Populus alba*) are able to withstand short periods of drought. The average annual temperature must be between 8.5 °C and 17 °C.

2.2. Choice of clones and nursery material

The choice of which poplar clones to cultivate depends on the final destination of the wood product, the soil and climate characteristics of the site and any environmental restrictions. Clones can be chosen from among those included in the national registers of European countries, with preference for those that can provide high-quality wood and are resistant or tolerant to the main biotic adversities. For Italian clones it is necessary to refer to the National Register of Basic Materials (Registro Nazionale dei Materiali di Base, RNMB), 'tested' category (see Annex 1).

The cultivation of clone 'I-214', the most widespread and appreciated in Italy particularly for the excellent characteristics of its wood for panel production, generally involves "forced" cultural choices that are not always fully environmentally sustainable because of this clone's susceptibility to various biotic adversities. By favouring genetic diversification and limiting the establishment of monoclonal plantations on vast areas, it is possible instead to prevent the emergence of phytosanitary problems and to mitigate those related to environmental changes.

Photo 1. Demonstration stand with different poplar clones.

Following the results obtained in numerous experimental plantations, a list is available of MSA clones (Table 4, see also Annex 3), characterized by resistance to woolly aphid (*Phloeomyzus passerinii*) and high tolerance to the main fungal leaf diseases such as Marssonina leaf spot (*Marssonina brunnea*), spring leaf and shoot blight (*Venturia populina*.) and leaf rusts (*Melampsora* spp.). These are clones that do not require the application of plant protection products (or require significantly less than 'I-214'). In a phase when it is still necessary to guarantee the availability of wood that is known and appreciated by end users, the cultivation of MSA clones alongside others that do not have the same characteristics, such as 'I-214', makes it possible to realize **diversified and more sustainable poplar plantations** through the reduced number of phytosanitary protection measures required and the containment of costs. Only certified nursery material is permitted in the establishment of new plantations. The saplings or poles must be lignified, correct in shape and free from pests and lesions (Table 5).

Table 4. Main characteristics of MSA poplar clones compared with clone 'I-214'

	CLONE	SPRING LEAF AND SHOOT BLIGHT	LEAF RUSTS	MARSSONINA LEAF SPOT	WOOLLY APHID	GENETIC ORIGIN
	I-214	*****	***	**	**	*Populus ×canadensis*
1	AF8	*****	****	*****	****	*Populus ×generosa × Populus trichocarpa*
2	ALERAMO	****	*****	*****	****	*Populus ×canadensis*
3	BRENTA	*****	***	*****	*****	*Populus ×canadensis*
4	DIVA	****	*****	*****	*****	*Populus ×canadensis*
5	DVINA	*****	****	*****	****	*Populus deltoides*
6	ERIDANO	*****	*****	*****	*****	*Populus deltoides × Populus maximowiczii*
7	HARVARD	*****	****	*****	****	*Populus deltoides*
8	KOSTER	*****	****	***	*****	*Populus ×canadensis*
9	LAMBRO	*****	***	*****	*****	*Populus ×canadensis*
10	LENA	*****	****	*****	****	*Populus deltoides*
11	LUX	*****	****	*****	*****	*Populus deltoides*
12	MELLA	*****	***	*****	****	*Populus ×canadensis*
13	MOLETO	****	*****	*****	*****	*Populus ×canadensis*
14	MOMBELLO	****	****	*****	*****	*Populus ×canadensis*
15	MONCALVO	****	*****	*****	*****	*Populus ×canadensis*
16	OGLIO	****	*****	*****	*****	*Populus deltoides*
17	ONDA	*****	****	*****	****	*Populus deltoides*
18	SAN MARTINO	*****	****	****	****	*Populus ×canadensis*
19	SENNA	****	*****	****	*****	*Populus ×canadensis*
20	SILE	****	*****	*****	*****	*Populus deltoides × Populus ciliata*
21	SOLIGO	*****	*****	*****	****	*Populus ×canadensis*
22	STURA	****	*****	*****	*****	*Populus ×canadensis*
23	TARO	*****	****	*****	*****	*Populus ×canadensis × Populus ×generosa*
24	TUCANO	****	*****	*****	*****	*Populus ×canadensis*
25	VILLAFRANCA	*****	*****	*****	*****	*Populus alba*

<u>LEGEND</u>

*	highly susceptible
**	susceptible
***	tolerant
****	resistant
*****	highly resistant

Table 5. Defects preventing young poplar plants from being classed as of fair marketable quality pursuant to European Directive 71/161/EEC.

a)	Sapling with unhealed wounds, except cutting wounds where excess leaders have been removed;
b)	Saplings partially or totally dried up;
c)	Stem showing considerable bending;
d)	Multiple stem;
e)	Stem with several leaders;
f)	Stem and branches incompletely ripened (except for clones of *Populus deltoides*);
g)	Damaged root collar (except for poplars butt-trimmed in the nursery);
h)	Saplings showing serious damage caused by harmful organisms;
i)	Saplings showing signs of heating, fermentation or mould following storage in the nursery.

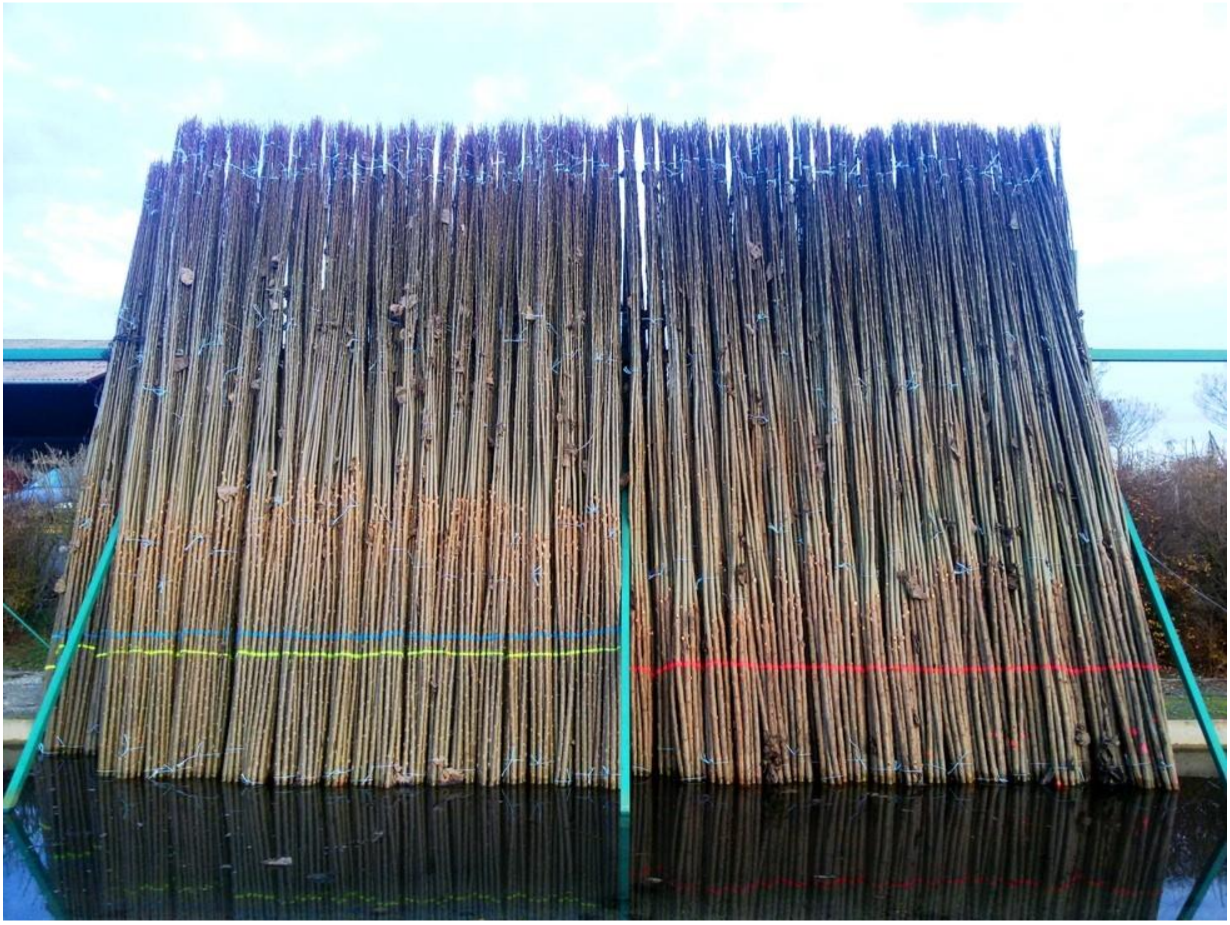

Photo 2. Saplings being hydrated before planting.

2.3. Method and density of planting

2.3.1. Planting geometry and spacing

In poplar plantations intended for the production of veneer logs, the number of trees per hectare can vary from a minimum of 150 (67 m^2 per tree) to a maximum of 330 (30 m^2 per tree), although **a density of 200 to 280 trees per hectare is generally preferable**, with a square, rectangular or hexagonal arrangement. The choice of spacing should take into account the characteristics of the site (climate, soil), the clone and the length of the rotation, with lower densities used in less fertile soils.

In poplar culture for the production of logs for other uses (oriented strand board [OSB] panels, pulp, packaging, energy, etc.), the planting density can vary from 600 to 1,700 trees per hectare. Square or rectangular arrangements are recommended, with spacing between rows sufficiently large to allow mechanized interventions (Bergante *et al.*, 2010).

2.3.2. Time of planting

Plantings for the production of material for the plywood industry can use one- or two-year-old nursery saplings, with average height of close to or more than 6 m. For short-rotation systems it is possible to use pole sections 1.5 to 2 m long. The planting material must be well hydrated and in vegetative dormancy. The most intense periods of frost should be avoided, as they could hinder the opening and correct closing of the holes.

Planting material with good **rooting capacity**, which is linked to genetic factors (species and clone) but also to interactions with the environment (soil, climate) (Zalesny *et al.*, 2005), is one of the fundamental requisites for the success of a poplar plantation. When *P.* ×*canadensis* clones are used, which are generally characterized by a good ability to form roots and to take root, planting can be carried out any time during the period of vegetative dormancy. Clones of *Populus deltoides* or of other species phenotypically similar to it must be planted towards the end of the period of vegetative dormancy because they root with greater difficulty and dehydrate more quickly in comparison with the hybrids of *Populus* ×*canadensis*.

To facilitate the rooting of *Populus deltoides* and more regular crown formation, it is preferable to use one-year-old nursery saplings, obtained directly from cuttings or, even better, from coppice.

It is good practice to minimize the time between nursery harvesting and planting of saplings or poles. Before planting it is advisable to soak the saplings (the entire plant or the basal part to be planted underground) in water for at least ten days.

2.3.3. Planting method

Careful **preparation of the land** is essential for the planting of poplar saplings. Ploughing to a depth of 30 to 50 cm is recommended, possibly combined with scarification down to 70 to 120 cm, avoiding the movement of layers of soil with unfavourable chemical or physical characteristics to the surface. For silty-clay soils it is advisable to plough when the soil is neither too wet nor too dry, in Italy preferably by the end of October.

The saplings should be planted at a depth equal to one-fifth of their height (at least 80 cm for one-year-olds and 120 cm for two-year-olds). Holes must be adequate in diameter, generally around 30 cm. In coarse-textured soils with little water-holding capacity, it is possible to use an auger of smaller diameter (up to 10 cm), and the depth of planting can be increased to the level of the permanent water table (maximum 300 cm). In fine or moderately fine soils, to facilitate rooting and expansion of the root system it is useful to dig holes of more than 30 cm in diameter. The holes must be dug in the period from November to December (in Italy) to allow atmospheric agents to break down the lateral surface of the holes, which are compacted by the auger (Stanturf and van Oosten, 2014).

For dense plantings using poles, the planting can be carried out with a mechanical transplanter in rows, at a depth of about 50 cm (Manzone *et al.*, 2014).

2.4. Fertilization

In areas with good water availability, generally characterized by loose and deep soils, good wood production can be achieved with limited use of mineral fertilizers. On the other hand, fertilization gives appreciable results in coarse soils or in soils with acid pH, low exchange capacity and nutrient deficiencies.

In establishing new plantations is opportune to refer to regional soil maps available online and/or to chemical and physical soil analysis before planning the interventions.

To avoid soil nutrient depletion it is advisable to fertilize the soil periodically using organic products (manure, compost or green manure) or mineral fertilizers, in quantities sufficient to give back to the soil at least the amount of nutrients removed at harvesting. Base fertilization, where indicated, does not generally include nitrogen, except for the contribution from organic fertilizers. For sustainable poplar culture, inputs of phosphorus (P_2O_5) and potassium (K_2O) should not exceed the applications recommended by **specifications for regional production or sustainable management**, such as ECOPIOPPO and/or certification scheme standards (see section 4.2) as PEFC-ITA-1004-1-2015.

Nitrogen top dressing can be carried out through localized applications in the crown projection area during the second, third and fourth year after planting. Phosphate and potassium top dressing, as an alternative or supplement to basal application, can be carried out in the first four years, for example using ternary fertilizers.

Application of organic matter (manure or compost), with subsequent burial, can be performed throughout the entire rotation, with the exception, in Italy, of the period from August to September and the winter months.

2.5. Pruning

Pruning in plantations for the production of wood for the plywood industry is aimed at obtaining timber that is free of knots and therefore of high quality. **Pruning height is proportional to planting density and rotation length.** In plantations of medium spacing and rotation it is sufficient to prune to a height of about 7 to 8 m at most to achieve satisfactory wood quality. In general, the branches to be eliminated are for the most part those growing on the part of the trunk corresponding to the planted sapling, and fewer on the part of the trunk corresponding to height increases from the first and second year after planting.

During the first two years of cultivation, **corrective and formative pruning** should be carried out to promptly eliminate double apices and apex proleptic branches growing vertically (one-year-old branches just below the apex). In the following years the lateral branches must be gradually eliminated to up to 5 to 7 m from the ground (cleaning the trunk).

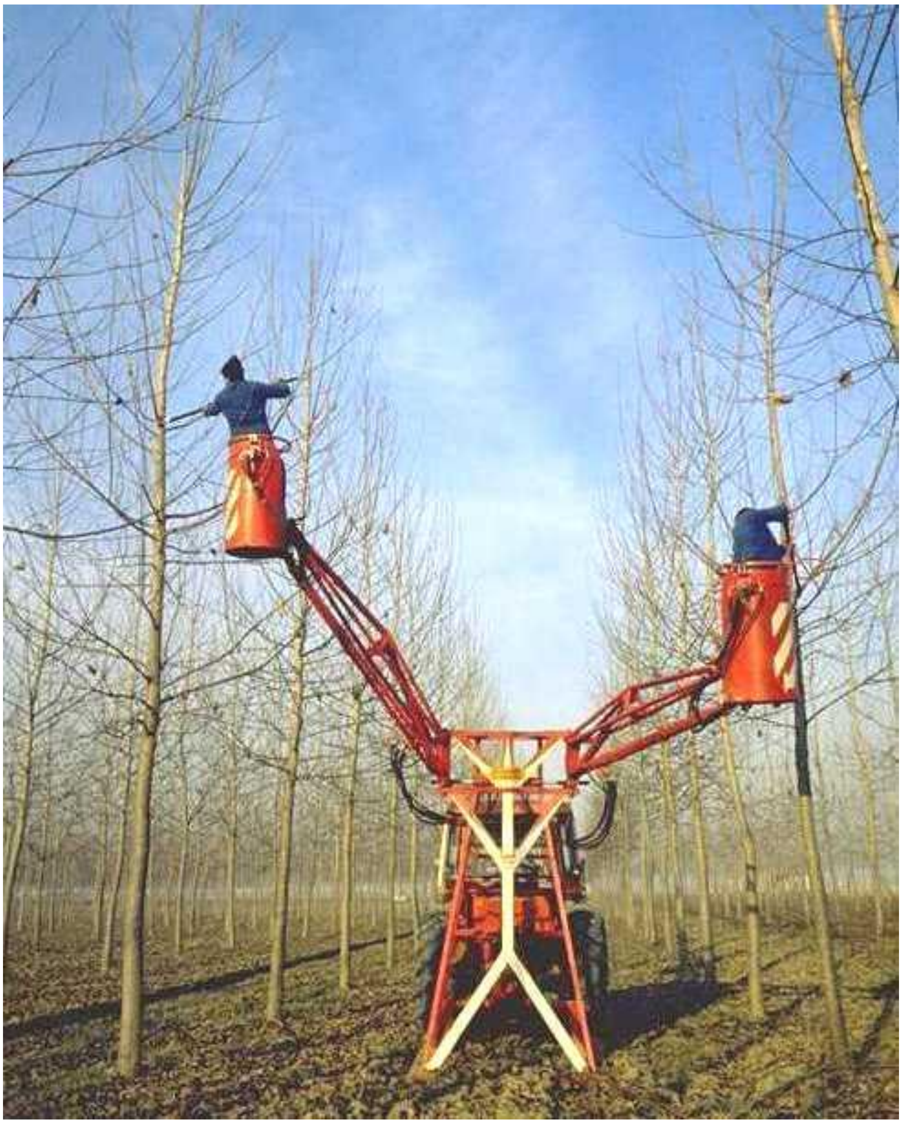

Photo 3 – Pruning a poplar plantation using hydraulic lifts

Pruning operations are usually carried out during the period of vegetative dormancy (Tables 6, 7 and 8). Only in the case of *P. deltoides* clones, which tend to produce a less orderly crown, in very fertile soils it may be convenient to bring forward the first formative pruning up to July of the first vegetative season.

Table 6. Pruning regime to be adopted in the period of vegetative dormancy in poplar plantations consisting of one-year-old nursery saplings and intended for the production of veneer logs.

Year 1	Eliminate double apices, the most vigorous apex proleptic branches and all branches up to a height of 1.5 m from the ground (these last can also be cut during the vegetative season)
Year 2	Cut the most vigorous apex proleptic branches of the second whorl and thin out those of the first whorl, removing the larger ones; also eliminate all branches up to a height of about 2 m from the ground
Year 3	Thin the branches of the second whorl, removing the larger ones, and remove all those below the first whorl, up to a height of about 3 m from the ground
Year 4	Thin the branches of the second whorl, eliminating the largest and the most vertical, up to a height of about 5 m

Year 5	Remove all the remaining branches of the second whorl and all branches up to a height of about 6-7 m

Table 7. Pruning regime to be adopted during the period of vegetative dormancy in poplar plantings consisting of two-year-old nursery saplings and intended for the production of veneer logs.

Year 1	Eliminate double apices and the most vigorous apex proleptic branches and clean the trunk to a height of 2 m from the ground (these last branches can also be cut during the vegetative season)
Years 2 and 3	Thin the branches of the first whorl, removing the larger ones, and remove all branches up to a height of about 3.5 m from the ground. If the second whorl has formed beyond 7 m it is not necessary to intervene; otherwise it is necessary to correct the top
Years 4 and 5	Remove all branches to a height of about 6-7 m or, in any case, up to where the trunk measures 12-13 cm in diameter

Table 8. Pruning regime to be adopted during the period of vegetative dormancy in poplar plantings intended for the production of logs for OSB panels or pulp.

Year 1	In the case of saplings, eliminate manually sprouts along the trunk up to 1.5 m from the ground; in the case of poles, no intervention.
Subsequent years	For reasons related to the greater density of the plants and the characteristics of the final material to be obtained, no particular pruning operations are required. Mechanical pruning up to 2-2.5 m from the ground can be carried out to eliminate branches that could hinder the transit of operational machinery

2.6. Irrigation

Irrigation, like fertilization, is a costly practice in terms of both energy and economics; therefore, it can be adopted as a **rescue intervention in the first year of cultivation** to enable young trees to take or, in the case of intensive cultural models, when the roots cannot reach the water table, in order to avoid slowing or stunting growth in the period of most intense vegetative activity.

Water consumption can be estimated with reference to the amount of water transpired per unit of dry matter. In the case of clone 'I-214', experiments have determined that about 350 litres of water are necessary to produce 1 kg of dry matter; thus the annual water requirement of the poplar plantation can be calculated by multiplying 350 litres by the predicted annual increase in weight of dry matter. Although other clones may have different water requirements, this value can be considered as a general reference (Navarro *et al.*, 2014).

Several criteria can be followed to determine the time of intervention. These often include observation of the characteristics of the plants, the soil and the climate; the best results are obtained with the help of soil moisture sensors or by calculating evapotranspiration, starting from meteorological data collected on site.

The most common irrigation methods are gravity-fed and spray systems. Recently, localized drip irrigation systems have also been tried and partly adopted, allowing more sound use of water. Localized systems make it possible to reduce the water loss from runoff or deep percolation into the ground that occurs with gravity-fed systems and with sprinkling of the foliage in the plantation's first years (which also encourages the development of leaf diseases such as rusts). The choice of irrigation method depends on the terrain, the availability of irrigation water and the equipment available. The gravity-fed method requires high flow rates (about 800 m^3ha^{-1}) and has limitations on terrain that is too loose or not flat. The spray method requires lower flow rates (300 to 400 m^3ha^{-1}) and can also be used on non-flat terrain. Drip irrigation is the most versatile; it reduces the water volume to a minimum and, if automated, also labour. However, the equipment and installation costs limit its use to high-input plantations where the expected production exceeds 30 m^3ha^{-1} $year^{-1}$.

2.7. Post-planting tillage

In plantations with ten-year rotation, **tillage**, carried out with disc harrows, is of fundamental importance during the first half of the rotation **to limit invasive vegetation and evapotranspiration losses** by improving the structure and permeability of the active soil layer. In heavy soils it is advisable to till no more than twice. Ploughing to create furrows between rows, necessary to avoid water stagnation, in Italy is carried out in autumn. In the first half of the rotation, spontaneous vegetation can also be controlled by using herbicides (see section 2.8).

In the second half of the rotation, tillage generally has no positive effect on the growth of trees and therefore can be performed fewer times or replaced by one or two operations to **mow or shred spontaneous vegetation**. In heavy and humid soils, the growth of grass, controlled with mowing or shredding, is recommended rather than the usual harrowing, in order to avoid soil compaction.

In higher-density plantations, tillage is advisable and practicable only in the first two years, with mechanical harrowing or mowing of invasive vegetation.

2.8. Choice and use of plant protection products

Current legislation only allows the use of active ingredients contained in commercial products that include “poplar” on the label and only for the biotic threat indicated, except for specific exemptions issued by relevant offices. Phytosanitary services and/or plant disease observatories may authorize interventions against other biotic adversities, if necessary.

In distributing plant protection products it is necessary to follow the prescribed rules and limitations, and especially to take all possible precautions to reduce damage to the operator and to the environment: to respect the dosages of active ingredients and instructions regarding water volumes, to spray in the absence of wind and in the cooler hours of the day, to choose low-toxicity commercial products, to perform periodic maintenance of spray equipment, and to use personal protective equipment.

It is desirable to limit the use of herbicides, distributing them only along rows, using active ingredients authorized for use on poplar, and using them only in the case of high coverage by perennial invasive flora. Treatments before the emergence of spontaneous vegetation are recommended only where there is high potential for infestation, such as in plantations on previously uncultivated land.

For the areas included in the Natura 2000 network, operators should refer to the provisions in any specific conservation measures or management plans for the individual sites.

Given the intensive nature of poplar cultivation and its frequent use of uniform genetic material (monoclonality), plantations are subject to biotic and environmental adversities which sometimes have such high incidence as to cause substantial economic damage. Even in the context of sustainable management, while productive and resistant clones are available but not yet sufficiently widespread, **it is not possible to exclude a need for phytosanitary treatments**, at least not in stands composed of clones susceptible to a given plant disease or insect pest. These treatments should be limited to situations where cultural practices are considered ineffective, and also based, if possible, on information made available through the so-called early warning approach (evidence of incipient plant diseases or insect pest attacks).

Photo 4. Phytosanitary tratment in a poplar plantation.

Annex 1 presents suggestions for phytosanitary protection of poplar plantations consistent with the Italian National Action Plan for integrated control, which however may be subject to modifications and additions depending on local regulations or new legislative provisions (European and national).

Specific requirements govern the use of plant protection products in plantations certified according to the schemes of FSC® or PEFC (see section 4.2). Key elements include prohibition of the use of products considered highly dangerous (although it is noted that commercial products suited to the certification schemes may be difficult to find) and promotion of integrated plantation management.

2.9. Logging

In specialized poplar systems, logging refers only to clearcutting at maturity, since as a rule no thinning interventions are planned during the cultivation cycle. **Clearcutting** can be organized according to either of two working methods, which are polar opposities in terms of the level of mechanization (Castro and Zanuttini, 2008).

The **traditional method**, which most companies adopted until a few years ago, involves the use of a suite of multipurpose agricultural machinery, possibly equipped with specialized equipment (hydraulic crane, claw, etc.). Felling is carried out by an operator with a chainsaw, generally supported by a tractor equipped with a swing-arm log handler. This step is followed by log preparation, divided into phases of selection and measuring, debranching and cross cutting (with a worker at the base of the trunk and another at the top for cross-cutting and debranching at the same time). The top-ends and thick branches are collected in small piles for subsequent loading on the transport equipment; the thinner branches (diameter less than 3 to 4 cm) are left on the ground and subsequently crushed on site. The logs are loaded directly on trailers or articulated lorries with the aid of loader arms mounted on the rear of the tractor or on a wheeled tractor equipped with a revolving motorised arm.

As an improvement on the traditional method, the use of a mobile crane (generally tracked) equipped with a claw and chainsaw kit for the preparation of treetops and branches is increasingly reported. This method involves limited investment and is very efficient for harvesting the main product (industrial roundwood), although it is not exactly suitable for smaller-diameter wood. A load-bearing articulated tractor (forwarder) is often used at the harvesting site for the operations of piling, yarding and loading.

The critical aspects of the low-mechanization approach include the manual work and fatigue of the operators and the danger of the operations, as well as difficulties in finding skilled labour.

At the other end of the spectrum, the **highly mechanized method** requires the use of specialized machinery (the harvester) that carries out the entire cycle of felling and wood preparation, for wood down to a minimum diameter of 4 to 5 cm. This method has great advantages in terms of productivity, but the costs of purchasing and running the harvester make it economically sustainable only if it is also used for sawing industrial roundwood, which still finds some resistance because of deeply rooted traditional practices and the habit of manual control. The use of the harvester for the preparation of thinner branches does not seem justifiable, in terms of either yield or the unit cost of processing. Further advantages are linked to the possibility of combining the harvester with a woodchipper for the mechanized preparation of smaller assortments. This represents a real evolution in the level of mechanization and the organization of the work in poplar plantations and can improve daily productivity to 35 tonnes per worker, as compared with 12 tonnes for the traditional method.

Photo 5. Felling in a plantation using a *harvester*.

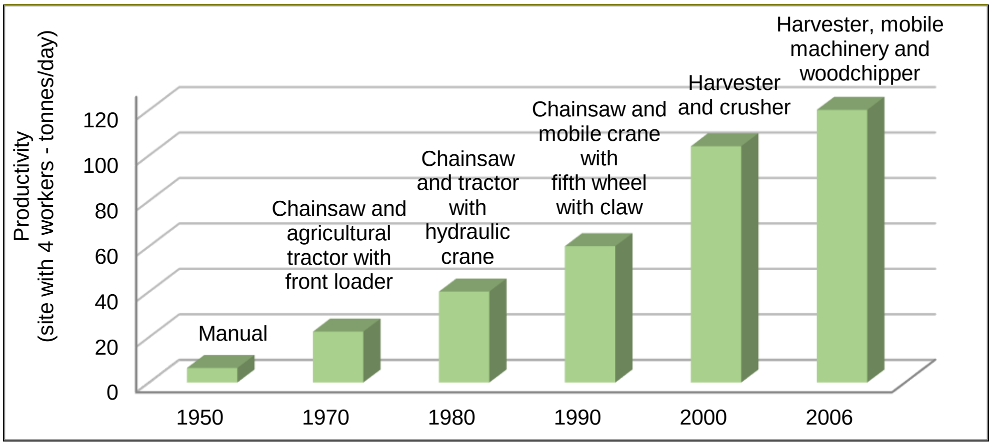

Figure 1. Increase in gross productivity of wood harvesting in poplar plantations (where unit weight of trees averages about 0.6 tonnes).

Controllare traduzione mezzi in figura 1

The unit cost of processing for the highly mechanized methods are lower than those of the traditional method (approximately 14-15 euros/tonne, as compared with 19-21 euros/tonne). Moreover, a team that adopts a high level of mechanization can work up to 100 hectares per year in contrast with about 12-15 hectares for those who work with traditional methods. However, the economic advantage in the use of combined machines is obtained only if the technical, logistical and commercial organization of the company allows optimal use of the available equipment through **continuous work throughout the day and year**; this condition occurs only in the areas most suited for poplar cultivation, characterized by larger lots and organized harvesting companies.

The use of harvesters may be constrained by the investment necessary for their purchase in relation to the moderate size of the companies in the sector, and by the assumption on the part of some industrial operators that mechanical processing results in lower quality, with inaccurate measurements and substantial damage to bark and wood. **Increasing the level of mechanization, however, is an unavoidable path** towards modernization which, together with potential improvement measures, creates a series of conditions linked to a shift towards more organized activities, favouring an increase in the economic value of standing timber and, consequently, in the competitiveness of the entire supply chain.

Finally, in view of the growing demand for biomass, in some geographical areas **the production of woodchips from poplar** can guarantee significant commercial exploitation of lower-grade wood, although in this case specialized transport equipment and a consolidated market are absolutely necessary.

3. POLYCYCLIC PLANTATIONS AND AGROSILVICULTURE

In the past, planted poplars were characteristic of the rural landscape of many lowland areas. The cultivation of poplar in rows inspired the development of an innovative type of plantation in which poplar is used both as the main crop, suitable for producing high-quality wood (veneer logs), and as an auxiliary crop which, by virtue of its rapid growth, its slender shape and the modest coverage of its foliage, is able to support the cultivation of other slower-growing trees such as valuable hardwoods.

3.1. Polycyclic and/or mixed-species tree plantations

Polycyclic and/or mixed-species plantations are proposed as a means of enabling management strategies in which silvicultural inputs can be replaced by natural dynamics that **favour wood production, through adoption of more environmentally sustainable cultural practices**. These systems promote the planting of different trees on the same plot to produce wood with different rotation lengths. They can include:

- *main plants* (arranged at a defined distance) of different tree species, with rotations of different duration:
    - medium-long rotation (valuable broad-leaved trees)
    - short rotation (poplar clones for the production of veneer logs)
    - very short rotation (poplar clones for the production of biomass, managed by coppicing)
- *dual-role plants* with a double function (wood production and improvement of the form of the main plants); these must be able to influence the architecture of the main medium-long rotation plants and to produce the wood assortments required by the market

- *auxiliary plants* which assist in the cultivation of the main plants by fixing nitrogen or favouring the control of weeds.

Polycyclic plantations can be divided in two types:

- ***temporary polycyclic plantations***, which are arranged so that the main plants with the longest rotation cover the entire plot surface at the end of the rotation, and are designed for their complete removal at the end of the rotation
- ***potentially permanent polycyclic plantations***, in which the main plants do not cover the entire area at maturity and are never removed at the same time, so as to guarantee continuous cover on at least part of the planted area.

Polycyclic plantations are covered by specific technical norms in the sustainable management standards of PEFC (see section 4.2).

Photo 6. Polycyclic plantation with poplar (clone 'I-214'), ash and oak.

3.2. Agrosilviculture

Agroforestry systems involve the cultivation of forest tree or shrub crops on agricultural land in association with agricultural crops and/or animal production activities. They are multifunctional systems that can provide a wide range of economic and environmental benefits. Rows of poplar have traditionally had a significant role: the cultivation of cereal crops between rows of young poplars, and rows of poplar interspersed with other species, once constituted a typical element of the landscape.

The areas cultivated in this way have gradually decreased since the 1980s, following the progressive specialization of farming, but there is currently renewed interest in this type of planting, especially in regard to its positive environmental implications (Paris *et al.*, 2014; Facciotto *et al.*, 2015). In terms of its suitability for obtaining wood for various industrial uses, it should be noted that in some cases there may be limitations, particularly for plantations arranged in rows or in any case having very "unbalanced" patterns (with the distance between plants within rows very different from the distance between rows); in these cases, the trunks of some clones can take on an elliptical shape and can form bands of tension wood, both phenomena that can reduce yield and the uniformity of the wood characteristics. It may be necessary therefore to aim for wood products of lesser economic value than traditional veneer logs, such as sawlogs.

In rural development planning, agrosilviculture is currently included as a component of greening, although the modest technical knowledge on the subject and its image as a practice whose value is mainly environmental are still significant limitations for its diffusion on a large scale.

4. POPLAR PLANTATIONS AND ENVIRONMENT

The cultural practices indicated in these guidelines for sustainable poplar cultivation, based both on the use of clones that are resistant to the main biotic adversities (MSA clones) and on the reduction of soil processing and phytosanitary interventions, **lead to a re-evaluation of the potential for cultivating poplar for production purposes in riparian areas and in areas designated for nature conservation**. The natural affinity of the *Salicaceae* for riparian and floodplain areas the most recent technical standards and procedures for eco-sustainable cultivation of poplar, suggest that poplar cultivation can have a positive impact with respect to other agricultural crops.

Indeed, in addition to being a source of wood supply, **poplar cultivation has important landscape and environmental functions**: poplars can be used as windbreaks, are part of the ecological network, absorb carbon dioxide, buffer polluting substances in the groundwater, reduce erosion of riparian soils during flood events, and can be used for phytoremediation of polluted areas (Bergante *et al.*, 2015).

Acquired knowledge suggests that the **carbon footprint of poplar cultivation** is more than positive thanks to poplars' high capacity to absorb CO_2 and accumulate it in wood (up to 25 t $ha^{-1}year^{-1}$) (Chiarabaglio *et al.*, 2014). In this sense poplar production, including industrial material and biomass for energy, can contribute to reducing emissions of climate-altering greenhouse gases (Tedeschi *et al*., 2005). The long duration of the plantations on agricultural land, with lower soil disturbance, results in an increase of organic content and fertility in comparison with annual agricultural crops. Poplar cultivation can adapt well to scenarios of global changes, with productivity gains under conditions of higher concentration of atmospheric CO_2 (Miglietta *et al.*, 2001; Liberloo *et al*., 2005; Luo *et al*., 2006). Finally, the storage of carbon in poplar wood has a long-life cycle thanks to the use of wood in furniture and other products that can be further recycled (Lovarelli *et al.*, 2018).

In order to determine the contribution of poplar cultivation to the carbon balance of the ecosystem, experiments were carried out to compare it with other forms of land use (agricultural crops, medium- to long-rotation wood plantations, semi-natural woodlands). The results have shown that the carbon balance of poplar culture is always positive, even when the wood is used for energy production, as in short-rotation forestry (SRF). Even if the clearing of the land after wood plantations can lead to a reduction in the positive balance of carbon stored in the soil, the creation of poplar plantations on agricultural land previously cultivated with cereal crops may nevertheless lead to a significant increase in the stock of soil organic matter. With appropriate cultural measures, such as those set forth in the *Ecopioppo* procedures for sustainable poplar culture, it is also possible to guarantee its longer-term conservation; for example, tilling the soil fewer times reduces the oxidation of the organic matter accumulated in the top layers of the soil, favouring the maintenance of soil fertility. This aspect is relevant considering that in the cultivation of poplars and other trees for wood production - as well as in natural forests and woodlands - leaves are deposited and incorporated in the soil annually, while for most agricultural crops they are generally removed, like the rest of the crop residues, which depletes the soil and necessitates subsequent fertilizer inputs.

In addition to their productive function, poplar plantations may also have other uses, for example as buffer strips, in prevention of soil erosion (especially if tillage is limited to the first years after planting) and in phytoremediation. In this last function poplars, together with other *Salicaceae*, have great potential because of their rapid growth and high transpiration rates, which translate into a significant quantity of contaminants absorbed and stored in the different parts of the tree (trunk and branches, leaves, roots); they also have demonstrated capacity for phytoextraction in soils contaminated by heavy metals and for absorption of nitrogenous substances in the disposal of livestock waste.

Photo 7. Diversification of the rural landscape with the presence of intensive poplar culture in a floodplain area.

As regards the functions of **soil protection and water regulation** to allow regular flows, investigations have been carried out to study the effects of wood and poplar plantations in floodplain areas following flood events. For example, in a survey conducted by CREA after the occurrence of floods in the Po valley in 1994 and 2000, it was found that planted poplars and other tree crops helped to contain soil erosion and hydrogeological instability as effectively as natural stands along the riverbanks.

Cultivated poplars diversify the agroforestry environment, form part of the ecological network in the often monotonous and relatively low-biodiversity landscape of agricultural areas, create niches with conditions favourable for the survival of animal and plant organisms, and can serve as windbreaks.

4.1. Ecosystem services

Sustainable management of poplar plantations provides many ecosystem services; the main ones are shown in Table 9.

Table 9. Main ecosystem services provided by poplar plantations.

Ecosystem service	Type
Production of industrial wood	Provisioning
Flood regulation and reduced soil erosion	Regulating
Reduced environmental impact with respect to agricultural crops	
Filtering of contaminants in soil and groundwater (nutrients and other pollutants)	
Reduction of greenhouse gases	
Creation of buffer zones between wooded and agricultural lands	Supporting
Constitution of elements of the ecological network	
Conservation of the rural landscape	Cultural and social
Conservation of biodiversity	
Public use for recreation (walking, cycling, horse riding)	

Payments for ecosystem services are voluntary transactions in which the producer is remunerated for an environmental function carried out to benefit the community. For example, in 2013 a group of poplar growers from the Bormida valley (province of Alessandria, Italy) received an economic contribution for the production of PEFC-certified poplar for the wood industry. There are examples of forest plantations created for environmental as well as production purposes, whereby companies interested in promoting their products also from an environmental standpoint have monetized the carbon credits produced.

4.2. Certification schemes for sustainable management

The FSC® and PEFC certification schemes (see section 4.2) have defined specific requirements for certified forest managers to verify effects related to the restoration, improvement and maintenance of ecosystem services. These instruments, which are voluntary, can support promotional statements on ecosystem functions, thus providing access to the emerging market in environmental services.

For example, certification of the sustainable management of wood plantations has been carried out in Italy for more than a decade and involves about 15% of specialized poplar cultivation. Sustainable plantation management, promoted by the schemes of the Forest Stewardship Council® (FSC®) and the Programme for the Endorsement of Forest Certification Schemes (PEFC), is a tool for the valorization and traceability of wood production. From this point of view, certification also provides a way to reduce the risks of illegal wood trade, helping to implement European and Italian regulations on due diligence and the EU Timber Regulation (EUTR). Poplar culture has lower environmental impact than agricultural crops, with positive implications also for conservation and protection of the landscape; however, its sustainability could be improved further with an appropriate choice of clones and the use of cultural practices with lower environmental impact. The PEFC and FSC certification schemes recognize polyclonality as one of the fundamental criteria sustainable plantation managements; although they do not refer specifically to improved MSA clones, they each impose a mandatory minimum percentage of a different clone from the main one: PEFC requires the use of another clone for at least 10% of poplars farmed on areas exceeding 20 hectares, while FSC® imposes a percentage of 20% for poplar plantations of more than 30 hectares.

5. SUMMARY AND OUTLOOK

Specialized poplar cultivation offers excellent production in numerous Countries all over the world, representing a highly significant share of annual industrial timber harvesting. At the same time, poplar culture contributes significantly to the sequestration of atmospheric carbon (through accumulation in above- and below-ground tree biomass and increase in the stock of organic matter in the soil when tree plantations replace traditional intensive agricultural crops) and allows a lower use of plant protection products in comparison with traditional agriculture. Poplar plantations have a positive carbon balance also because poplar wood replaces other materials more energy-intensive to produce (for example, cement and iron) when used as a raw material in the production of durable products and is used as biomass for energy production.

In this light, the availability of adequate communication and knowledge dissemination tools for this sector is important. This document represents a contribution in this direction, integrating the various technical and management aspects in an organic framework in line with a modern vision of ecological and economic sustainability. The document is accompanied by an extensive bibliography, intended to serve as a guide for those who want to explore topics in more detail. The concepts, views and content presented here can also serve as a direct stimulus for further operational advancement. For this purpose, for example, it may be appropriate to set the goal of a zero-chemical poplar plantations (zero herbicides, zero fungicides, zero insecticides, zero synthetic fertilizers, etc.), at least in a long-term vision.

It is therefore hoped that this document can serve as an effective reference, support and stimulus for growers, professional technicians, industrialists, public officials, researchers and policymakers, in the knowledge that worldwide the poplar value chain can represent one of the most dynamic sectors of the green economy.