International Commission on Poplars and Other Fast-Growing Trees Sustaining People and the Environment

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GUIDELINES FOR COUNTRY REPORTS

Activities Related to the Cultivation and Utilization of Poplars, Willows and other Fast-growing Trees 2020-2023

I. POLICY AND LEGAL FRAMEWORK

- *Guidelines for sustainable poplar cultivation*

Poplar cultivation represents for Italy one of the most important sources of timber supply for the first processing industry, despite a limited area compared to that of natural forests. These aspects were highlighted in the "Memorandum for the development of the poplar sector" signed in Venice in January 2014, innovative in the method because it was signed by the main poplar Regions, the poplar growers association, the agricultural associations, the industrial associations and the poplar research institution, in order to support all the sector.
To give substance to this agreement, it was considered appropriate to draw up a guidance document in support of rural development and land-use planning policies, aimed at identifying models for the sustainable management of value poplar cultivation, giving priority to obtaining high quality wood assortments for the plywood industry, without excluding all other uses including energy. The document "Guidelines for sustainable poplar cultivation" (https://www.reterurale.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/18732), elaborated in the year 2018 by CREA Research Centre for Forestry and Wood under the National Rural Network funded by the Italian Ministry of Agriculture, Agri-food and Forest Policies, refers to the cultivation of poplar in plantation, both in specialized cultivation for plywood production and by other means involving the use of poplar clones with broadleaf trees in a medium-long cycle (polycyclic plants) or in rows alternating with agricultural crops (agrosilviculture).
Together with the technical aspects of cultivation, the important environmental landscape functions of poplar cultivation were also taken into account, such as: windbreaks, ecological networks, protection against erosion, absorption of soil contaminants, as well as the efficient absorption of CO_2 with subsequent stabilization in the products of the manufacturing industry. These guidelines are therefore intended to be a first analysis document and a tool for comparison

between technical and institutional subjects (Ministry, Regions, research bodies), associations of producers and users, standardization bodies and environmental associations.
Italian poplar farming is still largely linked to the use of the 'I-214' clone, which certainly has ideal technological characteristics for the manufacture of plywood panels (lightness and colouring) but has some critical points due to its susceptibility to biotic adversities (aphid, rust and bronzing). The use of clones characterized by "Greater Environmental Sustainability" (called MSA clones) and improved resistance to the main biotic adversities (shoot blight, rusts, Marssonina leaf spot, and woolly aphid) makes it possible to develop semi-extensive cultivation models that, by minimizing cultivation and pest control interventions, make it possible to implement ecologically disciplined and sustainable poplar cultivation.

- *Poplar cultivation and rural development*

The Regions support and encourage the afforestation of agricultural land with specific measures of the Rural Development Programs (RDPs). These plantations, although with different modalities among the Regions most interested in poplar cultivation (Emilia Romagna, Friuli Venezia Giulia, Lombardy, Piedmont, Veneto), can benefit from a contribution to the planting if the principle of polyclonally is adopted (plantations consisting of 2 or more clones according to the size of the poplar stand) and/or if a process of adherence to the certification of forest management of poplar (GSP) is activated. At least 15% of poplar plantations are certified according to PEFC or FSC schemes.
Italian Regions have also adopted the list of MSA poplar clones, recognized as resistant to the main adversities, varying the percentage of contributions paid for the planting of new plantations according to the percentage of MSA clones used. By using MSA clones or by joining the GSP, the financial contribution for the planting of new poplar plantation varies from 60 to 80% of the eligible costs adopted by the various Regions.

- *Inventory of forest tree crops on farmland*

As part of the activities of the National Rural Network and with the support of Federlegno Arredo, CREA Forest and Wood Research Centre has carried out an inventory of forest tree crops on farmland in Italy, with reference to the year 2017, called INARBO.IT (https://drive.google.com/file/d/1sJ-pXKziVPMqrzFsZWS-SRUygj4fGL31/view). The estimated area of such crops is 96,750 ha. Hardwood plantations occupy more than 95% of the total surface area and are largely (46,125 ha) represented by specialized poplar plantations (about 50% of the total surface area). Specialized poplar cultivation is mainly concentrated in the Po Valley, with 70% of the plantations located in Lombardy and Piedmont.
Eucalyptus plantations are estimated in over 2000 hectares, managed according to the short rotation coppice model and located in South Italy.
Regarding *Eucalyptus* spp. data of the national forest inventory shows an estimate just under 20,000 ha (Tomé et al. 2021), mainly restricted to Sardinia even if less recent estimates indicated the national surface area of eucalypts to be around 70,000 ha (Ciancio et al. 1981-1982). Nevertheless, regional inventory estimates for Sicily alone 40,000 ha (Camerano et al. 2011) whereas a more accurate reading of the inventory data, in fact, highlights approximately 25,000 ha of eucalyptus plantations (in the regions of Sardinia, Calabria, Campania and Lazio) and over 30,000 ha of other evergreen broad-leaved forests in Sicily, in which there is a clear preponderance of eucalyptus as a fast growing woody species (Gasparini and Papitto 2022).
This data led to a national estimate of surface area over 50,000 ha underlining on the one hand the absolute relevance in terms of extension of Eucalyptus in the overall contribution of fast-growing

species. Secondly, they highlight one of the most peculiar aspects of cultivation in our country, namely the widespread use in contexts more specific to reforestation oriented towards hydrogeological protection, rather than in the more productive ones of wood arboriculture (Badalamenti et al. 2020).

The productivity of *Eucalyptus* plantations is extremely variable in Sicily (Badalamenti et al. 2020), with an average increase between 6 – 16 m3 ha-1 year-1 (depending on species, form of governance, age, site), although overall less than 10% of the surface exceeds the average increase of 5 m3 ha-1 year-1 (Barbera et al. 2001). The lesson from the past is to adopt specific cultivation techniques of wood arboriculture, which can be achieved, in our geomorphological and environmental conditions, only on small surfaces and with quality material (Ciancio et al. 1981-1982, Badalamenti et al. 2020).

Douglas fir (*Pseudotsuga menziesii* - MIRB. Franco) covers about 20,000 hectares in Italy, mostly distributed along the Apennines. However, most stands are managed under multifunctional silvicultural regime and just a few hundred hectares are managed as specialized tree crops for wood production. Results of European research programs such as EUDIREC have proven that even the material produced in Europe, including Italy, can be used successfully to produce casings, trusses and plywood.

At the beginning of the eighties of the previous century, the surface of *Pinus radiata* plantations in Italy was about 25,000 hectares, of which almost half in Sardinia. In recent decades, the area has been reduced due to the exploitation without replacement of old plantations and wildfires.

In Sardinia, Monterey pine (*Pinus radiata*) has been planted as a fast-growing species, following intensive interventions with mechanical equipment for site preparation and heavy impact on the native vegetation. Today, the main problem is soil degradation by maintaining forest cover as much as possible and controlling fire. Originally, the plantations were set up with an important public financial contribution and the main objective was to supply raw material to the pulp and paper industry that was developing in Sardinia on the central-eastern coast of Arbatax (Tortolì, NU). The failure of this industrial project, at the end of the last century, made the destination of plantation timber more uncertain, and today, as the planted radiata pines have reached economic maturity, the future of plantations is an issue of public debate.

Direct and indirect benefits are provided by ecosystem services which originate from the presence of these forest plantations. The development of local timber transforming economies, as well as environmental aspects (landscape, biodiversity, carbon sequestration, water quality, and soil erosion) represent new challenges for forest managers, but, on the other hand, plantations of non-autochthonous forest species can have negative impacts, such as an unnatural forest dynamism, and have gained a negative public perception when these have been ignored.

Wild cherry (*Prunus avium* L.) is a species widely distributed throughout Europe except for the northern part of the Scandinavian Peninsula and part of the Iberian Peninsula. Its range also extends to northern Africa (the Atlas Mountains), Anatolia and the Black Sea coasts. It is particularly present in the Caucasus and the Balkans, considered centers of origin from which the species then spread to the West after the last glaciation . The wild cherry is a species characterized by high plasticity and adaptability to different pedo-climatic conditions. It grows well in mixed mesophilic broadleaf forests of temperate climates.

In Italy, this species finds its vegetation optimum in the phytoclimatic belt of *Castanetum* and *Fagetum* di Pavari. Wild Cherry is a species widespread throughout the Apennines between 700 and 1700 m above sea level, in the Po Valley and in the valley floors of the Alpine areas. It is a tree that can reach heights of 25 - 28 m in optimal stationary conditions, with average diameters that can vary from 40 to 90 cm depending on the fertility of the soil. It generally shows good apical dominance, and in isolated trees the crown tends to be pyramidal. It is a sporadic species in Italy, present in the territory in a discontinuous manner, with isolated plants often very far apart from each other, or in small groups formed by very few mother plants and their root shoots.

II. TECHNICAL INFORMATION

1. Taxonomy, Nomenclature and Registration

1. *International Register for Populus Cultivars*

For the period 2020 to 2023, a few new applications to the International Register for *Populus* Cultivars were submitted to the Working Group and added to the Register.
Three new epithets were submitted in 2022. The *P.* × *generosa* ‘Chinook Landing’ and the *P. deltoides* x *P. maximowiczii* ‘Kamikawa’ and ‘Lake Albermale’, all requested by Brian Stanton, Poplar Innovations. The new clones were introduced in the Register that currently maintains three hundred and sixty-seven epithets. Italy has not requested the registration of any new poplar clone in the period considered. The Checklist of *Populus* Cultivars records 185 unregistered names and 103 cultivars with experimental codes.

2. *International Register for Willow Cultivars*

During 2020 -2023 twenty-six new cultivar epithets were submitted to the Working Group and included into the International Register of Cultivars of Salix (Willow) and the Salix Checklist. All epithets, which originated in Russia and US, were submitted in 2020. These new cultivars epithets were the first ones to be included into the newly established Register of Cultivars of Salix. In 2020-2023 30 names were added to the Checklist: currently it contains 854 cultivar names (Kuzovkina Y.A. and L. Vietto. 2021).

3. *The Italian National Register of Basic Materials*

Currently, Italian National Register of Basic Materials maintains 85 poplar clones registered in the ‘controlled’ category, of which 26 denominated as Greater Environmental Sustainability (MSA). The clone ‘AF13’ was placed in this category in 2022. No other poplar clones were registered in the period 2020-2023. Some natural populations belonging to *P. alba*, *P. nigra*, and *P. canescens* have been integrated into the 'qualified' and 'source identified' categories of the Register.
Regarding the other species indicated in the Annex I on Italian Law for register Institution and of interest for the report:

- *Eucalyptus* spp.: two clones were selected and patented in Italy by CREA Forestry and Wood Center although until now still not recorded in the national Register: ‘Veglio’ and ‘Velino’;
- *Pinus radiata*: not present in the National Register they modeled the future development of crops based on the possible environmental effects of climate change;
- *Paulownia* spp.: not present in the National Register;
- *Prunus avium*: in the National Register of Base Materials (RNMB) 68 base materials of *Prunus avium* (seed sorces), are registered in the 'Source-Identified' category, while three seed sources are registered in the 'Selected' category. Moreover, three seed orchards of the same species are registered in the 'Qualified' category;

- *Juglans regia*: in the National Register of Base Materials (RNMB), 20 base materials of *Juglans regia* and 5 of *J. nigra* are registered in the category 'Source-Identified', while five BMs of *J. regia* are registered in the 'Qualified' category;
- *Fraxinus* spp: BMs of the Fraxinus genus are recorded in both the 'Qualified' (1) and ' Source-Identified' (156) categories;
- *Pseudotsuga menziesii*: the currently accepted scientific name of Douglas-fir is *Pseudotsuga menziesii* (Mirbel) Franco, it is an evergreen conifer in the pine family *Pinaceae*.

Three main varieties, adapted to different values of continentality are recognized: i) *Pseudotsuga menziesii* a) var. *menziesii*, green Douglas-fir, native to the more humid coastal climate zones; ii) var. *cesia*, with silvery gray needles, variety of the internal and dry mountain climate zones; iii) var. *glauca*, from the more internal and mountainous climate bands with a more continental character, an intermediate taxonomic form between the other two. In the Italian National Registry of Basic Materials there are currently registered 8 BMs of Douglas fir in the 'Source-Identified' category and 2 in the 'Selected' categories.

2. Domestication and Conservation of Genetic Resources

The conservation and domestication of genetic resources of *Salicaceae* and Other Fast-Growing Trees takes place mainly at public research institutions such as Universities, CREA and CNR as well as in some regional and private nursery companies. The activities carried out at CREA concern various wood species as reported below.

Poplar sections

1 *Aigeiros section*

Accessions of *Populus nigra* (610), *P. deltoids* (450), and *P. xcanadensis* (340) are maintained in Casale Monferrato at the farm of CREA Research Centre for Foresty and Wood. Conservation involves both *in situ* efforts (natural and artificial *in-situ* conservation units to ensure adaptation of the species to climate changes) and *ex situ* (seed and pollen lot banks, clonal archives, seed-orchards, arboreta). A breeding program, operating since the 80's based on inter-specific hybridization between Eastern cottonwood (*P. deltoides*) and European black poplar (*P. nigra*), is still central to the CREA strategy. Both long-term (semi-recurrent selection in *P. deltoides* and *P. nigra*) and short-term strategies (commercial breeding) are adopted. Mating the parental of the highest general combining ability identified in the first phase of the program allowed to select interesting clones, currently in the final selection stage. Hundreds of new hybrids obtained within the following phases of crosses are under testing. Desirable traits measured in seedlings, nurseries, and 'ramet' stands (ease of establishment, fast growing, resilience to diseases, adaptability under different pedo-climatic conditions, improved wood quality) are the key selection criteria. To enhance *P. nigra* germplasm, a pool of native genotypes has been characterized and selected for environmental restoration activities; a restricted pool of *P. nigra* clones characterized by good growth performances and stem forms has been selected for cultivation in fluvial areas with restrictions for growing commercial hybrids.
As part of the activities of the H2020 B4EST project (https://b4est.eu/), accurate phenotyping and high-throughput genotyping, using the 4TREE array developed within the project and including 13,409 Single Nucleotide Polymorphism (SNP)-based molecular markers specific for poplar, of

poplar genetic resources belonging to the collections of CREA-Forestry and Wood, Casale Monferrato, have been conducted. These included 440 *P. nigra* and 168 *P. deltoides* accessions and two F_1 progenies respectively obtained by the cross of *P. nigra* N355 and *P. nigra* N385 (265 individuals) and *P. nigra* N074 and P. *deltoides* D066 (183 individuals). The phenotypic traits considered were represented by phenology, habit, and woolly poplar aphid (wpa) resistance. Phenotypic and genetic data have been integrated, applying linkage mapping and Genome Wide Association Scan (GWAS) approaches, and new loci associated to wpa resistance on different poplar chromosomes have been discovered. The search for loci associated to the other traits is in progress. Moreover, genomic prediction models based on Genomic Best Linear Unbiased Prediction (GBLUP) have been developed. The data obtained by these works represent valuable tools to develop breeder-friendly molecular markers to support efficient fast and early selection of poplar clones.

The selection and deep characterization of superior *P. nigra* and *P. deltoides* parental lines to be used in future breeding programs is underway. These will be used to generate new *P. xcanadensis* clones carrying useful traits for wood industry and biofuels/biomaterials production.

2 Leuce section

Collections of genetic materials from *P. alba* native genotypes (about 200) have been carried out in order to supplement the germplasm bank of this species that is also effectively used in restoration activities, urban forestry, phytoremediation, and biofuels/biomaterials production.

3 Tacamahaca section

Following cooperation activities on poplar breeding with the Chinese Academy of Forestry (CAF), a progeny obtained by crossing *P. simoni* and *P. nigra* parents is maintained at the CREA farm in Casale Monferrato for selection and phenotypic characterization.

<u>Willows</u>

Willow accessions (about 440) most referable to *S. alba*, *S. jessoensis*, and *S. matsudana* are maintained in clonal archives and/or arboreta. Few new clones selected among the progenies of *S. alba* × *S. alba* and *S. matsudana* (open pollinated) are under testing: growth-rate, tree architecture, tolerance to diseases and pests (*Asymmetrasca decedens*), and physical features (fiber length, cellulose content) are taken into consideration for biomass production and as biofuel resource.

<u>Eucalypts</u>

Ex situ genetic reserves of some *Eucalyptus* species are maintained at CREA experimental farm in Rome, e.g.: *Eucalyptus viminalis* (21 provenances), *E. globulus ssp globulus* (10 provenances), and *E. globulus ssp bicostata* (12 provenances). There is also an arboretum for the preservation of some accessions of *E. grandis* and a seed orchard of *E. camaldulensis* provenance Lake Albacutya (VIC AUS). The breeding activity led to the selection of 4 clones suitable for cultivation in the Mediterranean area and resistant to cortical cancer (*Teratosphaeria zuluensis*). The interspecific hybrids (*E. camaldulensis x E. globulus ssp bicostata*) clones 'Viglio' and 'Velino' have been registered at the European CPVO, while Sirente (*E. camaldulensis x E. globulus ssp bicostata*) and Majella (*E. camaldulensis x E. grandis*) are under evaluation in order to be registered in Italy.

Black locust

At the experimental farm of CREA Research Centre for Forestry and Wood, located in Rome, there is an *ex-situ* genetic reserve made up of about 180 provenances and accessions that represent the natural and cultivation area of the species. The assessments carried out so far have shown the good adaptability of the Oklahoma (USA) provenances.

Douglas fir

Douglas fir (*Pseudotsuga menziesii* -MIRB. Franco), a highly productive and adaptable forest species, offers numerous benefits for the European economy and environment. Native to the American Northwest, it has demonstrated a remarkable ability to adapt to climate change, which makes it valuable to produce high-quality timber in mountain regions. Its distribution range extends across the entire American Northwest which is characterized by wide environmental diversity that favours the existing wide genetic variability of this species, guaranteeing a high adaptive potential to changes climate, even outside the range of origin.

In Central and Northern Apennines and Calabrian areas, where Douglas fir was introduced in the early decades of the 20th century by Professor Pavari, it has shown to adapt successfully, with a mean annual increment of about 20 $m^3ha^{-1}year^{-1}$ and final mass varying between 500 and 820 m^3ha^{-1} at 40 years of age (minimum rotation age) (https://www.progettodonato.it/psr-toscana.html) (Pozzi and La Marca, 2022). These levels of wood production are very interesting for the economy of mountain areas, usually characterized by much lower production values. For this reason, it is fundamental to obtain good quality basic material for the plantations and to start a breeding program for productive and adaptive purposes.

For over 70 years, *in situ* and *ex situ* conservation activity of Douglas fir in Italy has been led by CREA Research Centre for Forestry and Wood, that has designed, realized, and managed different provenance tests. One of the most important is represented by the IUFRO experiment (built up in 1970), which comprises more than 80 provenances, plus 10 Italian artificial provenances sampled in different areas of the Apennines, from Tuscany to Calabria, among the best early-1900 introduction plots which had shown very promising performances.

These provenance tests were carried out in two different sites in the Tuscan Apennines: Vallombrosa (FI) and Faltona (AR). The tested provenances included populations belonging to *P. menziesii v. menziesii* (green Douglas fir, the variety distributed along the American Pacific coast), and to *P. menziesii* v. *glauca* (the gray variety, with more internal distribution). Quantitative traits related to growth, polycyclism, stem straightness, branch angle, forking, wood density, and mortality, as an adaptive index, have been observed. These tests, presently more than 50 years old, provide indicative results also for the medium-long term selection of seed populations. In this regard, the geographical origin of the best seed stands in Calabria (Mercurella) and Tuscany (Abetone) was recently identified, thanks to molecular markers, comparing materials from these two origins with those of the IUFRO 1969-70 collection. The results attributed the origin of Abetone to a restricted region between the forests of Yelm (1080) and Vernonia (1094) on the borders between Washington Cascades and the Oregon Coast area of the American Pacific coast. Similarly, the origin of Mercurella was primarily attributed to the area of the forest of Sandy (1096), in the Oregon Cascades region (De Rogatis et al., 2024). The experimental network IUFRO 1969/70 has highlighted for Italy the coastal areas of low altitude of Oregon and northern California and high altitude of southern California as sources of reproductive material. It should be stressed that Mercurella (Calabria) and Acquerino (Tuscan-Emilian Apennines), the so-called “second-generation Italian provenances” introduced by Pavari in the ‘20s, have proved for quality and adaptation.

For the two sites of Acquerino (northern Apennines, cooler and moister site, without summer aridity) and Mercurella (southern Apennines) climate sensitivity was also studied by Castaldi et al. (2020), using relationship between tree-ring chronologies and some climatic variables. The study highlighted how the growth of Douglas fir is positively influenced by the minimum temperatures of February and March, while in the northern sites Douglas fir is very sensitive to late summer temperatures, which influenced negatively the growth.

The survey by Marchi and Cocozza (2021) highlighted as the most probable seed sources for the current Italian populations are approximately 63.4% from the coastal provenances of British Columbia and 33.8% from the dry coast of Washington. Considering future climate change scenarios, the study by Marchi and Cocozza (2021) also highlighted that in the coming years the most suitable provenances in the medium term (2050) could be those of the dry coast of Oregon and subsequently (2080) those of the California.

The rapid evolution of climate change and their effects make the necessity to implement studies related to adaptive and genetic monitoring of the best populations. At the end of the 70s of the last centuries, a first test of progeny of superior phenotypes selected in Tuscany with repetitions at different altitudes was carried out in Faltona. This test has now been acquired as a seed arboretum officially registered by the Tuscany Region. Furthermore, in locality Capanno di Anghiari (AR), other tests of progenies, obtained from a first selection made in the previous provenance tests, were realized in around 1996. In these progeny tests, quantitative traits related to growth and survival have also been monitored.

More recently, new opportunities are offered by Douglas fir in prealpine areas, at medium-high altitudes ina relatively continental climate context, where origins from the more internal American range seem to have given excellent results. In these areas it is useful to spread a partial cultivation to integrate the losses in diversity and productivity caused by the spruce crisis following the effects of the Vaia storm in 2015 and the bark beetle (*Ips typographus* L.) infestations. Studies are underway to identify the origin of the populations that have demonstrated good adaptation.

In Italy, many of the Douglas fir stands have now reached maturity and even if the Douglas fir has shown a good ability to renew itself naturally, the renewal of these stands cannot ignore the availability of suitable planting material. Currently, Douglas fir seedlings are purchased mainly from foreign nurseries, which cannot always guarantee the suitability/adaptability of the planting material in our territories. Hence the need to have high quality genetic adaptive propagation materials (FRM), suitable for Italian territories. For this reason, over the last 4 years the CREA Research Center for Forestry and Wood (Arezzo), within the Do.Na.To project, starting from material selected among the best IUFRO provenances and progenies present in the experimental arboreta of Faltona and Vallombrosa, constituting a unique germplasm bank of enormous national and international value, it contributed to the creation of two new clonal seed arboreta (clonal common catalogues) for the germplasm conservation. After selection, within these comparative experimental arboreta, superior phenotypes (more than 60) showing the best technical-productive and adaptive performances for the Tuscany environments, CREA Research Center for Forestry and Wood collected the scions from the selected phenotypes for the creation of grafts to constitute the new clonal common catalogues taking a step forward in the breeding process for Douglas fir species. The collection was also genetically characterized with functional molecular markers associated with phenotypical characters related to wood quality, in order to develop a methodology to allow early selection of valuable material for wood supply chain.

Clonal production may seem at first sight incompatible with the maintenance of high levels of diversity, however, with enough genotypes included in the catalogue, the variability can be even higher than that of a normal seedling plantation, as already demonstrated for Norway spruce in Germany. This allows the balancing of the technical-production aspects (wood quality and wood production) with the conservation of an adequate level of genetic diversity. These common clonal catalogues, in addition to being a tool for the conservation of germplasm, represent a precious reserve to draw periodically for seeds, grafts producing genetically tested propagation material for our environments, suitable for quality mountain arboriculture. (https://www.progettodonato.it/psr-toscana.html) (Monteverdi et al., 2022).

Radiata pine

Monterey pine (*Pinus radiata*) plantations have been established since the late seventies of the previous century, mainly in the Southern part of Italy, where Mediterranean climate conditions, with mild winter and relatively cool and humid summer, are the most suitable for the species. Models for economic evaluation of silvicultural interventions in radiata pine plantations were developed in a study area in Sardinia by testing systematic and selective thinning in comparison to regeneration felling under a continuous coverage forest management approach (Pignatti et al. 2022).

Wild cherry and walnut

Wild cherry (*Prunus avium* L.) provides a precious wood with quality technological characteristics, dark red in color and distinctive veins, widely used in the production of furniture and panels. For these characteristics, starting from the 1980s, the CREA Research Centre for Forestry and Wood started a program of genetic improvement of wild cherry, starting from a careful selection in the forest throughout the national territory of superior phenotypes, in order to constitute a selected genetic basis for improvement programs to mainly support quality and certified wood arboriculture. The collection of propagation material from selected superior phenotypes has led to the establishment of comparative tests of provenances and progenies in different parts of Italy. Over 500 selected wild genotypes were propagated by grafting and placed in clonal archives, while approximately 100 clones were propagated in vitro and used for multisite comparative tests. The collaboration with the INRAE of Orléans has led to the enrichment of the collections with highly variable materials from the Caucasus. Furthermore, the collection of Italian genotypes available in the various arboreta has been enriched over time by accessions arriving from other countries. The genetic improvement program carried out by CREA for several decades now has led to the creation of seed orchards, some of which are registered as Qualified Basic Material (BM) in the National Register of Basic Materials (NRBM), and to the selection of some clones phenotypically superior with high quality wood technical characteristics, pending registration. This allows us to have material to be used in arboriculture plantations from quality wood derived from selected and certified basic material. Wild cherry wood has been widely used in past years because it is a type of valuable wood, and aesthetically very beautiful, but due to the absence of a structured and transparent market for medium-long cycle hardwood timber produced in Italy, but also due to the unsatisfactory production results of the 2080 plants due above all to the lack of knowledge of the specific construction and management techniques, and also because the ecology of the species and the genetic/adaptive aspect have often been underestimated, there has been a strong contraction of surfaces planted with fine hardwoods. To date, after years of research and experimentation, this "gap" can be considered mostly resolved. Recently there has been an increased interest in these valuable species, in particular for polycyclic plantations and agroforestry systems.

The same approach to the selection and genetic improvement programs was reserved for the walnut (*Juglans regia* L.). Also in the 1980s, CREA Research Centre for Forestry and Wood, through projects financed by MASAF, started a selection program for superior phenotypes of J. regia with the aid of improvement programs to produce valuable wood. Collections of genotypes with good architecture and adaptive characters that could avoid the effects of both late and early frosts were created. Furthermore, hybrid populations between black walnut (*J. nigra*) and common walnut (*J. regia*) have been identified, which have made it possible to create an important collection of good quality hybrids, some of which are even polyploid.

Walnut is a species naturalized in Italy for millennia, and is cultivated throughout the vegetation belt of the *Castanetum*, but where pedoclimatic conditions allow it, it can be cultivated from sea level up to altitudes of approximately 1220 m a.s.l..

The walnut is not found in the forest, but it is common to find trees at the edges of roads, ditches or near rural houses in small, isolated groups. In Italy there are areas particularly suited to its cultivation both in the Alpine and Apennine regions. It has traditionally been cultivated both for the production of valuable wood and for its fruits in association with agricultural crops. Also, for the cultivation of this species there has been a significant reduction in cultivated areas mainly due to imports of fruit from foreign markets and valuable tropical wood. The use of this species in modern agroforestry systems in association with agricultural crops on fertile land can be interesting and allow a revival of walnut cultivation (Chiarabaglio et al., 2023).

Paulownia

In Italy the first evidence of cultivation of trees of the Paulownia genus dates to the 1970s. The origin of most of these clones is Chinese and those marketed in Italy have generally been patented by private European companies of which Italians are the distributors at national level.

The first commercial activities for the diffusion of Paulownia tomentosa began in Veneto in the 1990s by the Paulownia Italia Company. Since 2013 the company Wonder K Green s.r.l has planted 1200 ha of paulownia using Cotevisa 2 clone (hybrid of *Paulownia elongata* x *P. fortunei*) of Spanish origin. The plantations are located in various regions of Central and Southern Italy and technical reports indicate a good performance.

Comparative study on paulownia clones started recently by Veneto Agricoltura in the pilot and demonstration farm “Sasse Rami” in Ceregnano (Rovigo). The field test was created with materials introduced into Italy thanks to the collaboration of Maurizio Lambardi, CNR IBAF, and the Chinese Academy of Forestry (CAF).

PEFC Italia has started also the process that should lead to the certification of paulownia plantations and wood even if some issues, including that of the invasiveness of the species, have blocked the development of the standard.

Regarding paulownia invasiveness in Italy, studies conducted by Nicola La Porta of FEM demonstrate that even in naturalization conditions the *Paulownia tomentosa* species is not able to permanently colonize the environment but does so only on a transitory basis. So, for invasiveness, it should be very useful to study the characteristics of the seeds produced by hybrids in the laboratory.

3. Plant Health, Resilience to Threats and Climate Change

Poplars

(a) Biotic factors

1. *Insects*

As previously reported droughts and high temperatures during the growing season were associated with an increased incidence of various pests. Buprestid beetles, i.e. Poplar jewel beetle (*Agrilus suvorovi* Obenberger) and Melanophila stem borer [*Melanophila picta* (Pallas)], were often reported in new plantations suffering from transplant stress or drought, causing weakening of young trees or stem breakages. These pests were observed with high incidence especially in the Po delta area, in Veneto and Friuli (North-Eastern Italy).

The poplar and willow borer [(*Cryptorhynchus lapathi* (L.)] was confirmed again as the most important pest in Italian poplar cultivation, with significant effort to prevent damage in young plantations and in nurseries. This pest is highly injurious in SRF biomass stands too, where a chemical control is not technically and economically suitable. *C. lapathi* would be effectively controlled by stem spraying in 1-3 year-old poplar stands during sprouting or even winter dormancy, with the goal of killing young larvae living in the bark. Pyrethroid insecticides are very effective both in winter and in spring sprayings. Heavy infestations, however, are unlikely to occur when healthy nursery stock is used for transplanting.

As regards the large poplar borer [*Saperda carcharias* (L.)] and the goat moth [*Cossus cossus* (L.)], their remain very injuring agents on plywood industry as in the past years. *S. carcharias* is generally controlled by chemical spraying against young larvae (at the end of May) only in young stands, in alternative to localized treatments by insecticide injection into the galleries; the latter are more commonly adopted in older stands.

An additional challenge versus all the aforesaid pests consists of the progressive inhibition for poplar of the use of many active ingredients very effective on them, that will have to be replaced by new molecules environmentally more sustainable, or these borers, quite indifferent to genetic improvement, will have to be faced by other control strategies, mainly biologic control. So for *S. sarcharias* is really useful to favour predation by the great spotted woodpecker (*Picoides major* L.), important natural enemy of the pest, preventing the elimination of dead or broken trunks, where the woodpecker is used to nest.

Among phytomyzous insect pests, the poplar woolly aphid [*Phloeomyzus passerinii* (Sign.)] has confirmed as the most injurious one, causing bark damage and death of trees when attacks were heavy and prolonged. Infestations were recurrently recorded, mainly in moist areas along rivers of the Central Po Valley. The incidence of this pest has been, till now, markedly enhanced by the extensive cultivation of highly susceptible clones in Italy (in particular ‘I-214’). Since *P. passerinii* can no longer be controlled by active principles (mineral oils, organophosphate insecticides), as they have been revoked on poplar by EU regulations, it must be managed with other types of defenses. Owing to its character of advanced specificity, very different in this from the non-specific wood borers, the most effective management of the woolly aphid is genetic improvement: all new MSA clones are resistant, and the recent discover of quantitative trait loci associated with aphid resistance will enhance further selection of resistant suitable genotypes.

In addition, we cannot avoid focusing on brown marmorated stink bug [*Halyomorpha halys* (Stål)], the polyphagous bug found for the first time in Italian plantations five years ago, which since then induces frequent and severe damage on young trees (1-4 years from transplanting) consisting of necroses and malformations on trunks. The infestations were observed between August and September, mainly at the same time with harvesting of nearby corn of soyabean crops, which the pest seems to prefer as host. For such non-specificity of *H. halys*, and for the increasing inhibition of current active ingredients, any proposal about its phytoiatric management does not appear realistic, whereas more beneficial, in perspective, may be biologic control by oophagous parasitoids, both autochthonous [*Ooencyrtus telenomicida* (Vassiliev)] and exotic [*Trissolcus japonicus* (Ashmead)] (however recently found in Italy), or alternative control by “attract & kill” pheromone traps and/or placement of protective nets where possible. In the last years, however, attacks by *H. halys* seem to have less dramatic proportions than in 2010s.

As regards the poplar clearwing moth [*Paranthrene tabaniformis* (Rott.)] and the poplar twig borer [*Gypsonoma aceriana* (Dup.)], they occasionally affected nurseries, and the former sometimes young poplar stands as well.

Among defoliators, the poplar leaf beetle (*Chrysomela populi* L.) as usual was agent of some outbreaks especially in nurseries, and the leaf-rolling weevil [*Byctiscus populi* (L.)] induced locally early defoliations mainly in *P. deltoides* plantations. More spread defoliations of young and mature plantations by the fall webworm [*Hyphantria cunea* (Drury)] were sometimes recorded, especially in *P.* ×*canadensis* plantations. All such defoliators may be controlled by *Bacillus thuringiensis* Berliner insecticidal proteins, especially active versus Coleoptera and Lepidoptera, or IGR (Insect Growth Regulator) insecticides, paying attention to the fact that *B. thuringiensis* treatments must not be extensive since recently cases of field-evolved resistance have been observed in some non-poplar pests.

The American ambrosia beetle [*Megaplatypus mutatus* (Chapuis)], dangerous for a large number of broadleaf trees (including some valuable productive species like walnut, apple, hazel in addiction to poplar) mainly in the Campania region of Southern Italy, is still absent in Northern Italy probably because of its temperature requirements. Anyway, investigations to find strategies of control (including the use of semiochemicals) are advancing in order to reduce damage in the affected areas and to avoid chances of spreading.

The last but not the least among pests, already damaging other wood species, the Japanese beetle [*Popillia japonica* (Newman)] has long since arrived in Italy, and was reported many times on cultivated poplar in the Po valley. While underground larvae have not been reported as harmful to poplar roots, adults feed on leaf tissues and may sometimes defoliate heavily in nurseries from the end of May. Object of mandatory defence since 2016, *P. japonica* may be controlled introducing entomoparasitic nematodes able to threat larvae in soil; but a possible host genetic resistance should be investigated, since in experimental nurseries genotypes immune to attacks were observed very close to others heavily defoliated.

2. *Wild mammals*

Damage by roe deers (*Capreolus capreolus* L.) and wild boars (*Sus scrofa* L.) has significantly increased in nurseries and especially in new plantations following the expansion of these mammals; it consists of bark removals, with consequent formation of proliferating scar tissues, inducing a quality loss and, in heaviest outbreaks, stem ruptures. Heavy occurrence of such damage have been reported mainly in north-eastern Italy and elsewhere in localized stands nearby wild areas.

3. *Diseases*

On the stressed just transplanted plants, weak attacks of *Phomopsis* spp. and *Cytospora* spp., inducing bark necroses, were observed; the same can be said for "Dothichiza" stem canker [induced by *Chryptodiaporthe populea* (Sacc.) Butin], in contrast with the past high incidence possibly in connection with climate change. On the contrary, in probable connection with the increasing drought periods (Fig.1), increasing stem necroses in nurseries and young plantations seem associated with *Fusarium* spp. [*F. solani* (Mart.) Sacc., *F. lateritium* Nees, and *F. incarnatum* (Desm.) Sacc. the most isolated species from affected tissues], similarly to some old reports of past century fifties.

The incidence of Marssonina leaf spot caused by *Drepanopeziza brunnea* (Ellis & Everh.) Rossman & W.C. Allen, since now a widespread foliar disease connected with severe phylloptosis and loss of production, was remarkably reduced during the last period in spite of the assessed susceptibility of 'I-214', the most cultivated clone in Italy (more than 80% of poplar stands). This negative Marssonina trend has probably been associated with the unsuitable meteorological parameters of the last years, characterized by dry summers, and with the conspicuous decrease of poplar cultivated surface till 2018; both these occurrences may have contributed to reduce its inoculum potential.

Also in the considered period, spring leaf and shoot blight caused by *Venturia populina* (Vuill.) Fabric. has not caused any economic damage due to the limited spread of the so called "Canadian clones". The disease is present only in some small areas of the Po Valley, where it maintains an endemic character. Recently, some attempts of reintroducing some very productive "Canadians" (e.g. 'Adige', 'Boccalari') in big farms are being successful, in spite of their well-known susceptibility to *P. elegans*, since they were planted in small groups widely spaced among them and separated by plantations made up of resistant clones. Probably, in this specific context the incidence of *P. elegans* remains on tolerable levels owing to the scattered inoculum target.

As regards leaf rusts by *Melampsora* spp. (i.e. *M. larici-populina* Kleb. and, in a lesser extent, *M. allii-populina* Kleb.), their incidence is fluctuating with the years and, in perspective, possibly decreasing because of the progressive introduction into cultivation of resistant/tolerant MSA clones. Instead, the damage of rusts on the Short Rotation Forestry must be seen more in terms of stump survival and, in the long period, of integrity of the coppice stand rather than in terms of quantitative losses of dry matter.

The incidence of leaf mosaic by Poplar Mosaic Virus (PopMV) remains very low, also considering the low amount of *P. deltoides* or susceptible hybrids in nurseries and plantations. The eradication in the nursery, with a rapid elimination of symptomatic plants, is the only method to prevent PMV epidemics.

The incidence of root rots by *Rosellinia necatrix* is not changed in the last four years, remaining limited to already affected stands, especially in case of lack of crop rotation.

(b) Abiotic factors

During the last years (2020-2023), in Po Valley the vegetative seasons were often characterized by extended periods of drought, not only during summer but even at the beginning of spring, remarkably in 2023. Even if the trees are still in vegetative quiescence, in the case of nursery or new plantations this condition induce a dehydration of the tissues of young trees, with consequent weakening of the sprouting shoots and predisposition of bark to be affected by latent fungal parasites.
Dry summer conditions with high temperatures induced typical symptoms, with drastic thinning of the crown and consequent reduction of the annual growth, defective lignification of young buds and reduction of reserve substances for the quiescent period. In mature plantations stressed by water deficit, the syndrome known as "brown spots" physiologic disorder has been frequently observed. Traditionally more associated with surviving "Canadians" or 'Luisa Avanzo' clones (but on the last one not in southern Italy), it could affect many new fast-growing poplar clones, whose high water and metabolic requirements are often impaired by recent prolonged droughts. "Brown spots", however, up to now have not yet been observed on MSA clones.
More generally, significant summer drought may have contributed, together with mild average temperatures in winter, to the frequent pest outbreaks that have been observed, increasing their voltinism, improving their overwintering, thus making poplars more attractive to various pests. Some hailstorms occasionally occurred with local damage to young trees. Winter temperatures never were significantly low; thus, frost cracks or cold damage did not constitute prominent adversities.

<u>Other fast-growing wood species cultivated in Italy</u>

Considering the small area planted with other fast-growing trees in Italy excluding poplar, in this section we will summarize the adversities of some species with remarkable importance for present production or in perspective.

<u>Willows</u>

Owing to the negligible diffusion of willow intensive cultivation in Italy, there is almost no new adversity to be signaled in these last years, as it is confirmed by the specific literature. The only pest worth of reference is the green leafhopper [*Asymmetrasca decedens* (Paoli)], a polyphagous species able to transmit phytoplasmas probably responsible for leaf deformations and yellowing. As for several poplar pests, a phytoiatric management of *A. decedens* appears difficult because of the increasing restrictions of use for the main part of active ingredients, in a perspective of sustainable cultivation. A biological control could be pursued enhancing the spreading of the egg parasitoid *Anagrus atomus* (L.), already present in Europe, including Italy.

Eucalypts

Differently from poplar and willow, in the last years an important new fungal pathogen was found on eucalypts in Southern Italy. It is *Teratosphaeria gauchensis* (M.N. Cortinas, Crous & M.J. Wingf.) M.J. Wingf. & Crous, pathogenic agent of the so called Teratosphaeria stem canker disease (formerly known as Coniothyrium canker), reported for the first time in 2015 on hybrid *Eucalyptus camaldulensis* Dehnh × *E. viminalis* Labill., but already well known worldwide. The cankers are first visible as small (2-5 mm) necrotic lesions on stems, becoming elliptical as they grow in size and penetrate the vascular cambium, that eventually merge with neighboring lesions to form cankers filled with gum, also known as kino pockets. Stem malformation typically ensues, and the bark covering these cankers often cracks vertically, creating a “cateye” appearance and causing the gum to exude. In the case of severe infections on susceptible clones, the cankers girdle the stems, epicormic shoots develop and the tops of the trees die. The susceptibility seems to be specific, since most of both parents of the affected clone did not show till now appearance of cankers.
Another disease concerns *Neofusicoccum australe* (Slippers, Crous & M.J. Wingf.) Crous, Slippers & A.J.L. Phillips, with the involvement of some similar species; it is associated with stem and branch cankers typical of an increasing decline in *E. camaldulensis* plantations of Sardinia.
Among pests, the red gum lerp psyllid (*Glycaspis brimblecombei* Moore), cosmopolitan, is spread in large territories of Campania, Latium, Sicily and Sardinia, and has become in a few years very detrimental especially on *E. camaldulensis*. New records of Liguria, Molise and Abruzzo, being the second two the first ones on the Adriatic side of Italy, east of the Apennines, highlight the expansion of the species more recently (Cianferoni and Ceccolini 2021). Its nymphs form the so called “lerp”, a sort of shield-like conical white waxy covering, probably used by the nymphs for protection against natural enemies. A biologic control with the hemipter predator *Anthocoris nemoralis* Fabr. seems potentially the most efficient.

Black locust

Only one pest has been reported with a certain frequency on the few black locust plantations in Italy. The locust gall midge [*Obolodiplosis robiniae* (Haldeman)] induces galls in leaflet tissues after the deposition of eggs; each one contains up to four larvae. The voltinism is high, since three or four generations may occur in one vegetative season. A wasp could be used in possible biologic control studies, i.e. the parasitoid *Platygaster robiniae* Buhl & Duso.

Douglas fir

Douglas fir stands, well established in Italy for decades, are subjected to the conifer root rot *Heterobasidion annosum sensu stricto* (Fr.) Bref., whose damage, in heaviest cases, can consist of the death of several trees. Its management may be preventive, by avoiding new plantations on former crop or grassland soils, or extinctive, by treating stumps, just after cutting, with a suspension of *Phlebiopsis gigantea* (Fr.) Jülich spores, a saprobic competitor. Both introduced pathogens, the ascomycete *Rhabdocline pseudotsugae* Syd. (inducing the Rhabdocline needle cast) and *Phaeocryptopus gaeumannii* (T. Rohde) Petr. (inducing the Swiss needle cast) are responsible for defoliations in high moisture locations.

Among diseases of possible introduction, we mention here for subsequent monitoring: the black stain root disease by *Ophiostoma wageneri* (Goheen & F.W. Cobb) T.C. Harr; the laminated root and butt rot by *Phellinus weirii* (Murrill) Gilb.; the sudden oak death by *Phytophthora ramorum* Werres, De Cock & Man in ’t Veld; and the red band needle blight by *Mycosphaerella pini* E. Rostrup. Among angiosperm parasites, attention must be paid to the introduction of Douglas-fir dwarf mistletoe (*Arceuthobium douglasii* Engelmann).

Monterey pine

Caliciopsis canker, induced by the ascomycete *Caliciopsis pinea* Peck, is at present the most incident disease in Monterey pine plantations. Once described as a secondary pine pathogen, *C. pinea* has been associated with severe damage actually in Italy, causing sharply delimited cankers on trunks and branches, crown wilting, defoliation and a profuse resin production. Damping-off by *Fusarium circinatum* Nirenberg and O’Donnell could become incident as in Spain, if an efficient seed treatment is not adopted, since the parasite can be transmitted by infected seeds; a biologic management can be obtained recurring to antagonist *Trichoderma* spp. or biofumigation.

4.Production systems for the bioeconomy

(a) Nursery

In the last four years at CREA Research Centre for Forestry and Wood, in Casale Monferrato, the activity concerning poplar propagation and nursery techniques continued based on vegetative reproduction (cuttings) with adapting the conventional practices (irrigation, fertilization and pruning) to the new poplar clones, especially for those with greater environmental sustainability (MSA), characterized by fast rooting and growth and big branches. Italian Poplar Nurseries maintain more or less the same cultivation methods with a higher water input to face the climatic changes effects. Alongside the more traditional clones (‘I-214’), many nurseries have also increased the cultivation of MSA clones which have recorded a slight increase in demand from poplar growers. The main product coming out of poplar nurseries remains the two-year-old poplar pole (without branches and roots) most in demand as it has a better shape and correctly performed pruning.

Given the growing interest in Douglas fir, Italian nursery production is currently recording a greater increase. From the last survey carried out by Martini et al, 2022, the average production of seedlings at public nurseries was approximately 25.666 seedlings in the year 2019, of which 14% bare root and 86% in containers.

(b) Planted Forests

Italian poplar cultivation has long contributed to the development of a qualified wood production chain that is economically significant for our Country. Despite some periods of decline in terms of cultivated area, the adoption of appropriate cultivation models and the selection of clonal varieties well adapted to the different cultivation environments, however, guaranteed the availability of woody material. The increase in demand for industrial materials, combined with an increase in prices, has led to a renewed interest in poplar cultivation and a significant increase in cultivated areas. Thanks to the subsidies of the Rural Development Plans and the reduction of cultivation interventions, the MSA poplar clones, in particular 'Tucano' and 'Diva' were the protagonists of the new plantings, together with 'I-214.’

Density of about 280 plants or less per hectare are used to produce logs of higher quality for plywood panel production. Cultivation is widely spread in North Italy in the Po valley. Recent Studies modeled both the possibility of cultivation in other areas of peninsula (particularly in Toscana and Lazio) and the future development of poplar stands based on the possible environmental effects of climate change and based on the new MSA characteristics; these latest results show a possible reduction in the North Italy, due to the progress of the drought but a possible new area available due to climatic changes. (Marchi et al.,2022; Corona et al., 2024)
For new clones capable of growing a lot, a new pruning method is needed, also suitable for industrial requests for increasingly higher quality wood. In some areas, intensive pruning developed by some nurserymen in association with industrialists is currently being applied but there are no ongoing experiments on the physiological and technological effects of this pruning. Regarding irrigation, some farmers started to improve underground drip irrigation that allow water optimization and very high yields. This method is expensive, but the same tubes plant can be utilized for two cycles, reducing costs. (Paris et al., 2018). The nitrogen fertilization remains widely applied both in nurseries and in poplar stands even if effects and the results are often contradictory, as widely reported in the literature. Recent studies have shown that the costs of nitrogen input are often not offset by the gain in production. Furthermore, the reduction of fertilization is among the carbon farming practices that could have the greatest effect on reducing direct and indirect emissions in agriculture. (Bergante et al., 2023).
Considering other models, densities of 1000÷1300 plants per hectare have the potential to produce larger assortments suitable not only for energy but also to produce logs for paper or OSB panel or saw products. This model provides to harvest after five years, requests more or less the same equipment used for traditional poplar cultivation and it has become the model currently most in use for others products, while in recent years the production of energy chips has returned to depend mainly on branches residuated from harvests, pruning waste, failed plants and forestry management.
Research activities on higher density for particle board or energy have been supported by ministerial or regional funding with the goal to obtain technical and economic information, to increase timber production per hectare and to achieve the objectives defined in the national strategy for rural development.
Recently at the CREA Research Centre for Foresty and Wood have been selected 8 *P. ×canadensis* clones of which two ('Imola' and 'Orion') to be used in the energy sector and for the production of particle board, and six ('Aleramo', 'Diva', 'Moleto', 'Moncalvo', 'Mombello' and 'Tucano') for the production of veneers for plywood panels. All these clones are included in the official list of clones with greater environmental sustainability (MSA). The adoption of cultivation models based on the use of these MSA poplar clones, as envisaged by the Rural Development Plans, allowed the objectives set out in the EU Reg 1305/2013, providing poplar growers with numerous productive, economic and environmental benefits. The choice of plantation density influences tree growth, time of cultural inputs, rotation length, wood quality and, finally, yields and economic income.
In Italy, typical SRC energy crop are now established with a density of 5500-8500 trees ha-1 with a 2 year rotation length, thus producing a "low price" woody material suitable only for energy purposes.
SRC plantations established with densities of 1100-1670 trees per ha and grown with a 5-year rotation length other more profitable destinations (i.e. packaging, OSB panel and pulp industries) so widening the market for the woody material derived from the crop. Short rotation coppice (SRC)

trials comparing very high-density model (vHDM - 8’333 trees ha-1 with 2-year rotation), and high-density model (HDM - 1’667 trees ha-1 with 5-year rotation).
Western Po Valley. Plant survival, stem diameter and number of living shoots per tree/stump were measured to evaluate biomass yield and re-sprouting ability. After 6 years from planting, the two treatments did not show significant differences in terms of cumulative biomass yield, while poplar was the most productive species at Casale Monferrato (64.65 and 63.76 Mg ha-1 with HDM and vHDM respectively) and its production potential was confirmed at Cavallermaggiore (105.83 and 57.22 Mg ha-1 with HDM and vHDM, respectively). Black locust showed the lower yield at both sites. Willow exhibited the highest resprouting ability at both sites and with both density models. In HDM plots poplar exhibited the highest stem diameter at both experimental sites, reaching mean values of 15.0 and 17.8 cm at Casale Monferrato and Cavallermaggiore, respectively; the lowest diametrical growth was observed with black locust at Casale Monferrato (7.3 cm) and willow at Cavallermaggiore (10.0 cm). In HDM plots, poplar was the only species capable to reach stem dimensions compatible with industrial destinations at the end of the first 5-year rotation. However, from the second rotation onwards HDM will produce predictably only wood for energy or particle boards unless sprouts emerging after cutting are properly thinned recovering a single-stem structure.

Even if some new selected poplar clones are more productive and resistant, able to grown with lower inputs in a more sustainable cultivation models, the poplar still remains very closely related to water availability. With the SUSCACE project, funded by MiPAAF, it was possible to establish a Short Rotation Crop (SRC) with poplar hybrid clone ‘Imola’, to study the impact of cultural inputs (fertilization and irrigation) and of climatic factors in Northern Italy. The plantation density was 1111 trees ha-1 with harvest at the end of 5th year; the experimental design was a split-plot: irrigation effects were estimated using the whole plots while fertilization and the interaction effects were estimated using the sub plots. The effect of irrigation has been positive in all years. The model highlighted the summer (June-August) as key season for the irrigation of trees while the combination between irrigation and fertilization was significant in the second half of the growing season (late Summer). At the end of the cycle the average yield was of 58,9 Odt ha-1; with a mean of 34.3 Odt ha-1 for the control, 39.4 Odt ha-1 for the fertilized plots, 76 t ha-1 Odt ha-1 for irrigated and fertilized plots and 86 t ha-1 Odt ha-1 for only irrigated plots.

In Italy the first Douglas fir plantations were created by planting approximately 3.000 plants per hectare, following the silvicultural model criterion of clear cutting and postponed artificial renewal, as generally used for silver fir. Considering the growth vigor of this species, subsequently less dense plantings were adapted (3 x 3 m), but maintaining the replanting after the clear cut, using the seedlings in containers or with bare roots.

Recent research has highlighted how in Italy the Douglas fir renews itself easily both in full light and under partial shade, so much so that, to suggest to manage the Douglas fir stands with silvicultural treatments oriented towards natural regeneration such as striped clear cuts, oriented towards the winds dominant to favor dissemination and with a width approximately equal to the height of the plants of the neighboring populations (about 40 m), interspersed with mature populations (45 - 50 years). Alternatively, good results are also obtained, managing the Douglas fir stands with small clear cuts of dimensions from 500 to 1000 m^2, as testify to nuclei of natural restructuring following localized collapses. Douglas fir stands can be treated also, with shelterwood cutting to obtain, through natural regeneration, stands that tend to be of the same age. In order to obtain irregular high forests, a treatment can be applied according to a selection tree system, for both mixed and pure stands.

If the forester wants to obtain the renewal of the stand naturally, he must keep in mind some fundamental points: generally, in even-aged woods, natural regeneration is favored by the N-E aspect which favors a better water balance, light and deep soils, a rainfall of at least 800 – 1,000 mm/year and well distributed. Late frosts can determine significant damage to the renewal, while the young seedlings seem to resist well to hot and dry years typical of the Mediterranean environment. The opening of too small areas does not facilitate the establishment of renewal, but of weed species. Excessive cover also limits the establishment of Douglas fir natural regeneration.

(c) Naturally regenerating forest

Different planting projects were developed along the Piedmont banks of Po River, adapted to the previous situation of each natural area where the activities were implemented. The white poplar (*Populus alba* L.) was introduced using natural genotypes maintained in nurseries and catalogued in the vegetal archives of the experimental CREA-FL 'Mezzi' farm; regarding the black poplar (*Populus nigra* L.), over 136 different clones, 35 of which belonging to the experimental clonal mixture named 'POBIA'. 'POBIA' is a group of 35 P. nigra clones coming from different Regions of Central and Northern Italy; they are 22 males and 13 females selected for rooting ability, fast growth and rusticity. The other native trees and shrubs species, provided by the regional nursery of Piedmont Region, have been introduced in the planting layout of establishments. In autumn 2021 a survey was carried out to identify all the trees alive, poplars (black and white poplars) and other species, to evaluate the current situation in non-managed natural stands and measure the diameter at breast height (Dbh) and total height (h) to estimate the aboveground volume (V) of all the species. With the aim to estimate the CO2 seized by the trees the total wood dry matter weight was calculated considering the wood density value and using an average value for each species obtained from literature (Giordano 1951). The wood density was multiplied for the volume to obtain dry matter. The carbon content in wood dry matter is internationally estimated in 50% (IPCC 2006). All the estimations were reported to 1 hectare of area reforested; the estimations of growth and carbon sequestration ability of poplar were compared to other species, and those of 'POBIA' mixture were compared to those of non-POBIA clones. High survival ability and fast growth simultaneously ensure the success of the plants and as demonstrated, improve the carbon sink capacity making these establishments doubly interesting from the point of view of ecosystem services. The 'POBIA' mixture of male and female clones showed a significant higher C sink performance in three of four trials, compared to non-POBIA clones average. The best performance has achieved 278.6 t ha-1 of CO_2 seized in 13 years. The pioneer ability of poplar, furthermore, is slowly favouring the reintegration of other tree and shrub species, towards a renaturalization of the area; at the same time, by providing shelter and new ecological niches in previously abandoned lands, for insects, birds, and mammals, it favours an increase in biodiversity (Rotach 2003). The poplar trees, after 13 years, are starting to die and settle towards a lower level of presence compared to the original planting. We also found some differences between sites probably due a high spatial variability of soil conditions. The poplar species (*P. nigra* and *P. alba*) clearly distinguished themselves in terms of fast growth compared to other species. Considering the C sink per m^2 of establishment in our trials, the poplars, while covering more or less the same surface on other species, during the first decade seized about the 90% al the whole CO_2 seized by the whole plantations. In our estimation we considered the C seized in aboveground and belowground wood but, due to lack of data, we were unable to consider another important pool influenced by tree planting: the soil. The presence of roots and root turnover, the litter, and the microclimate generated by the presence of foliage positively influence the activity of the soil linked to the accumulation of (Thomas et al. 2018). The process is generally very slow, influenced by many factors and quickly reversible in the event of deforestation due to anthropic or natural events. Soil protection and improvement represent a further ecosystem service (Zalesny et al. 2015). Furthermore, the European Community wants to quantify this accumulation capacity (Lal et al. 2015).

(d) Agroforestry and Trees Outside Forests

In the last 4 years there has been a strong increase in research activity on agroforestry systems with poplar and other fast-growing species (robinia, paulownia) and valuable tree species (walnut), with numerous international and national research projects. The study of innovative agroforestry systems concerns both practices of intercropping trees with agricultural crops (silvoarable cultivation models) and practices of intercropping with pasture and grazing animals (silvopastoral models). Hybrid poplar clones are the most frequent tree component, due to the wide commercial availability of selected and registered clones, their rapid growth, the relative crown lightness which limits the shading of the underlying crops, as well as the existence of a sufficiently structured and widespread poplar wood supply chain and market across the national territory.

For silvoarable models, research is underway both on the management of poplar for the production of logs for the plywood industry and for the production of biomass, such as wood chips for bioenergy or panels. In the first case, the poplar rotations last approximately 10 years, with low planting densities of 30-60 trees per hectare and tree rows spaced 35-40 m apart. In the second case, the cutting cycle lasts 3-5 years, with tree coppicing and mechanical harvesting, and the rows of short rotation poplar are spaced approximately 6 m apart. The aforementioned research activities are all conducted on alluvial flat land, suitable for both poplar cultivation and the main profitable industrial extensive arable crops (wheat, corn, soybean, sorghum).

Industrial poplar silvoarable systems for plywood are studied in northern Italy, in the Venetian-Po Valley, with 2 experimental areas (municipalities of Ceregnano and Masi) by VenetoAgricoltura, the University of Padua and the CNR IRET Porano, as well in central Italy, in coastal plain of northern Tuscany, from the University of Pisa. The data from Ceregnano site were published by Piotto (et al 2023-24), for the first 4 years of the poplar rotation. The data shows the following main advantages for this crop model for the benefit of poplar trees: i) superior trunk dimetric growth; delayed leaf phenology; lower incidence of diseases; greater tree stability. On the contrary, the following disadvantages are observed: ovalization of the cross section of the stem; more complex management of pruning, and longer times for removing pruning and trunks at the end of the rotation cycle. In the first half of the poplar trees rotation, the effect of poplar shading on associated crops is reduced. Research conducted in Masi, on the older silvoarable plantation, established in 2013, indicates an average reduction in the production of associated crops of approximately 20% in the second half of the poplar rotation (Paris, unpublished data).

For silvoarable systems with poplar under coppice management, there are 2 research areas, both in central Italy, in Pisa and Rome. Research at the University of Pisa is at an advanced stage and has given rise to the publication of Mantino (et al, 2023). The effect of the presence of rows of coppiced poplars on the qualitative and quantitative production of associated crops was studied on sorghum, soya and corn. For the latter, two grain hybrids were studied, FAO classes 500 and 300 respectively. The results for the year 2023 revealed significant differences in grain production between the compared systems: agroforestry and control (without shading). The results show a 21% reduction in yield for the Class 300 and 12% for the Class 500, with an average yield of 7.2 Mg ha-1 of grain. This suggests that, under the specific conditions of the study site, the introduction of poplar rows into the maize cropping system can significantly influence the yield of the intercrop. In perspective, this has negative effects on the profitability of the intercropping system. To overcome this, it is suggested to widen the distance of the coppiced poplar rows, to select crops varieties tolerant to the tree shade, and to have support measures within the Common Agricultural Policy for the poplar agroforestry systems for their environmental ecosystem benefits (eg. Carbon sequestration, biodiversity, interception of leached nitrogen). Similar research on coppiced poplar agroforestry systems has been recently initiated by CREA, Monterotondo, in the Tiber floodplain, near Rome. The Agroforestry experimental field was created from the thinning of a 12-year-old Medium Rotation Forestry (MRF) poplar planation coppiced in 2021 and thinned in 2022 with a distance between the poplar rows of 6 meters. The objective of the experiment is to evaluate the effects of the agroforestry system on the mechanical operations of the various cultivation phases of Safflower (Carthamus tinctorius L.), and Crambe (Crambe abyssinica) grown in the coppiced trees inter-rows.

Research on poplar silvopastoral systems are carried out in Veneto and Tuscany, respectively by Veneto Agricoltura and the University of Pisa. The first research concerns the semi-wild breeding of pigs. The presence of trees is necessary to improve the welfare conditions of the animals, through summer shading and the reduction of windiness on the ground in the cold season. Another positive action of trees concerns the constant absorption of part of the nutrients released by the excrement, reducing in particular the risk of nitrogen leaching. In the experimental tests conducted for over ten years by Veneto Agricoltura, some solutions for the semi-wild agroforestry breeding of pigs (commercial hybrids for high quality products) were evaluated. Mainly poplars (commercial clones) were used, and to a more limited extent willows (Salix spp.) and Robinia (Robinia pseudoacacia). The poplar trees are well suitable to various agroforestry planting solutions for breeding: linear plantings along the field hedges (150-230 plants/ha), or for more sparse plantings with poplars distributed across the pastureland (90-130 plants/ha) or with very dense plantings (2500-3000 plants/ha). In the first years of planting, to limit damage to pigs (mainly debarking, etc.), the plants must be protected with a suitable shelter. In the first two cases, at the end of the poplar commercial cycle (10-12 years) the plants are cut down and sold; in dense plantations, repeated cutting must be done, on average every 3-4 years, and the wood is intended for the production of wood chips (Chirabaglio et al., 2023).

At the University of Pisa, research is underway on the use of poplar branch in the summer ration of lactating sheep, comparing a control ration with alfalfa and a ration with poplar branch. The quality and quantity of milk and the ingestion of dry matter were not significantly different between the treated group and the control sheep groups, indicating that poplar branches represent a valid fodder protein source replacing alfalfa and strengthening the role of silvopastoral systems in adapting to climate change.

On walnut in agroforestry systems, the preprint by Paris (et al., preprint 2023-24) is worth mentioning, with data from 20 years of research on common walnut trees (Juglans regia) associated with various crops (wheat, alfalfa, clover), with or without mulching at tree planting, and with data on the possible option of the dual use of walnut trees, both for veneer logs and for the production of walnut fruit, which are severely lacking on the national market. The cultivation of walnut in agroforestry systems for the triple production of associated herbaceous crops, for valuable wood and nut fruit, has been a constant feature of Italian agriculture for millennia, which perhaps requires a significant relaunch with a view to sustainable agriculture, for reducing the dramatic import of valuable timber from countries chronically affected by deforestation, and for mitigating climate change via massive tree planting, even on agricultural land.

Report on the application of new knowledge, technologies and techniques in:

(a) Harvesting of poplars, willows and other fast-growing trees

Poplar and timber harvesting can be organized according to different methods, with various level of mechanization. The traditional method, which most companies adopted until a few years ago, involves the use of a suite of multipurpose agricultural machinery with specialized equipment (hydraulic crane, claw, etc.). Felling can be done 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 is increasingly adopted. 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 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. 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.

(b) Processing and utilization of poplars, willows and other fast-growing trees for various wood products.

In Italy, annual uses from specialized poplar cultivation amount to about 1 million cubic meters for the production of veneer / plywood for 60%, pulpwood for 20% and wood chips / fuelwood for 20%. The use of poplar wood reaches 46% in plywood production, 12% in woodpulp, 12% in sawnwood, 9% particelboard, 21% in fuelwood. Poplar plantation of the Mediterranean area in Italy takes places, in relation to pedoclimatic characteristics of the station and planting distance, normally between 9 and 12 years, when the plants have a weight of about 0.6-0.7 t. In central and southern Italy, however, cases in which the harvesting is prolonged beyond 15 years are quite frequent, with average weights per plant exceeding one ton.

The main assortment deriving from the stem is represented by logs (50-60% if the plant has been pruned properly), with a minimum diameter of 20 cm (18?) to be used for production of plywood, while the remaining part of the round wood (diameter less than 18-20 cm) is used for packaging or for the production of chipboard panels and wood chips for energy purposes from top and branches. A large industrial group has recently established in Italy an OSB (Oriented Strand Board) production line; it is the first one of this kind in Italy and the first expressly set up to use only poplar wood.

A research project carried on at the University of Turin and was aimed at developing, testing and manufacturing wood-based products for acoustic improvement. The project studied and tested innovative products such as perforated panels and frames and round and cubic bass traps mainly produced with poplar plywood, also using round wood from the selection of new clones. The more interesting schemes were then realized and tested on panels in their final dimensions, which were installed in a dining hall. Finally, their sound-absorption properties were determined using the reverberation room method.

A second research project focused on poplar was concerning the use of high temperature to perform a wood-modifying treatment. ThermoPoplarPly was a project on process and product innovation, as it planned to apply the vacuum-heat treatment on a wood species (poplar) and its assortments (veneer, plywood and logs) not yet considered for the application of such treatment. In particular the project was aimed primarily at the pre-competitive development and performance characterization of new poplar plywood panels treated by thermo-vacuum technology; the main objective was to make them suitable for use in external environment or in situations subjected to risk of biodegradation, as those characterizing some sectors (outdoor furniture, marine, transport), currently precluded for traditional panels (i.e. untreated poplar plywood).

New MSA clones are characterized by higher wood density; this is leading to greater interest in applications with engineered products for construction (X-lam, multilam).

Douglas fir produces durable wood with excellent mechanical characteristics, easily workable and suitable for both indoor and outdoor uses. The properties of Douglas fir wood make it usable for various uses and is highly appreciated by operators of first and second transformations. The Douglas fir trunks can be used both for peeling for the production of plywood panels and for the production of beams (worked with four wires or Uso Fiume or Uso Trieste) while the sawn wood of finer thickness can be used in carpentry for the production of fixtures and furniture, for packaging, but also for the production of laminated beams and board panels. Recently, several

Italian companies have focused on these latter uses, obtaining excellent results from both a technical and commercial point of view.

(c) Processing and utilization of poplars, willows and other fast-growing trees as a renewable source of energy "bioenergy").

In Italy the uses coming from short rotation coppice (SRC) for fuelwood amount to about 70 thousand cubic meters. Poplar SRC utilization from the Mediterranean area in Italy were compared in the province of Viterbo (VT), Rome (RM) and Campobasso (CB), using AF2 (2 years of stem and 2 years of roots, for VT and CB) and AF2, AF6, Monviso clones (3 years of stem and 6 years of roots, for RM). The integral biomass harvesting operation was carried out using a modified forage harvester of high power, flanked by two tractors with trailers.

The most productive site was RM, with harvest of 42.54 t h^{-1} compared to 27.6 in VT and 17.96 in CB. This was justified by the considerable amount of biomass per hectare of RM compared to the other two sites. The better result obtained by VT compared to CB, is explained by greater experience of the operators even though the biomass per unit of surface was lower (18 t ha^{-1} for VT vs. 22.9 t ha^{-1} for CB and the less powerful machine). In terms of harvested area per unit of time, VT was the most efficient site with 1.54 ha h^{-1} compared to 0.79 ha h^{-1} of CB and 0.51 ha h^{-1} of RM. This result is supported by the operational harvesting speed obtained in the VT site (6.82 km h^{-1}) which was more than triple compared to the RM site (2.06 km h^{-1}) and almost double compared to the CB site (3.71 km h^{-1}). The cost per unit of surface area is higher in the RM site (888.14 € ha^{-1}), followed by CB (531.29 € ha^{-1}) and VT (327.33 € ha^{-1}). About the average time of harvesting per ton, the highest value was recorded in the CB site (2.84 min t^{-1}), the intermediate one in VT (1.95 min t^{-1}), while the lowest at the RM work site (1.25 min t^{-1}). This is explained by the type of plantation harvested in RM (3 years of stem and 6 years of roots) and the machine, by cutting the stump and collecting more suckers, necessarily decreased the speed of progress; at the same time, the harvested biomass was definitely higher (stump weight of 13 kg vs. an average weight of 4.1 kg and 3.3 kg for the CB and VT sites). This gives a positive indication of a possible extension of the production cycle, from two years to three years.

The biomass increases per surface area and per year, at least in the case under consideration, actually increases considerably (27.8 t ha^{-1} yr^{-1} in the three-year cycle of RM vs. 11.4 and 9 t ha^{-1} yr^{-1} respectively in the biennial cycle of CB and VT) and the modified forage harvester had no technical difficulty in harvesting (diameter of the stems at the base of 13-14 cm).

From the utilization of *Pinus radiata* plantations, firewood, pallets for packaging and wood chips for energy production are obtained. Traditional mechanization is used (chainsaw, tractor with forest winch) as well as harvester (delimbing and bucking of trees) and woodchipper.

In the more mature stages of the pine stands, grazing is allowed locally in fenced areas and native species (*Quercus ilex* and *Q. pubescens*) naturally start to settle under pine cover. This kind of management of the fast-growing *Monterey pine* allows to obtain multiple advantages: economic (by activating the local economy linked to the firewood and small packaging industry), environmental (progressive improvement of soil conditions and settlement of native species, bioenergy production) and social (local occupation). An indispensable requirement is the presence of an efficient fire protection system during summer month. Despite these positive aspects, that seems quite relevant for transitory forest systems managed with the aim of rehabilitation of degraded Mediterranean landscapes affected by rural abandonment, there are no direct financial or fiscal subsidies that favour new plantations.

5. Environmental and Ecosystem Services

(a) *Site and landscape improvement (bank stabilisation, combating desertification and salinization, shelterbelts and windbreaks, soil rehabilitation, urban and peri-urban forestry for climate modification etc).*

Circular Economy will play an important role in the reduction of carbon emissions and poplar might be one of the winning choices in according to Agenda 2030 for sustainable development. As for agricultural crops, high quality production is strictly related to genetic variability and best management practice.

In 2021 an evaluation of the environmental impacts of different poplar stand managements was carried out using 4 different poplar tree plantation systems located in the Padana Valley, Northwest of Italy. According to LCI ISO 14041:1999 a Life Cycle Inventory Analysis was performed for each stand management phase, with all the raw material, energy, and emissions related to cultural inputs. Different options from our databases were simulated with Simapro to test their sustainability performances. The samples' overall environmental impacts were identified, and four scenarios were considered through an LCA study “from the cradle -to -the -gate”.

Four scenarios were considered:

1. Standard poplar management is a poplar plantation with inorganic fertilization, weeds and diseases are chemically and mechanically controlled, when necessary, with tailored machinery [Mezzi standard];
2. PEFC poplar management is a poplar plantation with the same treatments for the first scenario, with a percentage of MSA clones (Corona et al. 2018) [Mezzi PEFC];
3. “Case1” is a poplar plantation fertilized with compost (0.7 t ha-1) (scenarios 1-2), plant protection with eco-friendly treatments, and tailored machinery. No irrigation was applied due to the availability of water resources [Case1];
4. “Case2” is a poplar plantation fertilized with compost (3.4 t ha-1), plant protection with eco-friendly treatments, and oversized machinery. No irrigation was applied due to the availability of water resources [Case2].

The impacts on climate change of the four models were calculated, comparing the CO2 eq. total emissions, and utilizing the IPCC 2013 GWP 100a method. Concerning compost as a substitute for inorganic fertilization, we considered the compost as avoided life cycle waste [24]. The emissions of each cultural operation were firstly calculated separately, then they have been added to get the total emissions LCA computations were carried out applying the ReCiPe methods for evaluating the water consumption, greenhouse gases emission, impacts on human health, effects on ecosystem biodiversity, and impact on primary resources. Both mid- and endpoint levels were used to acquire an overview of the environmental impacts (midpoint level) and damages (endpoint level) of the four models considered.

The PEFC standard contributes to reduce the impacts from a range between 1 to 8%. At the same time the Case1 and Case2 have a positive trend.

Concerning the impact categories Terrestrial acidification, Terrestrial ecotoxicity and Human toxicity in Case2 there is an increase due to oversized machinery and compost production. Analyzing the water consumption during a rotation of 10 years the PEFC model showed a 6% reduction due to a reduction in processing and phytosanitary treatments possible thanks to MSA poplar clones' resistance to main adversities, compared to “Mezzi” standard. Case1 and Case2 referring to farms are interesting: using organic fertilizer (compost of Urban Solid Waste mixed with pruning residues of urban green waste) with a water content of 30% helps recover water. In

Case1, 3.5 m^3 of water equivalent was saved thanks to 7 tons of compost in the first year. In Case2, where the contribution of compost was higher and equal to 26 tons (10 tons during the soil preparation phase, 8 in the second, and 8 in the third year), the water-saving was 13 m^3. The Case1 and Case2 are more environmentally friendly regarding phytosanitary treatments (pest and diseases): against woolly aphid (*Phloeomyzus passerinii* Sign.) they use mineral oil as alternative to conventional pesticides, with low impacts on ecosystem. Case2 has a higher equiva-lent water consumption than Case1 due to more powerful operating machines. The over-sizing of machinery also increased the use of fossil resources. Concerning the stratospheric ozone depletion and land use the scores showed that PECF management decreased the impact, while the use of organic soil improver increased the ozone depletion; these results are similar to and are related to compost production.

The difference between the standard model and the PEFC is equal to 6% due to fewer plant protection products, avoidance of glyphosate, and lower water consumption. The use of organic fertilizers also contributes to significantly reducing the emission of greenhouse gases: in fact, Figure 2 shows how the use of compost in Case1 allows CO_2 sequestration equal to 29 tons due to the contribution, at the first year of 7 tons of compost. In Case2, where the contribution of compost in the cultivation rotation shift is 26 tons, the sequestration is equal to 129 tons of CO_2.

The comparison with crops showed interesting results: the cultivation of corn, in 10 years to compare it with the poplar stand, produces emissions equal to 42 tons per hectare [34] against 10.5 tons of the “Mezzi” Standard management, more impactful among the considered scenarios. It means that poplar cultivation has a three times lower greenhouse gas impact index than corn.

The analysis of the effects on human health according to the ReCiPe endpoint meth-od demonstrates the greater sustainability of the PEFC model than the traditional one (8% less) due to lower use of plant protection products and avoidance of glyphosate. Moreover, Case1 and Case2 indicated virtuous stand management: the benefits of compost as alter-native fertilization and avoided waste procedure improve human health. Comparing these results against crops, the impact of poplar on human health is lower: for example, for the cultivation of tomatoes in greenhouses in Spain, the index shows 0.065 years of disability for just one year, while in the case of “Mezzi” standard cultivation, reported the same value, but for ten years of cultivation. Concerning tomato management for ten years, the impact on human health value would be ten times higher than the poplar. Also, for corn, the values (0.196 per year) are almost thirty times higher than for poplar.

Also, regarding the impact on ecosystems, expressed as the number of extinct species per year, PEFC cultivation reports values 7% lower than the traditional model and Case1 and Case2 much lower values thanks to the positive effects of the use of compost and the avoided waste treatment produce on the environment. Compared with other crops, the values are one hundred times lower than the tomato cultivation on a turn of ten years.

Regarding the consumption of resources, it should be noted that the use of compost produces a more significant impact due to the processing required for the transformation of MSW (Municipal Solid Waste) and wood chips from pruning into organic fertilizer that can be used in the field. If the PEFC model allows a reduction of the impact of 6% com-pared to the standard one, Case2 reached the same value of "Mezzi" standard: this result is due to oversized machinery that leads to greater fuel consumption; Case1, which uses of compost and eco-friendly plant protection treatment, showed a decrease of 22% compared to the standard model. However, the damage to resource availability is in each scenario lower than tomato production.

The “Mezzi” standard produced 158 m3 of poplar wood per hectare; the “Mezzi” PEFC produced 197 m3 with an increase of 24.7% compared to the traditional one with the clone ‘I- 214'. Case1

and Case2 obtained at 10-year rotation 240 m3 of poplar wood with the clone ‘I-214’. Considering that the wood density of the clone 'I-214' is 290 kg m-3 and that of the MSA clone 330 kg m-3, the “Mezzi” standard poplar plantation with clone 'I-214' alone has sequestered 84 tons of CO2 in 10 years, while PEFC models with 10% of MSA clones has sequestered 119 tons of CO2, while Case1 and Case2 sequestered 128 tons of CO2.
Soil organic carbon (SOC) is considered one of the best indicators for soil quality (Reeves, 1997) and can be used as an indicator to investigate the sustainability of the agricultural supply chain. Indeed, SOC is strictly correlated to the biological, physical and chemical soil parameters and is considered strategic in order to reduce carbon dioxide emissions as defined by the article 3.4 of the Kyoto Protocol of the United Nations Framework Convention on Climate Change (UNFCCC). The sustainable management practices applied in agriculture to reduce greenhouse gasses (GHGs) are various and show a growing scientific interest, indeed beyond fixing CO2 into the soil they activate a series of indirect advantages to the soil and the relative culture (e.g. increase of soil organic matter, water retention, erosion stabilization etc).
Despite the good productivity of the poplar production chain the cultivation is to be considered made with energy inputs that can have negative environmental impacts although these impacts are far less than those of agricultural crops (Allegro et al., 2006). For this reason, European rural development plans (RDP) financing for crops that provide for simplified cultivation techniques and at the same time researchers are moving towards improving the sustainability of the production with the introduction of agroforestry systems (Yasin et al., 2018) and sustainable cultivation techniques and certification schemes for sustainability (Corona et al., 2018).
The purpose of this analysis is to investigate and quantify the potential of poplar plantations in mitigating climate change by reducing GHG emissions, capturing CO2 from the atmosphere and storing it in wood and soil as carbon. Consequently, the SOC carbon of poplar plantations was derived from the scientific literature using the most common search sources (e.g., Scopus; web of science, etc.).
The literature search was used to construct a database collecting all European studies focused on the annual SOC carbon sequestration rate and its stock in poplar plantation soils. The stock of SOC measured in Mg carbon per hectare (Mg C ha^{-1}) was taken directly from each study when available or calculated using Equation 1 when it was not reported but present data for its calculation. The annual rate of organic carbon measured in Mg C ha^{-1} $year^{-1}$ was calculated using the following equation: SOC stock (Mg C ha^{-1}) = SOCconc x BD x Depth x (1-Rockmass) where:

- SOCconc is the organic C concentration of the fine earth (g C kg^{-1} soil), BD is the apparent soil bulk density (g soil cm^{-3}), depth is the depth of investigated soil layer (cm), and the Rockmass is the rock fragments fraction in mass percentage (mass%/100)
- $SOC\ sequestration\ rate\ (Mg\ C\ ha^{-1}\ yr^{-1})$ = (SOC final – SOC initial) / years where:
- SOC final represents the carbon stock at a certain period after the plantation establishment (Mg C ha^{-1}) while the SOC initial is the carbon stock of the previous land management before the plantation (Mg C $ha^{-1)}$, while years is the number of years after the poplar plantation establishment.

Additional variables that may influence SOC storage have also been recorded, e.g., land use prior to planting and its relative management, time since last cycle cut, soil type, age of planting (Rowe et al., 2016). Data in the literature report a soil carbon sequestration rate ranging from 0.75 to 1.75

Mg C ha^{-1} year-1 depending on climate zones, in Italy the average value is around 0.89 Mg C ha^{-1} $year^{-1}$.
The poplar plantations located in the Mediterranean north and south climate showed the highest potential in terms of SOC rate and are the unique boxplots with the interquartile range that shows only positive values. Grouping all the variables under investigation in the different climates in all Europe, land use-change, and wood array production, we observe that in 50% of the cases there is a negative impact of poplar plantations on median SOC sequestration rate with a range that goes from -1.75 Mg C $ha^{-1}yr^{-1}$ to 0 Mg C ha^{-1} yr^{-1}. The remaining 50% of the observations show a positive SOC sequestration rate with a range from 0.76 to 1.5 Mg C ha^{-1} yr^{-1}.
For the analysis of the carbon stock in wood products harvested in Italy a production accounting approach was adopted using various available databases as well as field data collected within the study region by CREA. The analysis was done breaking down the value chain into two fundamental portions:
1. From standing trees to raw material delivered to the processing facilities.
2. From raw material to raw finished product, to be employed for the various applications.
The biomass present in poplar plantations was analysed and the carbon content on a hectare basis was derived, considering the average basal density of poplar timber and the average yield per hectare based on a 10-year rotation. Then standard IPCC values were utilized for the calculation of the standing stock of C in the average Poplar plantation at the end of its 10-year rotation. Using 220 m3 ha^{-1} of wood production in about ten years, a basal density of 0.29 for the 'I-214' clone, 117.1 Mg CO2eq ha^{-1} were calculated.
Among the Ecosystem Services that poplar plantations can perform Carbon sequestration in Italy is at the moment the only one for which a voluntary market is possible. For this reason, a Life Cycle Assessment (LCA) was performed according to ISO 14040 series recommendations using software SimaPro 8.0. The environmental impact of poplar production cycle was analyzed using Ecoinvent v3 as main database for input data and the IPCC 100 (kgCO2eq) is the method applied for impact calculation.
To consider the whole cycle of poplar production, three cultivation processes were considered, characterized by different planting layout, densities and crop purpose: stoolbed with an usual density of 62500 cuttings ha^{-1}, maintained for 3 years, and every year, at the end of vegetative season, is harvested for cuttings production; nursery, with lower plantation density, 7140 trees ha^{-1}, using the cuttings obtained from stoolbed and maintained for two years with the purpose to produce two year old poplar stems as vegetal material to establish poplar stand; poplar stand with 278 trees ha^{-1} , derived from nursery, planted with square layout of 6 × 6 m and growth for 10 years for the production of wood for plywood industry. All the cultural input, products and material utilized were collected from a real experience. The clone 'Senna', a MSA clone (the acronym for Italian 'Maggior Sostenibilità Ambientale', that means 'greater environmental sustainability)' was compared with the traditional 'I-214'. The two-plantation considered for data collection reached different yields at the end of ten-year cycle. The 'I-214' stand produced 158 m^3 ha^{-1}, compared with the 'Senna' stand that reached 197 m^3 ha^{-1}, corresponding to 84 t ha^{-1} and 119 ha^{-1} of CO_2 sequestred. The GHG emissions per hectare found for the two models, calculated following the IPCC 100 method, are very similar. For the cultivation of traditional clone 'I-214' total emissions, at the end of cycle, were of 7.35 t CO_2 equivalent per hectare, and were a little greater that emissions produced for the cultivation of MSA clones, that reached 7.22 t CO_2 equivalent per hectare. The net balance is in favor of the clone 'Senna' with 111 t of CO2 compared to 76 for 'I-214' with an advantage of 46 % if referred to 'I-214'.

(b) Phyto-remediation of polluted soil and water (buffer zones, contaminated sites, waste water management/treatment etc).

The use of trees to preserve, improve or restore the structure and the functioning of soils contaminated by heavy metals represent a promising strategy (dendroremediation). In this context, fast-growing and high biomass-producing species showed interesting potentialities. The CREA Research Centre for Forestry and Wood together with the University of Turin carried out a study aimed at investigating the effects of heavy metals on 11 poplar and 8 willow clones by assessing their tolerance and phytoextraction potential and the accumulation pattern. Two-months-old sprouting-cuttings were cultivated in hydroponic system and treated with one of these salts: cadmium sulphate, lead nitrate, copper sulfate pentahydrate and zinc sulfate heptahydrate. Treatments were carried out in four replicates and untreated cuttings were included as reference. Biomass production variables were measured and phytotoxicity symptoms were assessed. At the end of the trial, the heavy metal accumulation was quantified in leaves, stems and roots. Clones were ranked and clustered based on biomass-production, phytotoxicity symptoms, pathogens and pests resistance, phytoextraction potential and accumulation pattern. Treated clones did not show substantial phytotoxic effects. However, the phytoextraction efficiency and the accumulation patterns displayed high variability depending on the heavy metal. While zinc was the most accumulated metal, cadmium, copper and lead were absorbed with lower concentrations. Although some heavy metals were more efficiently sequestered by leaves, some clones achieved good performances in the absorption at stem level. A first screening of the best scoring clones resulted in the selection of potential candidates for dendroremediation purposes, with special emphasis on clones with high accumulation of heavy metals in the woody tissues.

Sediments are various materials deposited on the bottom of water bodies or on the Earth's surface, following thermal variation, surface water circulation and sea currents. Anthropic activities, particularly agriculture and forestry can modify the natural sediment cycle, with the acceleration of the water and wind erosion, triggering landslides and other processes of soil loss. Human activities can mitigate the accumulation of sediments through reforestation, grassing and similar practices. Sediments of water bodies of anthropic areas must be regularly dredged for the correct management of ports and waterways, and also for controlling the environmental pollution in case of sediment pollution.

Among the sediment remediation technologies, phytoremediation and co-composting of sediments have proven to be effective in reducing the concentration of organic pollutants and toxicity, and induce physical, chemical and biological fertility in dredged contaminated sediments. Reclamation of large volumes of dredged sediments with low cost and low inputs has great environmental value. Sediments dredged from canals, co-composted with pruning waste of urban trees, have been used as growing media for poplar and willow clones. Their use in the nursery sector and in environmental recovery projects has the advantage of replacing the local excavated soil used, which in Europe amounts to about 5.2 million m^3/year. Results of this experience shown that the composted sediments can be as good growth media for poplars and willows as common soil used in the nursery phase, although rooting of cuttings was slower likely due caused the presence of macro-porosity due to the presence of coarse pruning residues. An interesting aspect of the sediment concerned its thermal buffering capacity due to the greater water retention and organic matter content, which mitigated the adverse effects of the particularly high temperatures.

An experiment aimed at verifying the usefulness of phytoremediation using Short Rotation Coppice (SRC) was carried out in an urban Zn-contaminated site of Turin, by University of Turin

and CREA. The city was characterized by the heavy metallurgical industry and has suffered from deindustrialization over the past three decades. As a consequence, vast areas of former industrial plants were abandoned, and a new urban planning action had to be devised. A large part of the ex-industrial areas was allocated to green infrastructures such as parks and other types of public spaces. Besides elemental uptake and reclamation, the SRC method was applied to evaluate the additional benefits of a green infrastructure. Nine different plants with rapid growth and large biomass production were selected: three Poplar clones, three Willow clones and three Robinia provenances. Annual and biennial coppicing were evaluated too. All the tested plant genotypes showed good adaptation to the particular environment. Robinia clones were demonstrated to be the most productive species in field conditions, probably due to the poor fertility of the soil, with respect to an agricultural soil, and to drought. Coppicing management modified the biomass relationships between roots, stem, and leaves. This, together with the differences in accumulation and translocation behavior of the genotypes, made evident the need, prior to a field trial, of a study to identify the management approach and suitable genotypes. Poplar clones were more productive using annual coppicing, while Salix and Robinia produced higher biomass with biennial coppicing. Poplar had the highest phytoextraction rate of Zn during the second year, with 1077 g ha^{-1}. Salix clones extracted similar quantities using biennial coppicing. After two years, the bioavailable fraction of Zn in the soil decreased significantly using all species, from the 26% decrease of Robinia to the 36% decrease of Salix. The short rotation coppice method proved to be useful in an urban context, for both landscape and limiting the access to the contaminated area. Improving the biomass yield through the phytomanagement options (fertilization, irrigation, coppicing, etc.) could make SRC phytoremediation an economic and effective solution to manage urban contaminated areas, coupling the added values of biomass production to the landscape benefits.
An added value for Douglas fir is that of being able to sequester high quantities of CO_2 with a storage speed almost double compared to other forest species, highlighting a high mitigation potential by adopting medium-long cycles. In North America, Douglas fir stands at approximately 68 years of age, with a stock of 930 m^3ha^{-1} can store 565 t C $year^{-1}$. North American tree volume tables, they are highlighted with regards to the accumulation capacity of this species, that for Douglas fir stands of 60 years of age, the net productivity of the ecosystem (NEP) is still high, setting on average 20 t/CO_2eq ha^{-1} $year^{-1}$, corresponding to total emissions of 2,8 Italian citizens (source: EUROSTAT). This species represents a great opportunity for new quality mountain arboriculture for our territories. Thanks to the multiple qualities of Douglas fir, this species can create not only stands of high economic and landscape value, but also of extraordinary efficiency in terms of carbon storage and combating the effects of climate change. Douglas fir represents a significant opportunity for the economic and environmental development of Italian mountain areas, offering quality wood, resistance to climate change and the possibility of replacing species in crisis. Its adaptability and productivity make it a valuable resource for the national forestry sector.

III. GENERAL INFORMATION

1. Administration and Operation of the National Poplar Commission or equivalent Organization

b. Indicate here any changes in the composition of the Commission, amendments to its statutes, changes of address, etc.

The National Poplar Observatory (ONP), which in Italy has been playing the role of National Commission for Poplar since 2015, had a change in the coordination structure which took place in such a way as to ensure full continuity of its activity within the Ministry of Agriculture, Food Sovereignty and Forestry (*Ministero dell'agricoltura, della sovranità alimentare e delle foreste* - MASAF). After the first three-year period (2015- 2017) of the launch of the new national structure dedicated to poplar (ONP), managed by the DISR III Office of the Rural Development General Directorate of the European International Policies Department Rural Development (DIPEISR), since 2018 the coordination of the ONP has been ensured by the DIFOR III Office of the new General Directorate Forests, established within the departmental structure of the Ministry dedicated to European and International Policies and Rural Development. In the two-year period (2018 – 2019), the new ONP coordination has ensured regular activities with at least two meetings a year and, in continuity with the previous three-year period, finalized many administrative acts (departmental decrees) that defined the tools for updating the list of poplar clones, evaluating and approving new clonal constitutions, in compliance with the rules of the National Register of Basic Materials. The ONP and its Coordination Office also ensured the participation of the General Director (DG) of the Forests as Italian Head of Delegation in the extraordinary session of the IPC held at FAO. Since 2018 the ONP activity has taken place under an extension of the deadline set by the founding decree. The last renewal procedure with confirmation or replacement of members but without any modification of the bodies represented was implemented with the Ministerial Decree of 11 november 2021, no. 0590352. The departmental decree of 02 July 2020, no. 0002356 concerns the Revision of the Composition of the Technical Experts Group (GET) of the National Poplar Observatory.

c. *Report briefly on meetings, congresses and study tours, and on other activities of a general nature organized by the Commission at the national level.*

The ONP has done an active participation in relevant forest congress areas including the National Forestry Congress. In collaboration with CREA the ONP supported events for the dissemination of poplar cultivation techniques in various regions of Northern Italy, or at the CREA Research Center in Casale Monferrato. In addition, the holding of a meeting in the Northern Italy with a study tour on MSA clones in poplar plantations.

d. *Indicate also the difficulties encountered by the Commission in the course of its work and any lessons learned*

The main difficulties encountered were those caused by the institutional changes; however, the solutions adopted, flanking the two coordination and extension for the three-year period have made it possible to ensure the smooth functioning of the ONP. In the last three years the ONP worked very well through the Technical Experts Group that has followed actively the experimental fields.

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3. Relations with other countries

Include here information also on the international exchange of cuttings and plants of poplars, willows and other fast-growing trees, training etc.

4.Innovations not included in other sections

IV. SUMMARY STATISTICS (Questionnaire)

Complete the attached questionnaire on poplars, willows and other fast-growing trees summarizing statistics of key parameters in poplars, willows and other fast-growing trees resources, production, utilization, trade and future trends.