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Performance models for poplar clonal Forest Reproductive Material and deployment guidelines

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crea Consiglio per la ricerca in agricoltura e l'analisi dell'economia agraria

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B4est

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1. SUMMARY

Specialized poplar cultivation has contributed for decades to the development of important economic and productive sectors such as those of paper, wood-based panels and furniture, by providing high-quality raw materials. The global area of specialized plantations for the production of wood for industrial uses is estimated at approximately 9.4 million hectares and annually supply over 12 million cubic meters of wood, contributing significantly to the sequestration of atmospheric carbon. In EU the poplar cultivated area is about 900,000 hectares where France Spain Hungary and Italy are the main countries.

Performance models for the production of poplar wood are considered according to cultural practices for sustainable poplar cultivation, resilient to climate change, based on the use of clones adaptable to different environmental conditions and resistant to the main biotic and abiotic stresses. For this reason, in several European countries new different poplar genotypes are under evaluation in trials with different cultivation model: conventional stand with densities ranging from 250 to 270 trees ha^{-1}, medium-density plantations (1,100 – 1,600 trees ha^{-1}) with five-year harvesting cycle (Short Rotation Coppices - SRC), and high-density plantations (up to 10,000 trees ha^{-1}) with two-year of harvesting cycle for the biomass production (very Short Rotation Coppices - vSRC). Other cultural models considered innovative also for greater resilience to climate change such as polycyclic plantations (PP) and agroforestry systems (AF) have been implemented also in order to assess their environmental, economic and productive sustainability.

Cultural practices developed in Mediterranean area such as soil preparation, pruning, weed and diseases control, fertilization and harvesting methods were described for each model as applied in the main European countries (Italy, France and Spain) for poplar cultivation and wood quality production. Performance models for plywood and biomass production and their first results with different genotypes with improved characters are described, taking into consideration possible future scenarios linked to potential climate change effects, in order to project the future availability of suitable timber for different uses from eco-friendly plantations. In this light, the availability of adequate communication and dissemination tools for this sector is important and this document represents a contribution, integrating the technical and management aspects with a modern vision of ecological and economic sustainability.

These guidelines will serve as an effective reference and support for growers, professional technicians, industrialists, public officials, researchers and policymakers, in the knowledge that the poplar value chain can represent one of the most dynamic sectors of the green economy.

2. INTRODUCTION

Specialized poplar cultivation has contributed for decades to the development of important economic and productive sectors such as those of paper, wood-based panels and furniture, by providing high-quality raw materials.

The planted poplar area is estimated worldwide at approximately 31.4 million hectares, the largest part in Canada and China, which respectively account for 69% (21.8 million hectares, managed by semi-extensive methods) and 27% (8.5 million hectares) of the total.

Poplar cultivation in EU is amount to 900,000 hectares (FAO 2016) and France is the most important country for poplar production with more than 200,000 hectares cultivated (Fig. 1). Spain and Hungary follow with values above 100,000 hectares and Italy with about 70,000 hectares of cultivated poplars. Other countries (Belgium, Serbia, Germany, Croatia, Switzerland, Sweden, Moldova, Bulgaria, United Kingdom, Slovenia) have a lower poplar cultivation area.

More than half of the areas planted with poplar are under multifunctional management (58%), while smaller areas are primarily designated for environmental protection functions (9%) and biomass production for energy use (3%).

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

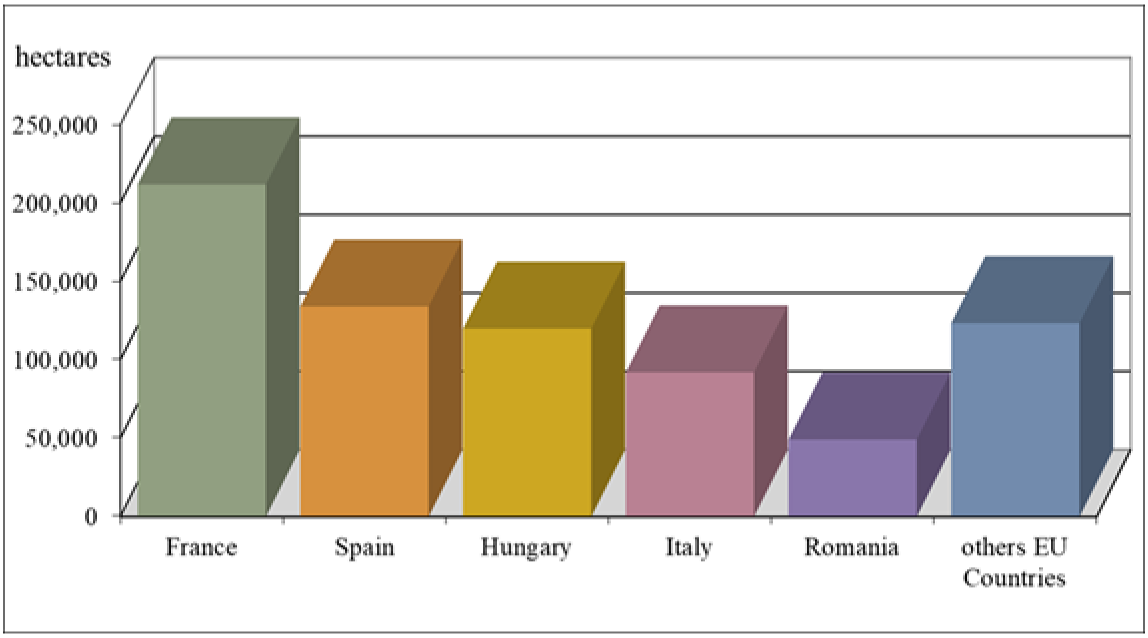


Figure 1 *– European countries with greater poplar cultivations.*

In several European countries new poplar clones of different origin and genetic are under evaluation for agronomic and productive characters (fast juvenile growth, biomass productivity, wood quality), planted with different plant density and cultivation model. Conventional stand (Fig. 2) with densities ranging from 250 to 270 trees ha^{-1}, medium- density plantations (1,100-1,600 trees ha^{-1}) with five-year harvesting cycle (Short Rotation Coppices - SRC), and high-density plantations (up to 10,000 trees ha^{-1}) with two-year of harvesting cycle for the biomass production (very Short Rotation Coppices - vSRC). These FRMs, validated in different

pedoclimatic conditions, are also subject to observation for possible future scenarios also following climate change (Bergante et al., 2020; Marchi et al., 2022).
Other cultural models considered innovative also for greater resilience to climate change such as polycyclic plantations (PP) and agroforestry systems (AF) have been implemented in order to assess their environmental, economic and productive sustainability (Bergante, 2022). Cultural practices such as soil preparation, pruning, weed control, fertilization and harvesting methods were evaluated taking into consideration possible future scenarios, in order to ensure the availability of suitable timber for different uses from eco-friendly plantations.

Figure 2 *– Specialized poplar plantations for plywood production in France.*

3. TECHNICAL GUIDELINES

The clonal choices and the technical guidelines given here refer to the cultivation practices generally adopted for poplar cultivation in Italy, with appropriate indications with respect to the differences found in other important European countries such as France and Spain.

3.1 Poplar cultivation in the Mediterranean area

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

Italian poplar cultivation is widely linked to the use of P. ×canadensis clone 'I-214' (Fig. 3), which has ideal wood characteristics for the manufacture of plywood panels (light weight, white colour) but presents challenges owing to its susceptibility to biotic threats (woolly aphid, rusts, Marssonina leaf spot). The preference of the Italian industrial sector for the quality of the wood produced by clone 'I-214' has significantly influenced the choice of FRM, limiting the dissemination of new clones and favouring widespread monoclonal plantations. On the other hand, the availability of clones offering greater environmental sustainability ("Maggiore Sostenibilità Ambientale", thus referred to as MSA clones) characterized by better resistance to the main biotic adversities, makes it possible to develop semi-extensive cultivation models that, by minimizing cultural practices and pest control, allow a more eco-sustainable poplar cultivation. The wood peeling process of these clones is similar to that of 'I-214' even if the different wood characteristics may require the industry to adapt their processing methods (for example, by separating logs of various clones in the yard and semi-finished products in the warehouse, differentiating drying regimes, etc.).

Figure 3*- Poplar plantation in Italy using 'I-214' clone.*

In other Mediterranean Countries, like Spain the situation is similar in many aspects although it differs in others. The rotation length in plantations for veneer, logs or boards production is between 12 and 15 years.

Clone ‘I-214’ continues to be the most widely planted also in Spain, although companies make great efforts to encourage the diversity of genetic material and incorporate new clones that are more tolerant to diseases and ensure higher yields. Some clones such as ‘Diva’, ‘Tucano’, ‘Aleramo’, ‘AF8’, ‘AF13’,’Raspalje’, and ‘N277’ are obtaining interesting results in several experimental poplar plantations (Fig. 4). For biomass production, rotations are between 2 and 4 years, although at present they are not carried out commercially.

Figure 4 *– Experimental plantations with new clones for veneer production in Spain.*

In France poplar growth is generally carried out between 15 and 23 years depending on the quality of the soil and the local climate, which depend on the geographical area (Fig. 5).

The varieties currently used in France are diversified to take into account the quality of the soil, the climate and the future uses of the wood. While ‘Koster’ has been the most widely planted variety for several years, many other varieties are also currently widely planted, such as ‘Tucano’, ‘Diva’, ’I45/51’, ‘Trichobel’, ‘Polargo’, ‘Vesten’, ‘Albelo’, ‘Rona’ and ‘I-214’. These 10 varieties represent 80% of the plantings in the 2019-2020 season (https://agriculture.gouv.fr/statistiques-annuelles-sur-les-ventes-de-graines-et-plants-forestiers). Poplar wood is mainly used for plywood (32%) and light wood packaging (37%) while the remaining 31% is used for sawn timber.

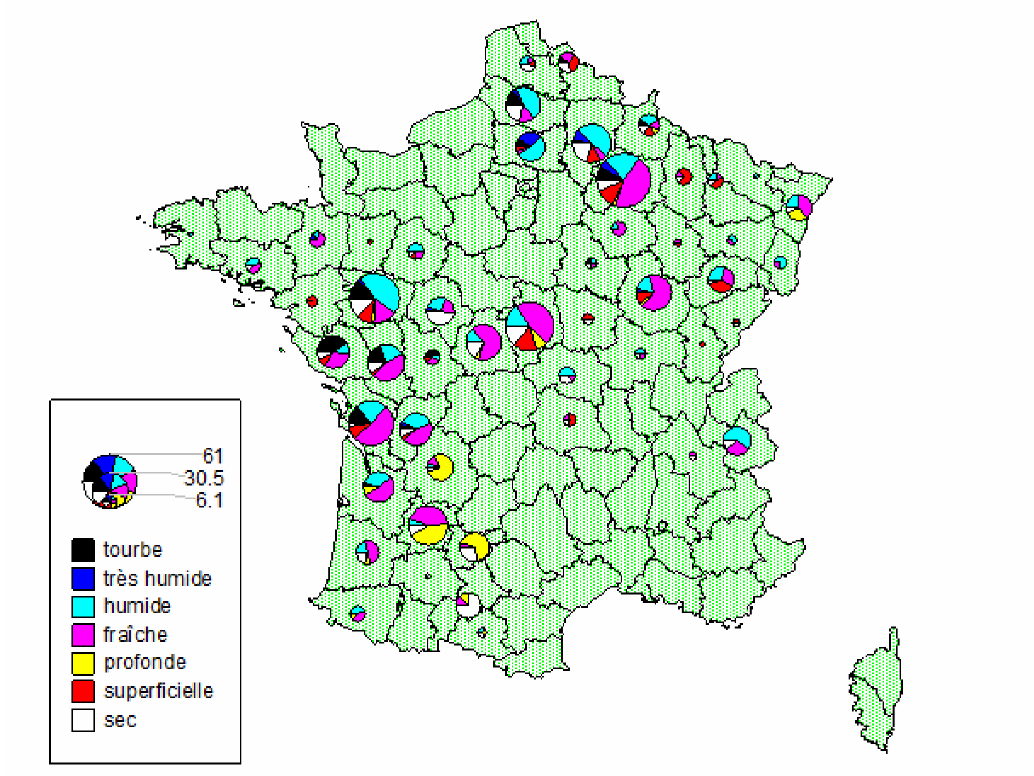


Figure 5 *- Geographical distribution on different types of soil of poplar plantations in France.*

3.2 Requisite soil and climate conditions

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

For poplar cultivation the most appropriate soils are deeper than 50 cm, permeable, with good water availability (the level of the water table is considered optimal at 100-150 cm depth), characterized by sandy-silty or sandy-clay texture, not excessively loose or heavy, with a uniform profile and a pH from subacid to moderately alkaline (Table 1). In these conditions it is possible to limit plant stresses caused by many primary pests and pathogens (including *Marssonina brunnea* and *Melampsora* spp.) and to prevent damages caused by opportunistic pests and pathogens (including Discosporium populeum, Melanophila spp., Agrilus spp.) or the appearance of disease (for example,' brown spots' physiologic disorder). As mentioned, soils with a high content of active calcium carbonate (above 10%) and saline soils are to be avoided: sodium chloride concentrations even of only one part per thousand are able to provoke phytotoxicity in most cultivated clones, especially during the phase when saplings are taking root (Frison and Facciotto, 1992).The most widely cultivated poplar species are heliophilous and hygrophilous; as a rule, they require average annual rainfall of not less than 700 mm or supplemental irrigation during the summer. Black poplar (*Populus nigra*) and white poplar (*Populus alba*) are able to withstand short periods of drought. The average annual temperature must be between 8.5 °C and 17 °C.

__Table 1__ - Soil characteristics limiting realization of specialized poplar plantations.

Soil characteristics (1)	**Degree of importance (2)**		**Importance of the limitation**		
			absent or very light (3)	**moderate (4)**	**severe (5)**
Texture (6)	***	medium to coarse	X		
		moderately fine to fine		X	
Depth available for roots (cm) (7)	**	> 50	X		
		< 50			X
Permeability (8)	***	good or moderate	X		
		imperfect		X	
		poor to very poor			X
Acidity (pH)	*	5.5 - 8.5	X		
		4.5 - 5.5		X	
		< 4.5 and > 8.5			X
Drought risk	*	absent to moderate	X		
		strong to very severe			X
Salinity (EC5 mS/cm) (9)	***	< 0.15	X		
		0.15 - 0.4		X	
		> 0.4			X
Active calcium carbonate (%)	***	< 6	X		
		6-10		X	
		> 10			X
Flood risk (frequency)	*	none to frequent	X		
Flood risk (duration)	**	< 1 month	X		
		> 1 month		X	

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

In Spain irrigation in the summer months, with temperatures ranging in the vegetative period (April-September) between 15.9 and 22.5°C and an average annual temperature of 14.4°C, is mandatory except in areas where deep root planting is practiced, which ensures contact of the tree with the water table (Castilla y León).

In France on deep soils, without an accessible water table, and with possible root exploration beyond 2 meters (good soil microporosity), it is possible to obtain very good productivity if the soil's water reserve is sufficient.

For this to happen, the winter rains must be optimal to recharge the soil with water. This type of soil is characteristic of the poplar groves in the Garonne valley and constitutes one of the best soils for poplar plantation in France. There are also, especially in the North of France, poplar groves called "out of valley". On these soils, no water table is accessible, but the local climate with regular rainfall throughout the year and especially during the vegetation period compensates for the absence of a water table. On these soils productivity is average. In France, it is also possible to produce poplars on very clayey soils (>45% clay) provided that their structure allows sufficient root exploration. The growth dynamics of poplars on these soils is then slow at the beginning and sustained thereafter. The duration of rotation is then lengthened due to the slow establishment of the stand. On the website of the Conseil National du Peuplier, 18 sheets describe 18 types of poplar soil encountered in France (https://www.peupliersdefrance.org/page/54-fiches-stations).

3.3 Choice of clones and nursery material

The choice of which poplar clones to cultivate should mostly depend on the final destination of the raw material, the soil and climate characteristics of the growing site and any environmental restrictions. Clones can be chosen from among those included in the National Registers of European Countries, with preference for those that can provide high-quality wood and are resistant or tolerant to the main biotic ad abiotic adversities. For Italian clones it is necessary to refer to the National Register of Basic Materials (“Registro Nazionale dei Materiali di Base”, RNMB), ’tested’ category.

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

Also in Spain there is a National Catalogue of Base Materials that includes those clones that have been systematically tested in the poplar coltivation areas. However, plantations can be made with any poplar included in the National Registers of other European Countries, even if their behaviour towards the main adversities of poplar grown in Spain should be considered (Table 3).

The clones mostly planted in Spain are ‘I-214’ (56%), ‘MC’ (9%), different clones of *P. ×generosa* (28%) as ‘Beaupre’, ‘Raspalje’ and ‘Unal’, and other clones of *P. ×canadensis* (7%) as ‘Triplo’, ‘Branagesi’ and ‘Aghate F’. Many experimental plantations are being carried out to evaluate the adaptability of new clonal selections in the different cultivation areas with particular regard to the most suitable areas of Castilla and Leon (Fig. 4) also in order to increase clonal diversification and therefore biodiversity.

Table 3 - *Susceptibility to pests and diseases detected in the main clones planted in Spain.*

CLONE	*Melampsora* spp.	*Marssonina brunnea* (Ell. et Ev) Magn.	*Phloeomyzus passerinii* Sign.	*Leucoma salicis* L.	*Chrysomela populi* L.	*Pharanthene tabaniformis* (Rott.)	GENETIC ORIGIN
I-214		**	**	**	**	**	*P. ×canadensis*
AGHATE F		****					*P. ×canadensis*
BEAUPRE	*	****		****	****	****	*P. ×generosa*
BRANAGESI							*P. ×canadensis*
MC							*P. ×canadensis*
RASPALJE	***	****	***	****	****	****	*P. ×generosa*
TRIPLO	****	***	*	****	****	****	*P. ×canadensis*
UNAL	**	***					*P. ×generosa*

LEGEND	*	Highly susceptible
	**	Susceptible
	***	Tolerant
	****	Resistant
		No detail information

In France, the clones used are mainly from the species *P. deltoides*, *P. trichocarpa* and *P. nigra*. They are either pure species (P. *deltoides, P. trichocarpa*) or interspecific hybrids (notably *P. ×canadensis* from the crossing of P. *deltoides* and *P. nigra*; and *P. ×generosa* from the crossing of *P. deltoides* and P. *trichocarpa*).

Black poplars (P. *nigra*) are available in the form of clonal mixtures representative of the genetic diversity observed in the major national water basins. They are the subject of a specific use advice sheet.

The clones, that can be used in French conditions suitable for poplar growth, are registered in the National Register of Basic Forest Materials; all clones are accepted in the 'Tested' category and some of them can be used for biomass purposes. In addition to the National Register, a regionalised list of clones (Table 4) eligible for state aid is published by the Ministry of Agriculture, Agri-Food and Forestry, after consultation with a group of national experts.

__Table 4__ - Poplar clones recommended for cultivation in different territories of France

RECOMMENDED POPLAR CLONES	South-East			South-West		North-West					North	Noth-East	
	Auvergne-Rhône-Alpes	PACA	Corse	Occitanie	Nouvelle Aquitaine	Pays-de-la-Loire	Bretagne	Normandie	Centre-Val-de-Loire	Île de France	Hauts-de-France	Grand-Est	Bourgone-Franche-Compté
Populus euramericana													
ALBELO	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible
ALERAMO	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Not eligible	Not eligible	Eligible	Not eligible	Not eligible	Not eligible	Not eligible
BLAC DI POITOU	Eligible	Not eligible	Not eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible
BRENTA	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible
DANO	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible
DIVA	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible
DORSKAMP	Eligible	Eligible	Not eligible	Not eligible	Not eligible	Not eligible	Eligible	Eligible	Not eligible	Eligible	Not eligible	Eligible	Eligible
FLEVO	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible
GARO	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible
KOSTER	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible
I-45/51	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Not eligible	Not eligible	Eligible
LAMBRO	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Not eligible	Not eligible	Not eligible	Not eligible	Not eligible	Not eligible	Not eligible
LUDO	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible
MOLETO	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible
MONCALVO	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible
MUUR	Not eligible	Not eligible	Not eligible	Not eligible	Not eligible	Not eligible	Not eligible	Not eligible	Not eligible	Not eligible	Eligible	Eligible	Eligible
OUDENBERG	Not eligible	Not eligible	Not eligible	Not eligible	Not eligible	Not eligible	Not eligible	Not eligible	Not eligible	Not eligible	Eligible	Eligible	Eligible
POLARGO	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible
RONA	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible
SOLIGO	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible
TARO	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible
TUCANO	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible
VESTEN	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible
Populus interamericana													
RASPALJE	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Not eligible	Not eligible
Populus trichocarpa													
FRITZI-PAULEY	Eligible	Not eligible	Not eligible	Not eligible	Eligible	Not eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible
TRICHOBEL	Eligible	Not eligible	Not eligible	Not eligible	Eligible	Not eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible
Populus deltoides													
ALCINDE	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Not eligible	Not eligible	Eligible	Not eligible	Not eligible	Not eligible	Eligible
DELGAS	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Not eligible	Not eligible	Eligible	Eligible	Not eligible	Not eligible	Eligible
DELLINOIS	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Not eligible	Not eligible	Eligible	Eligible	Not eligible	Not eligible	Eligible
DELVIGNAC	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Not eligible	Not eligible	Eligible	Eligible	Not eligible	Not eligible	Eligible
DVINA	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Not eligible	Not eligible	Eligible	Not eligible	Not eligible	Not eligible	Eligible
LENA	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Not eligible	Not eligible	Eligible	Not eligible	Not eligible	Not eligible	Eligible
OGLIO	Eligible	Eligible	Eligible	Eligible	Eligible	Eligible	Not eligible	Not eligible	Eligible	Eligible	Not eligible	Not eligible	Eligible
hybrids *trichocarpa* x *maximowiczii*													
BAKAN	Not eligible	Not eligible	Not eligible	Not eligible	Not eligible	Not eligible	Eligible	Eligible	Not eligible	Eligible	Eligible	Eligible	Eligible
SKADO	Not eligible	Not eligible	Not eligible	Not eligible	Not eligible	Not eligible	Eligible	Eligible	Not eligible	Eligible	Eligible	Eligible	Eligible

Eligible

Not eligible

This list directs the beneficiaries, depending on the region, towards the clones offering the best guarantees. This list is updated every two years to take into account changes in the sanitary context and the appearance of new clones on the market with the aim of improving production performance, meeting the expectations of the wood industry and diversifying the product range (Source: French Ministry of Agriculture advice sheet on cultivated poplars, (https://agriculture.gouv.fr/graines-et-plants-forestiers-conseils-dutilisation-des-provenances et-varietes-forestieres).

In Italy, following the results obtained in experimental plantations, a list of MSA clones, characterized by resistance to woolly aphid (*Phloeomyzus passerinii*) and high tolerance to the main fungal leaf diseases is also available (Table 5).

Table 5 - *Main characteristics of MSA poplar clones compared with clone 'I-214'*

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

LEGEND

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

These clones (Fig. 7) were selected for resistance to Marssonina leaf spot (*Marssonina brunnea*), spring leaf and shoot blight (*Venturia populina*) and leaf rusts (*Melampsora* spp.). They don't require the application of phytosanitary products with the exception of the control of wood insects, only for the first years after planting. For this reason, they allow to pursue the objectives of greater environmental sustainability and containment of cultivation costs through the reduced number of phytosanitary defense treatments.

Figure 7 *– Poplar clones selected in Italy for resistance to woolly aphid and leaf diseases.*

About the quality of FRM, only one or two-year-old stems, certified in nursery is permitted in the establishment of new poplar plantations. The young plants must be lignified, well hydrated (Fig. 8) correct in shape and free from pests and lesions (Table 6).

Table 6 - Defects preventing young poplar plants from being classed as of fair marketable quality pursuant to European Directive 71/161/EEC.

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

Figure 8 *- Two-year-old poplar stems in the hydration phase before planting.*

In France, a large network of poplar variety experiments conducted by the CNPF-IDF has been studying the growth behaviour of a large number of varieties (more than a hundred) for 40 years, depending on the soils, their geographical location (climate) and the forestry model applied (Figure 9 and 10). In 2021, more than 500 systems are being monitored throughout France. In Table 7 it is represented a synthetic results obtained from these experimental devices and information available on vulnerability to biotic risks.

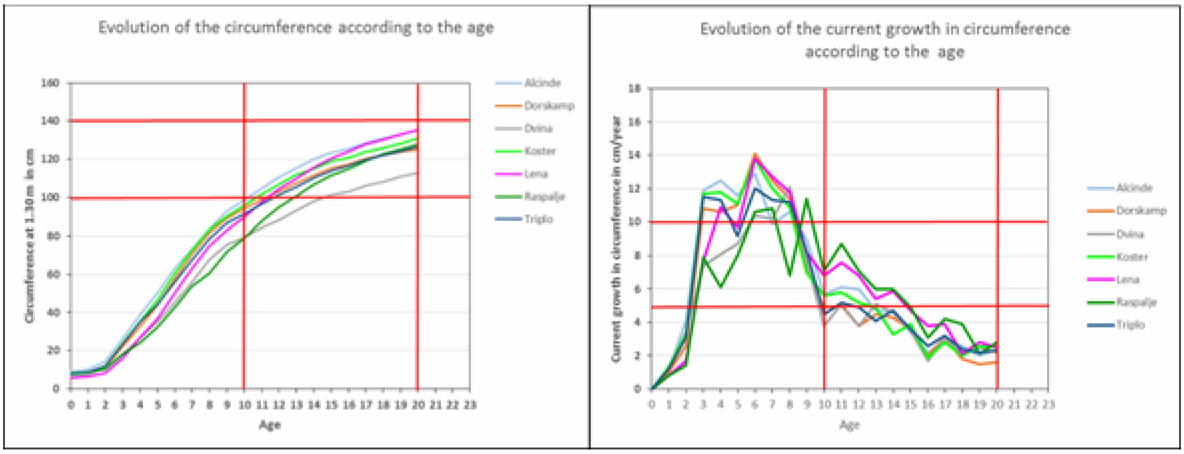


Figure 9 *- Growth (in circumference, cm) of seven different poplar clones compared in France.*

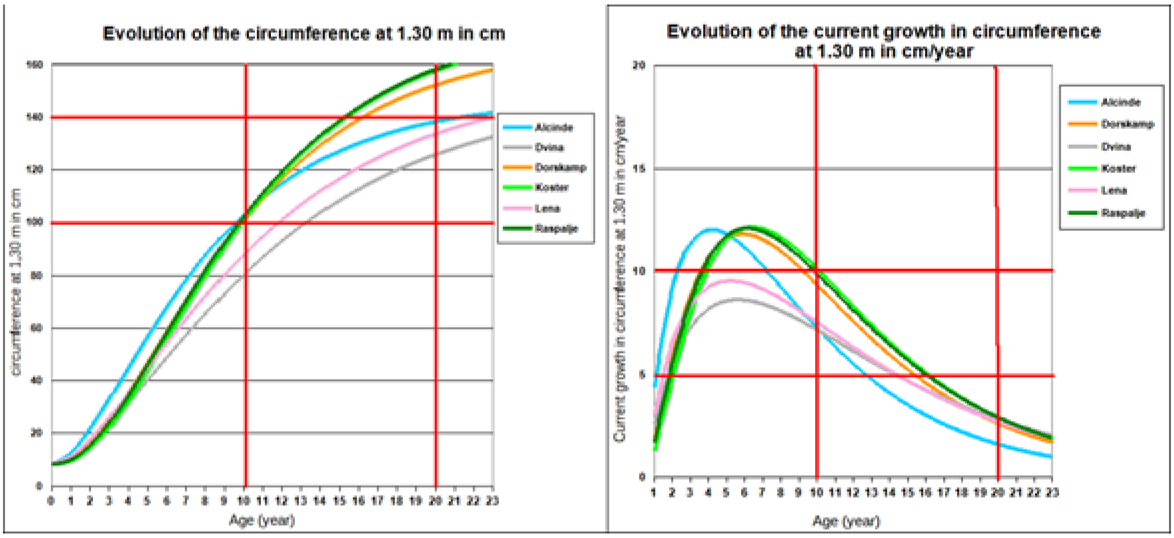
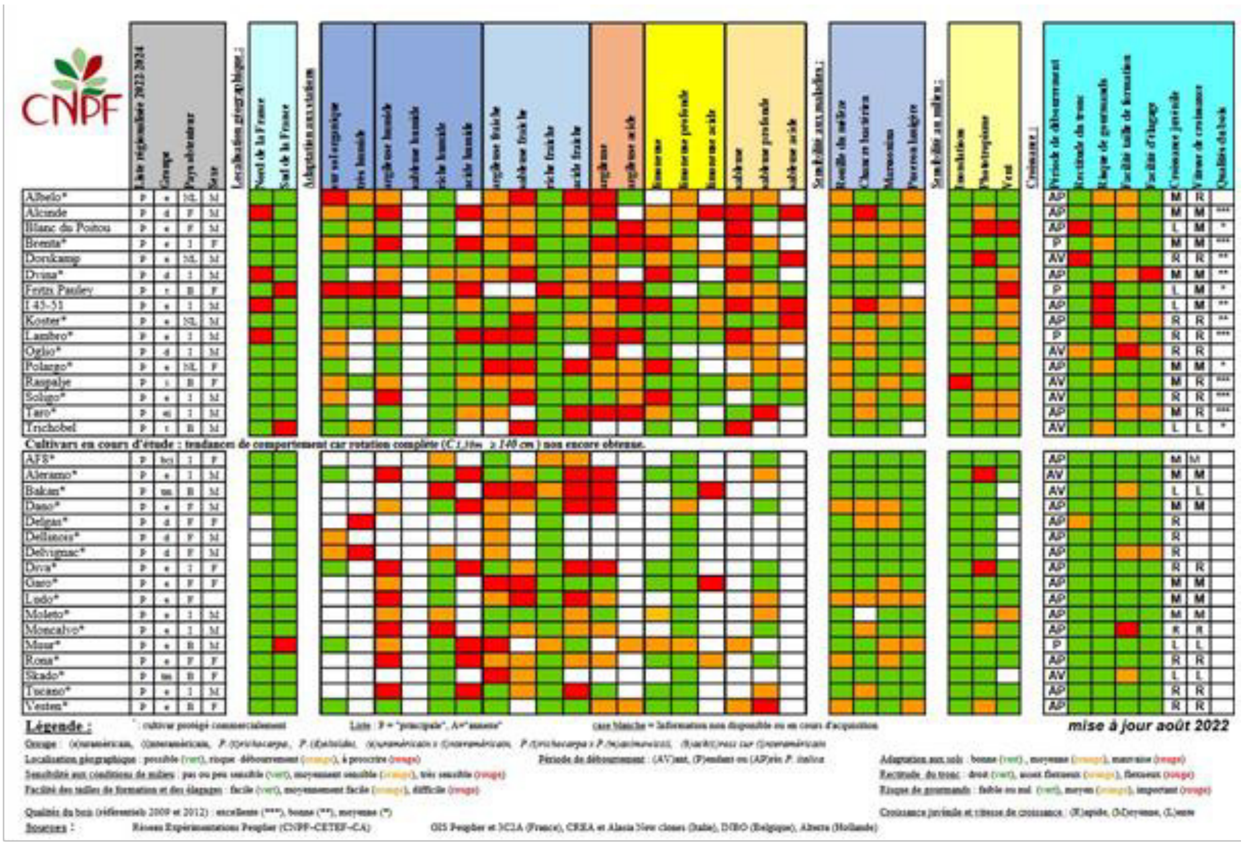


Figure 10 *- Growth model for six poplar clones on moist soil with a balanced texture in a trial in France.*

Table 7 *- List of clones allowed for cultivation in France, with their known adaptation to different conditions (updated in 2022)*



3.4 Method and density of planting

3.4.1 Planting design and spacing

In poplar plantations for the production of veneer logs, the number of trees per hectare can vary from a minimum of 150 (67 m^2 per tree) to a maximum of 330 (30 m^2 per tree), although a density of 200 to 280 trees per hectare is generally adopted in Italy, with a square (6 × 6 m), rectangular (6 × 7 m) or hexagonal arrangement. The choice of spacing should take into account the characteristics of the site (climate, soil), the clone and the length of the rotation, with lower densities used in less fertile soils. The same arrangements are adopted in Spain for plywood production but with a particular attention to planting deep (see below). In France higher spacing can be adopted (7 x 7 or 7 x 8) to allow a more extensive management practices. In Italy, Spain and France the plantation density is definitive, no thinning is foreseen in the traditional cultivation of poplar.

For the production of logs for other uses (oriented strand board [OSB] panels, pulp, packaging, energy, etc.), the planting density can vary from 600 to 1,700 trees per hectare. Square or rectangular arrangements are recommended, with spacing between rows sufficiently large to allow mechanized interventions (Bergante et al., 2010). In Spain, when the use of wood is biomass, planting densities are between 10,000 and 15,000 (Cañellas et al. 2012). Also in Italy this design is used but only for biomass purposes (chips for combustion) or particle panels production (low quality due to high bark content).

3.4.2 Time of planting and rooting

To create specialized poplar plantations, dedicated to the production of veneer logs, one- or two-year-old nursery saplings (live poles) are used. They must have the sapling qualities mentioned above and an average height of six meters or more and are planted without roots and branches. For SRC systems it is possible to use one-year-old live stakes with an average height of 1.5 to 2 meters or simple cuttings of 25 - 35 cm in length.

In Spain, for short rotations, it is usual to use cuttings between 25 and 40 cm in length obtained from one-year-old plants but this choice will affect the final quality of the material; for higher quality material it is recommended to use one-year old live poles. All the planting material must be well hydrated and in vegetative dormancy. For plantations activities the most intense periods of frost should be avoided, as they could hinder the opening and correct closing of the holes.

Planting material with good rooting capacity, which is linked to genetic factors (species and clone) but also to interactions with the environment (soil, climate) (Zalesny et al., 2005), is one of the fundamental requisites for the success of a poplar plantation. When *P. ×canadensis* clones are used, which are generally characterized by a good ability to form roots and to take root, planting can be carried out any time during the period of vegetative dormancy (avoiding frost). Clones of P. deltoides or of other species phenotypically similar to it must be planted towards the end of the period of vegetative dormancy because they root with greater difficulty and dehydrate more quickly in comparison with the hybrids of *P. ×canadensis*. To facilitate the rooting of *P. deltoides* and more regular crown formation, it is preferable to use one-year-old nursery saplings, obtained directly from cuttings or, even better, from coppice.

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

3.4.3 Planting method

Careful preparation of the soil is essential for the planting of poplar plantlets. Ploughing to a depth of 30 to 50 cm is recommended, possibly combined with scarification down to 70 to 100 cm (for silty-clay soils), avoiding the movement of layers of soil with unfavourable chemical or physical characteristics to the surface. For silty-clay soils it is advisable to plough when the soil is neither too wet nor too dry, preferably by the end of September and in France, if possible, at the end of summer.
In France, in the case of reforestation on wet soils, generally no soil preparation is recommended. On new soils, soil preparation is recommended, but not always necessary depending on the context. On dry soils, however, soil preparation before planting is essential. The saplings should be planted at a depth equal to one-fifth of their height (at least 80 cm for one-year-old plantlets and 120 cm for two-year-old live poles). Holes must be adequate in diameter, generally around 30 cm (Fig. 11). In coarse-textured soils with little water-holding capacity, it is possible to use an auger of smaller diameter (up to 10 cm), and the depth of planting can be increased to the level of the permanent water table (maximum 300 cm). In fine or moderately fine soils, to facilitate rooting and expansion of the root system it is useful to dig holes of more than 30 cm in diameter. The holes must be dug in the period from November to December (in Italy) to allow atmospheric agents to break down the lateral surface of the holes, which are compacted by the auger (Stanturf and van Oosten, 2014).

Figure 11 *- Poplar plantation in Italy: drilling of the ground to plant two-year-old live poles.*

In some situations in Spain, the deep of holes depends on water table deep and the holes can reach up to 2 or 2.5 meters; differently from Italy, the spacing is proportioned accordingly and can be reduced as the implantation depth increases (Rueda et al., 1997).
For SRC plantings using poles, the planting can be carried out with a mechanical transplanter in rows, at a depth of about 50 cm (Manzone et al., 2014). For dense SRC plantations in Spain using cuttings, the planting is carried out in a similar way to how it is carried out in a nursery (Sixto et al., 2015).
In France, live poles are planted at a minimum depth of one meter. Planting at a depth of less than one meter is often the reason for failure of the plants to take root. For light-textured or balanced soils, the use of a spiral auger is widely used. On heavy soils, digging a one cubic metre pot with a shovel greatly facilitates the recovery of the plants and the start of growth.

3.5 Fertilization

In areas with good water availability, generally characterized by loose and deep soils, good wood production can be achieved with limited use of mineral fertilizers. However, it is necessary to distinguish a basic fertilization, carried out at the planting of the poplar grove, which may have the purpose of returning the nutrients removed from the previous crop, and favoring a good rooting and a good start of the new plant, from a top nitrogen fertilization, carried out annually during the growth of poplar. In this last case conflicting results derive from research on its effect in many Countries (Rennenberg et al., 2010; Dimitriou and Mola-Yudego 2017). Generally the fertilization can gives appreciable results in coarse soils or in soils with acid pH, low exchange capacity and nutrient deficiencies but limited effect were registered in sandy soils or in adult trees.

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

In France, many poplar plantations located on the banks of rivers or streams are regularly flooded in winter or spring, with nutrient inputs from soil erosion upstream. On these soils, fertility is preserved and fertilisation is not necessary. Base fertilization, where indicated, does not generally include nitrogen, except for the contribution from organic fertilizers. For sustainable poplar culture, inputs of phosphorus (P_2O_5) and potassium (K_2O) should not exceed the applications recommended by specifications for regional production or sustainable management.

Nitrogen top dressing can be carried out through localized applications in the crown projection area during the second, third and fourth year after planting. Phosphate and potassium top dressing, as an alternative or supplement to basal application, can be carried out in the first four years, for example using ternary fertilizers. Application of organic matter (manure or compost), with subsequent burial, can be performed throughout the entire rotation, with the exception, in Italy, of the period from August to September and the winter months.

3.6 Pruning

Pruning in plantations for the production of wood for the plywood industry is aimed at obtaining good stem shape and timber that is free of knots and therefore of high quality. Pruning must be carefully planned and performed in order to optimize the quality of the wood without limiting the growth and energy supply of the tree. (Danilovic et al., 2022). Pruning height is proportional to planting density and rotation length. In plantations of medium spacing and rotation it is sufficient to prune to a height of about eight or nine meters at most to achieve satisfactory wood quality. In general, the branches to be eliminated are for the most part those growing on the part of the trunk corresponding to the planted sapling, and fewer on the part of the trunk corresponding to height increases from the first and second year after planting.

During the first two years of cultivation, corrective and formative pruning should be carried out to promptly eliminate double apices and apex proleptic branches growing vertically (one- year-old branches just below the apex). In the following years the lateral branches must be gradually eliminated to up to 5 to 7 meters from the ground (Fig. 12) in order to “clean the trunk”.

Figure 12 *– Poplar pruning using hydraulic lifts in Po Valley plantation in Italy.*

Pruning operations are usually carried out during the period of vegetative dormancy (Tables 8, 9 and 10). Only in the case of P. deltoides clones, which tend to produce a less orderly crown, in very fertile soils it may be convenient to bring forward the first formative pruning up to July of the first vegetative season.

In France, due to the productivity of varieties that vary greatly depending on the soil and climate, pruning is no longer based on the age of the poplars, but on their growth dynamics. Thus, based on the industry's need for knot-free wood over 8 cm in diameter, a simple method for triggering pruning has been developed by monitoring the circumference at 1.30 meters. Three pruning are recommended: the first up to 3 meters in height when circumference at 1.30 meters is 35 cm, a second up to 4.5 m when circumference at 1.30 meters is 45 cm and the third up to 7 m when circumference at 1.30 meters is 50-60 cm. Pruning beyond 7 meters is not economically relevant. (Paillassa, 2021)

Some others specific consideration in relation to pruning in the Spanish case can be checked at Rueda et al. (2019).

Table 8 *- Pruning regime to be adopted in the period of vegetative dormancy in poplar plantations consisting of one-year-old nursery saplings and intended for the production of veneer logs.*

Year 1	Eliminate double apices, the most vigorous apex proleptic branches and all branches up to a height of 1.5 m from the ground (these last can also be cut during the vegetative season)
Year 2	Cut the most vigorous apex proleptic branches of the second whorl and thin out those of the first whorl, removing the larger ones; also eliminate all branches up to a height of about 2 m from the ground
Year 3	Thin the branches of the second whorl, removing the larger ones, and remove all those below the first whorl, up to a height of about 3 m from the ground
Year 4	Thin the branches of the second whorl, eliminating the largest and the most vertical, up to a height of about 5 m
Year 5	Remove all the remaining branches of the second whorl and all branches up to a height of about 6-7 m

Table 9 *- Pruning regime to be adopted during the period of vegetative dormancy in poplar plantings consisting of two-year-old nursery saplings and intended for the production of veneer logs.*

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

Table 10 - Pruning regime to be adopted during the period of vegetative dormancy in poplar plantings intended for the production of logs for OSB panels or pulp

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

3.7 Irrigation

Irrigation, like fertilization, is a costly practice in terms of both energy and economics; it can be adopted as a rescue intervention in the first year of cultivation to enable young trees to take or, in the case of intensive cultural models, when the roots cannot reach the water table, in order to avoid slowing or stunting growth in the period of most intense vegetative activity. The anomalous climatic trends observed in recent years as a consequence of climate change have increased the situations of water stress in plantations, even in floodplain areas traditionally suitable for poplar cultivation. The considerable lowering of the water tables has led to the use of ever more frequent irrigation relief supplies, especially in the summer months, in addition to the development of aridoculture practices and the use of clones more tolerant of drought.

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

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

The most common irrigation methods are gravity-fed and sprink systems. Recently, localized drip irrigation systems (underground or top systems) have also been tried and partly adopted, allowing more sound use of water. Localized systems make it possible to reduce the water loss from runoff or deep percolation into the ground that occurs with gravity-fed systems and with sprinkling of the foliage in the plantation's first years (which also encourages the development of leaf diseases such as rusts).

However, an optimal positioning of the drip fins must be defined and adopted to avoid malformations of the root system which result in greater sensitivity to wind and drought in case of suspension of irrigation.

The choice of irrigation method depends on the soil, the availability of irrigation water and the equipment available. The gravity-fed method requires high flow rates (about 800 m^3ha^{-1}) and has limitations on terrain that is too loose or not flat.

The sprink method requires lower flow rates (300 to 400 m^3ha^{-1}) and can also be used on non-flat terrain. Drip irrigation is the most versatile; it reduces the water volume to a minimum and, if automated, also labour. However, the equipment and installation costs limit its use to high-input plantations where the expected production exceeds 30 m^3ha^{-1} $year^{-1}$.

In Spain, in plantations for veneer, logs or boards, irrigation is carried out mainly by gravity, except in areas where deep roots are planted in contact with the water table. In high-density plantations, however, irrigation is mainly done using drip systems.

In France, there is no irrigation for poplar groves. If certain areas become limited from the point of view of water supply, in particular as a result of climate change, poplar production is replaced by forestry production that is better suited to the risks of water stress.

3.8 Post-planting tillage

In plantations with ten-year rotation, tillage, carried out with disc harrows, is of fundamental importance during the first half of the rotation (Fig. 13) to limit invasive vegetation and evapotranspiration losses by improving the structure and permeability of the active soil layer. In the first half of the rotation, spontaneous vegetation can also be controlled by using chemical products (see section 3.9). In the second half of the rotation, tillage generally has no positive effect on the growth of trees and therefore can be performed fewer times or replaced by one or two operations to mow or shred spontaneous vegetation.

Figure 13 *– Tillage, carried out with disc harrows, during the first half of the rotation.*

In heavy soils it is advisable to till no more than twice. Ploughing to create furrows between rows is necessary to avoid water stagnation; in Italy is carried out in autumn. In heavy and humid soils, the growth of grass, controlled with mowing or shredding, is recommended rather than the usual harrowing, in order to avoid soil compaction. In higher-density plantations, tillage is advisable and practicable only in the first two years, with mechanical harrowing or mowing of invasive vegetation.
In Spain, it is generally accepted that the soil should be tilled every year until the fifth or seventh, which must be carried out between mid-May and mid-June. The number of tillage ranges from one to three depending on the site. Sometimes these activities are carried out throughout all the life of the plantation as a preventive measure (for example, fire avoidance). In vSRC model the control of the grass is undertaken the year of the installation and the first year after each cut; increasingly, this control is carried out mechanically given the restrictions on the use of many phytosanitary products.
In France, it is advisable to adjust the tillage according to the soil and climate conditions that may induce risks of water stress during the vegetation period (Table 11). Thus, on soils with a predominantly humid climate, no tillage is recommended during the life of the stand.
On cool soils, tillage is generally recommended in the first years, when the stand is established. After that, depending on local climatic conditions, it may be recommended for a longer period. Finally, on predominantly dry soils, annual tillage is essential.

Table 11 - Soil works according to soil characteristics.

Water table	Prospectable depth /Texture	Station type	Soil work			
			Never	Every 5 years	Every 10 years	Every years
Accessible	At 50 cm	Very wet	X			
	between 50 and 1 meter	Wet	X			
	more than 1 meter	Fresh		X	X	
Nonexistent or inaccessible	Clay (from 80 to 120 cm)	Clayey		X	X	X
	Silt (from 80 to 150 cm)	Silty		X	X	
	Silt (more than 150 cm)	Deep silty		X	X	
	Sandy (from 120 to 200 cm)	Sandy				X
	Sandy (more than 200 cm)	Deep sandy				X

	Independent of area rainfall conditions
	Zone with average precipitation during the growing season
	Area with low rainfall during growing season

3.9 Choice and use of plant protection products

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

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

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

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

In Italy, for the intensive nature of poplar cultivation and its frequent use of uniform genetic material (monoclonality), plantations are subject to biotic and environmental adversities which sometimes have such high incidence as to cause substantial economic damage. Even in the context of sustainable management, while productive and resistant clones are available but not yet sufficiently widespread, it is not possible to exclude a need for phytosanitary treatments (Fig. 14), at least not in stands composed of clones susceptible to a given disease or pest. These treatments should be limited to situations where cultural practices are considered ineffective, and also based, if possible, on information made available through the so-called early warning approach (evidence of incipient plant diseases or insect pest attacks).

Figure 14 *- Phytosanitary treatment in a poplar plantation in Italy.*

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

In France, the recent tightening of legislation concerning the use of phytosanitary products (including the forthcoming ban on the use of glyphosate) has led to a gradual and widespread abandonment of the use of these products in poplar groves. With regard to poplar pests and pathogens, the choice made over the last 30 years has been to rely on genetic improvement (selection of varieties that are less susceptible to disease) and to diversify the varieties used as much as possible in order to limit the risk of damage and the need for chemical protection. The abandonment of 'I-214' because of attacks by woolly aphyd is an illustration of this strategy.

3.10 Logging

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

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

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

Figure 15 *- Felling in a poplar plantation using a harvester.*

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

At the other end of the spectrum, the highly mechanized method requires the use of specialized machinery (Fig. 15) 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 (Fig. 16), 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.

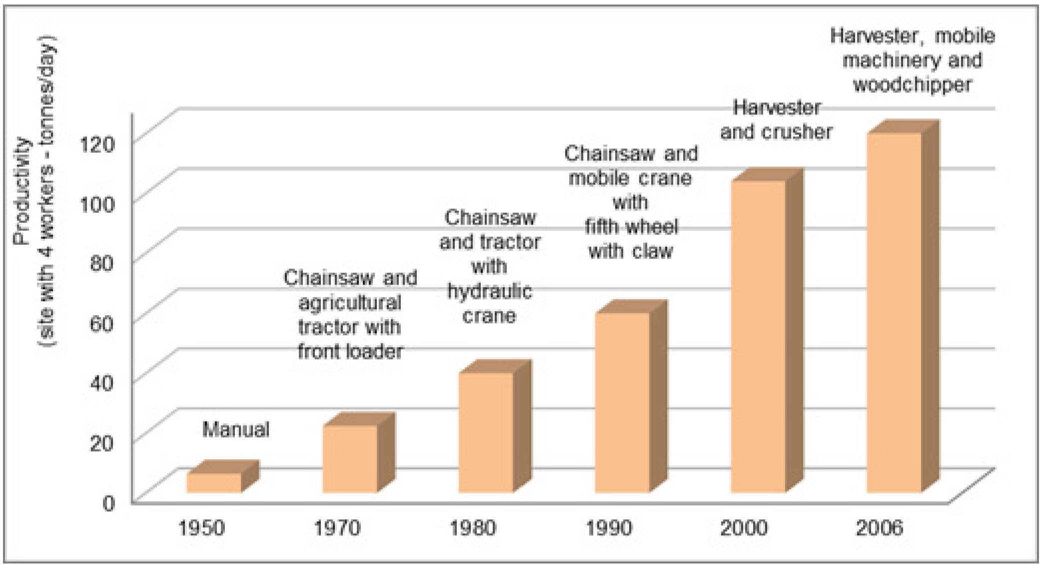


Figure 16 *- Increase in gross productivity of wood harvesting in poplar plantations (where unit weight of trees averages about 0.6 tonnes).*

The unit cost of processing for the highly mechanized methods are lower than those of the traditional method (approximately 14-15 euro/ton, as compared with 19-21 euro/ton). Moreover, a team that adopts a high level of mechanization can work up to 100 hectares per year in contrast with about 12-15 hectares for those who work with traditional methods. However, the economic advantage in the use of combined machines is obtained only if the technical, logistical and commercial organization of the company allows optimal use of the available equipment through continuous work throughout the day and year; this condition occurs only in the areas most suited for poplar cultivation, characterized by larger lots and organized harvesting companies.The use of harvesters may be constrained by the investment necessary for their purchase in relation to the moderate size of the companies in the sector, and by the assumption on the part of some industrial operators that mechanical processing results in lower quality, with inaccurate measurements and substantial damage to bark and wood. Increasing the level of mechanization, however, is an unavoidable path towards modernization which, together with potential improvement measures, creates a series of conditions linked to a shift towards more organized activities, favouring an increase in the economic value of standing timber and, consequently, in the competitiveness of the entire supply chain.

Finally, in view of the growing demand for biomass, in some geographical areas the production of woodchips from poplar can guarantee significant commercial exploitation of lower-grade wood, although in this case specialized equipment (Fig. 17) and a consolidated market are absolutely necessary.

Figure 17 *- Harvesting equipment for poplar biomass.*

4. PERFORMANCE MODELS FOR POPLAR CLONES (FRM)

4.1 Performance models for plywood productions

Breeding and selection activities in progress at CREA – Research Centre for Forestry and Wood (CREA-FL) aim to develop P. ×canadensis clones with appropriate adaptation profiles, higher growth rate, resistance to pest, tolerance to diseases and high-quality wood. According to a 'semi-reciprocal' recurrent selection of the parental species, P. deltoides (as females) and P. nigra (as males) have been evaluated in a first cycle of inter-specific crossings (Bisoffi, 1996). On the basis of results obtained from progeny test, a sub-group of both the parents has been selected to create a new breeding population. These, subdivided in multiple sub-populations for single traits of cultural and economic importance, will improve genetic variation for future generations with a second cycle of intra-specific crosses. In addition to the characteristics already considered initially in the second cycle of crossings, other aspects related to adaptability to different environmental conditions, drought and the consequences deriving from climate change are carefully evaluated. Moreover, these aspects are subject to analysis and evaluation of the genetic materials obtained and selected within the B4EST project.

The genetic materials developed in the first stage of the breeding program entered in the selection process and have been evaluated in multi-sites nurseries and stands localised in Central and Northern Italy. As a result, eight new P. ×canadensis clones have been selected and listed in the National Register of Basic Materials: 'Imola' and 'Orion' for biomass for energy and particles panel production; 'Aleramo', 'Diva', 'Moleto', 'Moncalvo', 'Mombello' and 'Tucano' for the traditional plywood productions. These clones ensure good wood quality, resistance to woolly poplar aphid (*Phloeomyzus passerinii*), fungal diseases tolerance (Marssonina brunnea, Melampsora spp.) and have shown a good growth and adaptability in different pedoclimatic conditions. Their ability for growth and adaptability to different soil and clime conditions has been tested in several trials both in Italy (Fig. 18, 19, 20) and in other Countries (France, Spain and Hungary).

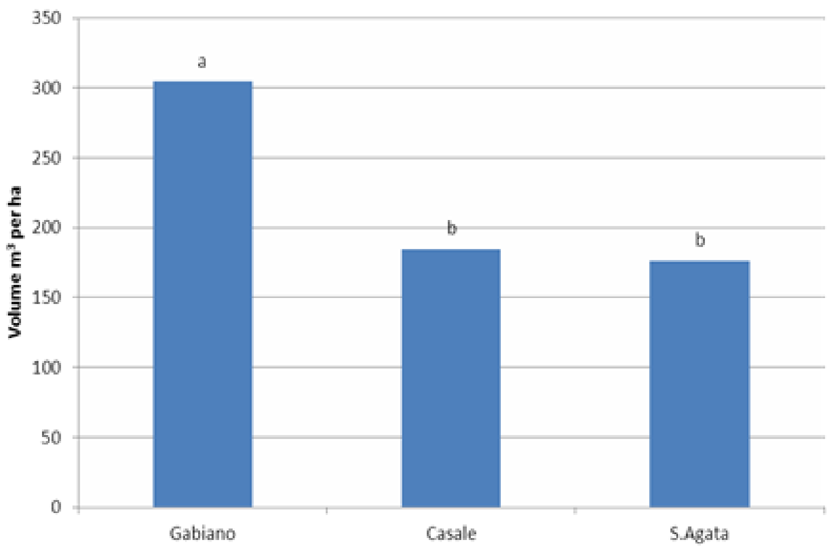


Figure 18 *- Average production of all clones obtained in different places in Po Valley (Italy).*

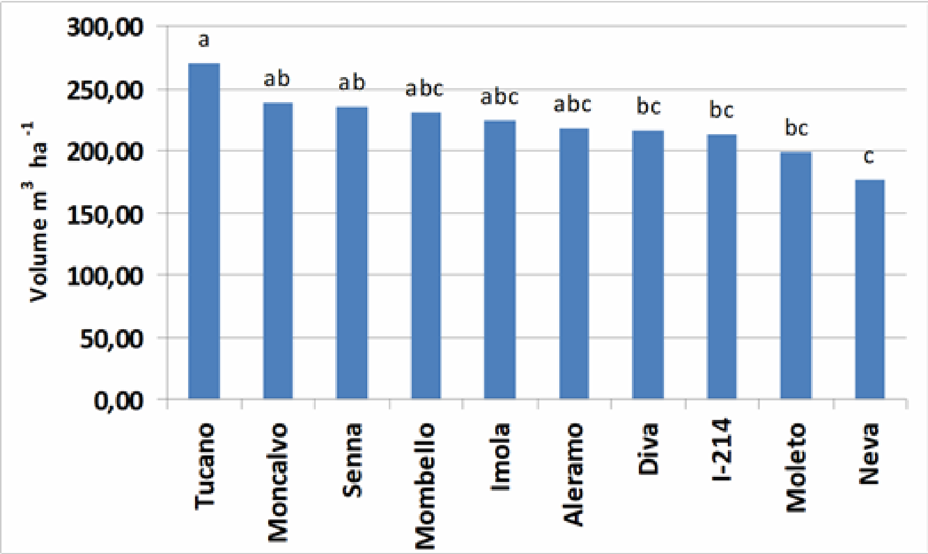


Figure 19 – *Poplar clone productivity as volume average in three sites in Po Valley.*

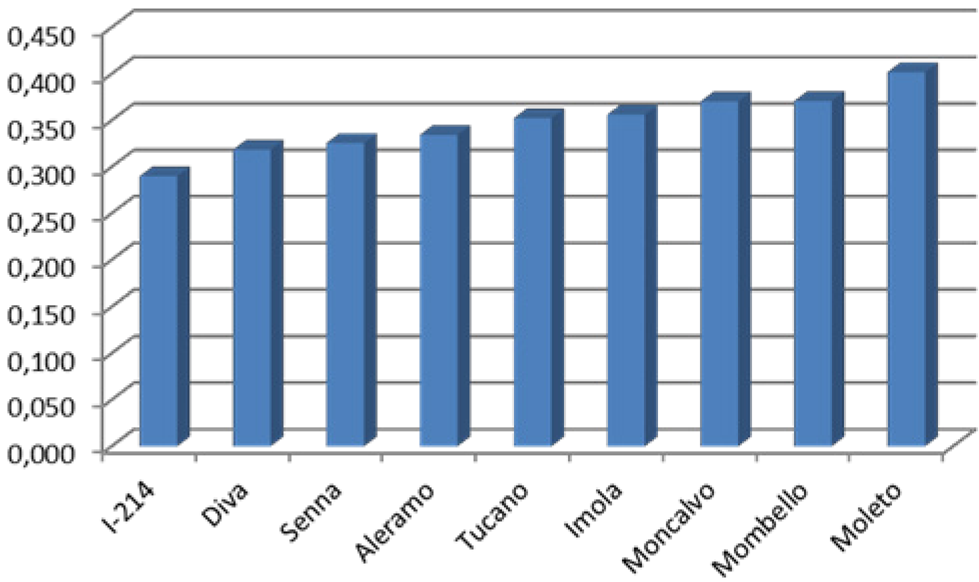


Figure 20 – *Basal density of new poplar clones selected for plywood production*.

In Spain, most of the mentioned clones obtained in Italy are under experimentation by the company Bosques y Rios S.L.U. as well as others from other European programs (Garnica et al. 2018).
In France, all the poplar varieties obtained by the various European breeders (for timber production) are evaluated under French soil and climate conditions, in order to select those best suited to the different situations. Thus, at present it is mainly Italian, Belgian and French varieties that are being carefully considered by the production chain.

4.2 Performance models for biomass productions

The two cultivation models mainly applied in Italy are the vSRC model, with very high density (about 8000 trees ha-1) and harvest every two years for wood chips production for energy purposes and SRC model with high density (about 1600 trees ha^{-1}) and harvest every 4-6 years for multipurpose wood production. The second one was preferred and most cultivated during last years, for the multipurpose material production and with a quite high yields (Facciotto et al., 2020; Bergante et al., 2022) In such cultural models (vSRC and SRC) management practices dedicated to wood quality (pruning, treatments and irrigation), are avoided or reduced, due to the low income obtained from woody biomass. The use of improved material with high rusticity and diseases resistance is therefore recommended.

In figure 21 the yield results in vSRC model (biennial harvest) of first test with improved poplar genotypes (‘Orion’, ‘Baldo’ and numbers) compared with genotypes for traditional cultivation are shown. The clones selected for biomass purposes are characterized by very fast growth in juvenile stage (first 4-5 years) and generally by high wood density; the rusticity and the ability to regrow after coppicing are also considered very important. The average yields with clones improved can reach (in average during three rotations) 15 t ha^{-1} y^{-1} of dry matter (0% humidity) with 10,000 trees ha^{-1}; different characteristics of genotypes in biomass model can ensure high production: high rooting ability, typical of *P. ×canadensis*, high growth ability typical of *P. deltoides* which are often thus able to compensate for a lower rooting, but also, some clones, are characterized by an explosive production of new shoots after cutting, which leads them to visibly increase production during the second cycle.

Figure 21 *- Dry biomass production obtained in Casale Monferrato with high plantation density (10000 p/ha – average of 9 years), considering single and double row.*

In the sector of biomass production the high basal density is considered as good quality both for combustion (along with a low moisture content) and for bio-ethanol production (Guo et al., 2015). In relation to the production of biomass in SRC, a set of clones comes from different European breeding programs is being tested in different countries of the EU (Oliveira et al. 2021). Based on the results obtained from the PCA analysis it was possible to evaluate thir adaptability and productivity in different environments in EU (Fig. 22).

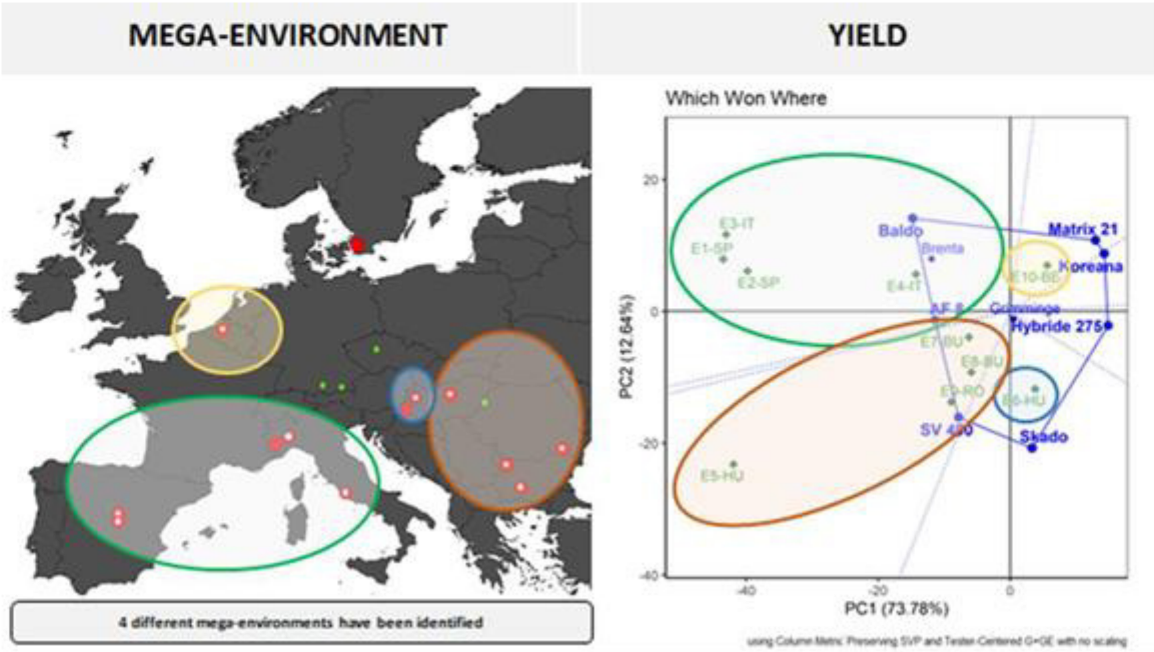


Figure 22 *- Behaviour (analysis PCA) of several poplar clones in different environments in EU.*

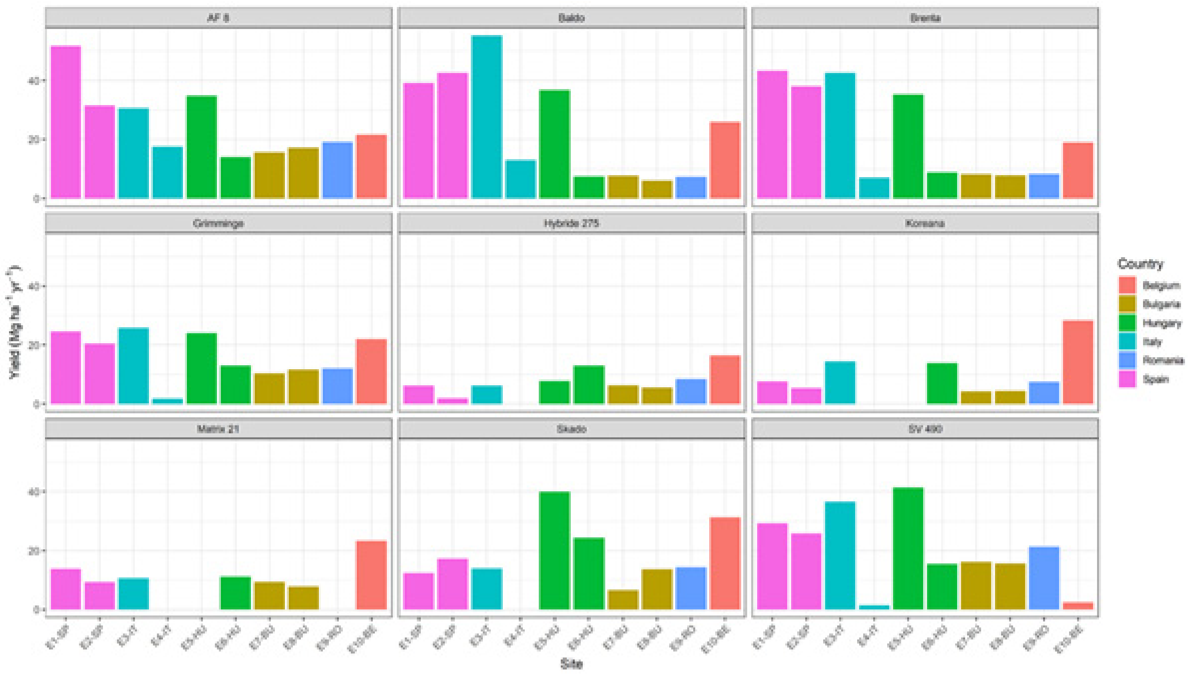


Figure 23 *- Biomass yield obtained from nine poplar clones from six different European countries in different environments in EU.*

From the comparison of nine common poplar clones from six different European countries the most productive and stable genotypes were 'AF8', 'Brenta', 'Grimminge'. Considering the behaviour in the individual countries, 'Baldo', 'AF8', 'Brenta' and 'SV490' grow better in Spain and Italy, while 'Matrix', 'Koreana', 'Skado' and 'Baldo' were the most productive in Belgium; in Bulgaria, Romania and Hungary the best were 'SV' '490', 'AF8' and 'Skado' (Fig. 23).

4.3 Performance models to predict the potential productivity of poplar clones

Spatial modelling of forest tree species niche suitability provides a useful technique to support forest management strategies and conservation planning (Schueler et al. 2014; Booth 2018). Among the range of tools and algorithms currently available, several conceptual approaches have been developed. The first and oldest group is represented by Species Distribution Modelling techniques (SDM), where the spatial distribution of a target species is considered as a proxy of its realised niche (Elith et al. 2006; Pecchi et al. 2019). Tree breeders and forest ecologists have developed models to account for genetic components such as: Response Functions (O'Neill et al. 2008; Wang et al. 2010; Chakraborty et al. 2016), Transfer Functions (Berlin et al. 2016, Hallingbäck et al. 2021), Reaction Norms (Fréjaville et al. 2019) and ΔTrait-SDM (Benito Garzón et al. 2019). The last of these (ΔTrait-SDM) is able to evaluate the genetic adaptation (or variation) and the phenotypic plasticity of a phenotype in a single model.

As part of the B4est project, this modelling framework was applied to hybrid poplar clones grown mainly in Italy, distinguishing the group of 'old' clones, not improved for disease resistance - FGN, from new ones - IMP. Data between 1980 and 2021 for 49 poplar clones widely tested in Italy with traditional cultivation model were here clustered in two groups and single-group reaction norms were calculated to predict the potential productivity across time and space. More information about methods and results are reported in Marchi et al. (2022). The most important results about the future potential scenario (2026-2055 = 2040s) of poplar growth in Italy are reported considering two possible variants (numbers 01 and 21 of UKCP18 scenarios RCP2.6 and RCP8.5) calculated by 'ClimateDT' (https://ibbr.cnr.it//climate-dt/), a web portal where scale- free climatic data are provided freely at global level.

The Universal Reaction Norms (URN) developed show the possible effects of a changing climate on poplar clone cultivation in Italy (expected Diameter at Breast Height- DBH at ten years). Starting with a current situation, overall, the improved clonal material, which include MSA material (Higher Environmental Sustainability clones), show less sensitivity to climatic aridity and a lower effect on growth from irrigation (Fig. 24 and 25).

These results may suggest a possible reduction of cultivation inputs as well as a more stable production of wood assortments in the future than with the current standard clonal types. In addition, the resistance to biotic stress that MSA clones achieve marks them as an important candidate source of FRM for poplar cultivation in the future. Adding to the traditional and widely cultivated clones such as 'I-214', here included into the FGN group (genotypes of first generation, not improved for disease resistance), new clones selected in recent years show a predicted growth rate comparable with 'I-214' and better in places.

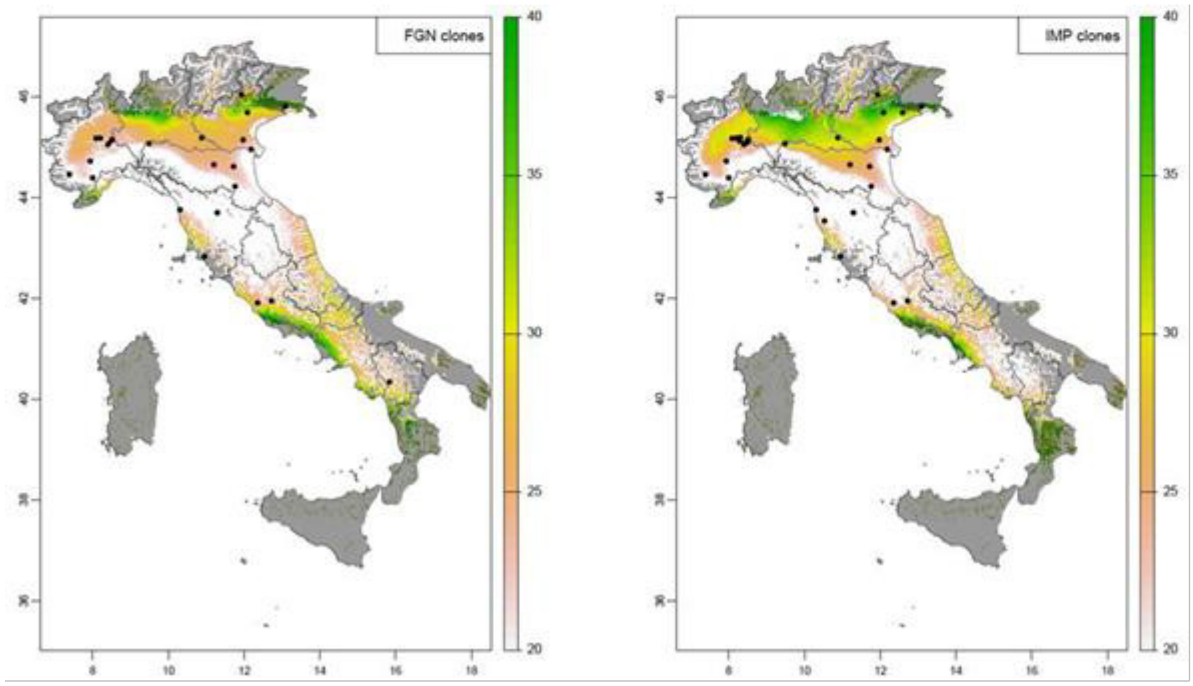


Figure 24 *– Expected DBH in cm at age 10 without irrigation under the current 30-years normal climate (1991-2020). FGN = clones not improved for disease resistance are represented on the left; improved clones (IMP) on the right. The experimental sites used for modelling the group are shown as black dots and the statistical extrapolation outside the ecological domain is shown as shaded area.*

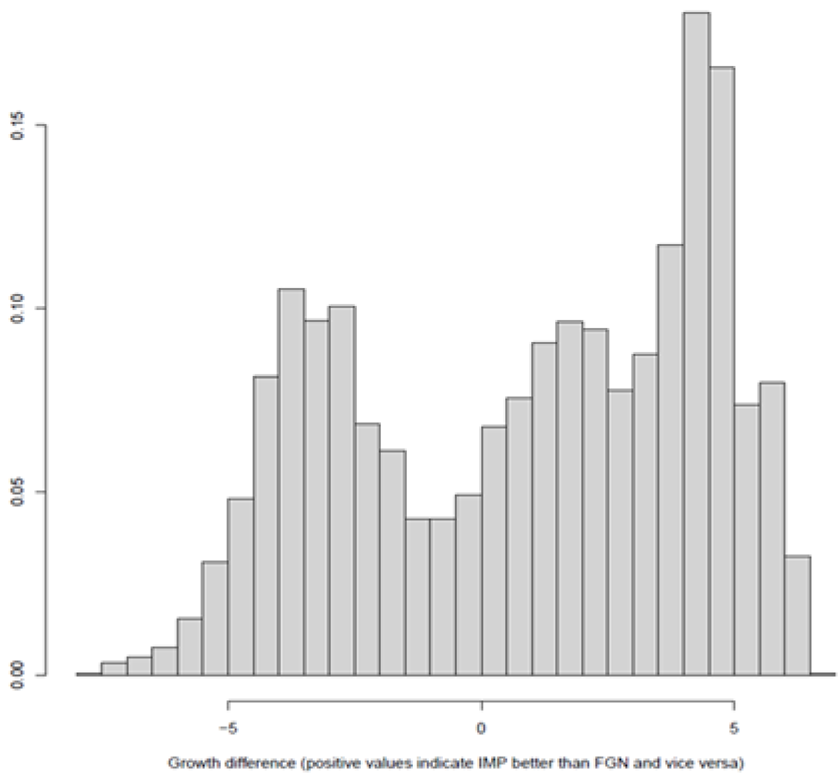


Figure 25 *– Predicted 10-year DBH difference (in cm) between FGN and IMP clones across the whole Italy. Positive values indicate that IMP are more productive than FGN and vice versa and values expresses the delta of DBH in centimetres.*

While projections across RCPs and time-slices were almost in agreement with the expectations of a decrease in land suitability which was delayed for the RCP2.6 scenario compared to the RCP8.5 scenario, a regular trend across time (i.e., 2030s-2040s-2050s) in both RCP s due to a warmer and drier climate was forecast, with a very large difference between variants.

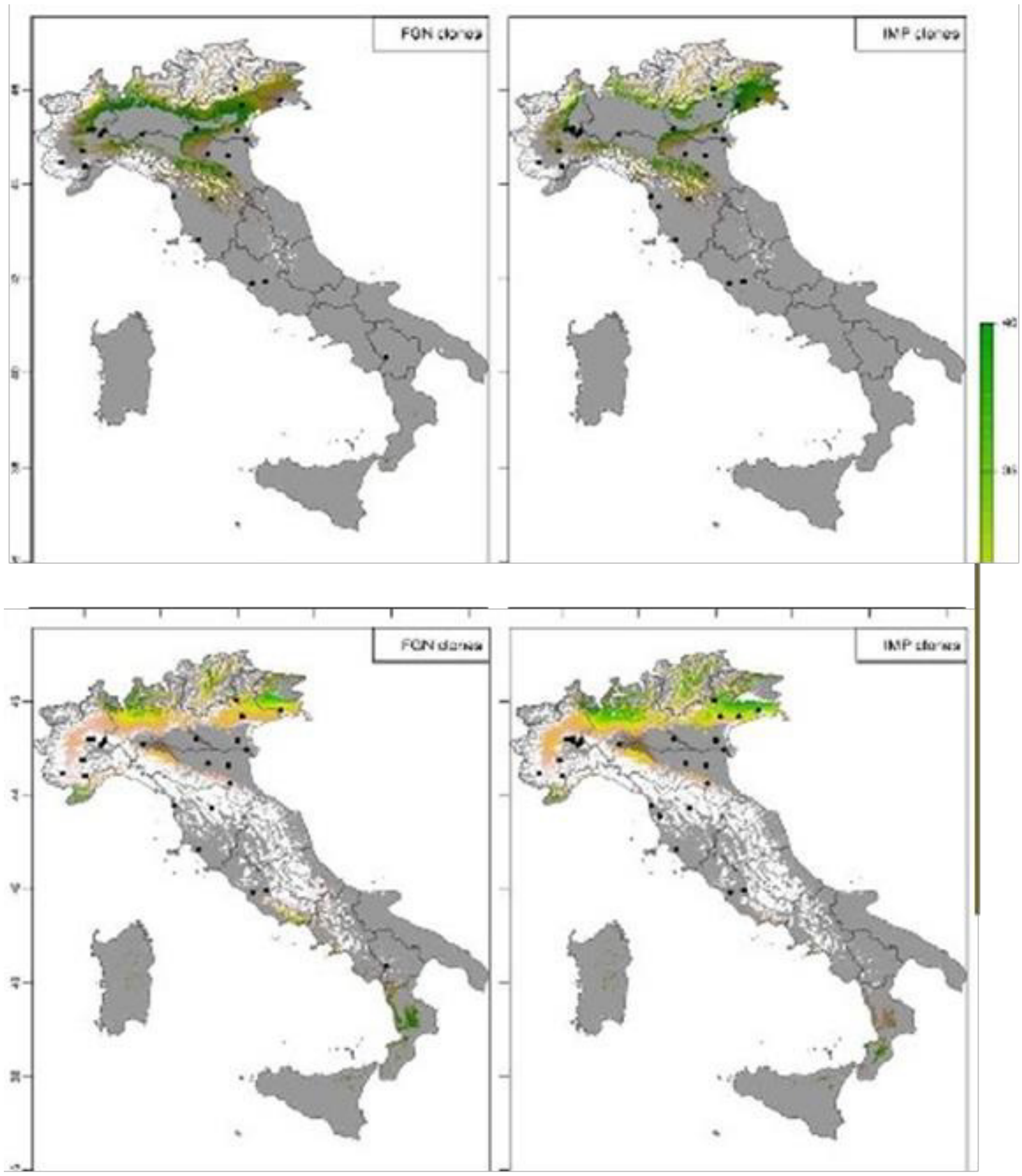


Figure 26 *- Predicted DBH in cm at age 10 for the two groups in 2040s under RCP 8.5 using the variant 01 (up) and variant21 (down). The experimental sites used for modelling the group are shown as black dots and the statistical extrapolation outside the ecological domain is shown as shaded area.*

Currently this difference was much larger than that observed between RCPs or between time slices. An example is reported in figure 26 where the difference between the two variants in the 2040s for RCP8.5 is proposed.
The use of the two different UKCP18 variants produced completely diverging scenarios after the 2030s. In addition, the projection made with variant 01 was mostly from extrapolation, with high uncertainty. For these

reasons, much more effort is needed to support decision makers with additional data. Additionally, researchers must test genotypes outside the “expected” ecological niche. In this framework the spatial projections were provided for the current time (i.e., 1991-2020 climatic normal period) and the 2030s to represent a valuable guideline to plan the future establishment of additional trials using the same materials to be tested outside the environment observed in this work.

5. INNOVATIVE POPLAR PLANTATIONS AND ENVIRONMENTAL ASPECTS

In the past, planted poplars were characteristic of the rural landscape of many lowland areas. The cultivation of poplar in rows inspired the development of an innovative type of plantation more sustainable and resilient to climate change, in which poplar is used both as the main crop, suitable for producing high-quality wood (veneer logs), and as an auxiliary crop which, by virtue of its rapid growth, its slender shape and the modest coverage of its foliage, is able to support the cultivation of other slower-growing trees such as valuable hardwoods (Fig.28). In other cases, the appropriately spaced rows of poplar favored the cultivation of other crops (cereals, vegetables, etc.) protecting agricultural crops from the action of strong winds and creating a more suitable microclimate for cultivated plants (Fig.27). In addition, the root systems of trees perform a filter and phytoremediation action by absorbing excess fertilizers or other soil and water contaminants.

Figure 27*- Agroforestry system of poplar rows between alfalfa fields in Po Valley in Italy.*

5.1 Polycyclic and/or mixed-species tree plantations

Polycyclic and/or mixed-species plantations are proposed as a means of enabling management strategies in which silvicultural inputs can be replaced by natural dynamics that favour wood production, through adoption of more environmentally sustainable cultural practices. These systems (Plutino et al. 2022) promote the planting of different broad-leaved trees on the same plot to produce wood with different rotation lengths (Fig. 28 and 29). They can include:

- main plants (arranged at a defined distance) of different tree species, with rotations of different duration:
    - medium-long rotation (valuable broad-leaved trees);
    - short rotation (poplar clones for the production of veneer logs);
    - very short rotation (poplar clones for the production of biomass, managed by coppicing);

- ❖ dual-role plants with a double function (wood production and improvement of the form of the main plants); these must be able to influence the architecture of the main medium-long rotation plants and to produce the wood assortments required by the market;

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

Figure 28 *- Polycyclic plantations with woody species with diversified growth.*

Polycyclic plantations can be divided in two types:

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

In Italy, polycyclic plantations have found a certain amount of interest especially in the Po Valley, following the incentive action for the plant promoted by some Northern Regions and these plantations are covered by specific technical norms in the sustainable management standards of PEFC.
Also in Spain mixed plantations of poplar / walnut are being tested (Pelleri, et al. 2020; Ripoll et al. 2014) for the production of wood. Combined wood / biomass uses are also being explored in Atlantic farming conditions (Emil-Fraga et al. 2021) as well as mixed poplar / black locus plantations for biomass (Oliveira et al. 2018; González et al. 2020).
In France, a few experiments with mixed plantings have been carried out, such as poplar / walnut or poplar / ash, but this choice has not been pursued.

Figure 29 *- Polycyclic plantation with poplar, ash and oak.*

The risks of monoclonal poplar plantations can be mitigated also by a clonal diversification in the same poplar stand, as an alternative model, useful to avoid the problems deriving from climatic changes and biotic and abiotic stress, as already reported in D 4.3. In order to increase the genetic diversity in plantation, planting model based on clonal mixture or a mosaic of monoclonal plots with a group of different clones was already proposed in the past (Heybroek 1982). Even if no benefits of clonal mixtures have been evidenced in terms of wood production (Bisoffi 1992; Debell & Harrington 1997; Miot et al. 1999) it is extremely important to maintain a considerable genetic variability to reduce epidemiological risks, using select clones with a diversified genetic background. In connection to this, it is notable that research on the topic of clonal group selection and genetic diversity is ongoing in Task 2.3 of B4EST project. Various cross combination of P. maximowiczii, P. trichocarpa, P. nigra and P. deltoides led to new cultivars suitable for deployment in varietal mixtures of five to ten genotypes characterized by compatible growth curves, high productivity and phenotypic stability (Weisgerber 1993). Moreover the adoption of cultivation models based on the use of poplar clones with greater environmental sustainability, allows to pursue the strategic objectives set out in the European Rural Development Plan.

5.2 Agrosilviculture

Agroforestry systems involve the cultivation of forest tree and shrubs on agricultural land in association with agricultural crops and/or grazing animals as a multifunctional system that can provide a wide range of economic and environmental benefits and help to conserve and protect natural resources for generations to come (Fig. 27 and 30).

Many traditional land-use systems in Europe involved agroforestry in the pre-industrial era, but, over the years, increased mechanization led to the development of increasingly specialized production systems. As a

consequence, the area under agroforestry declined in many regions of Europe, and also in Italy the areas cultivated in this way have gradually decreased since the 1980s. Since the mid-1990s, however, European policies have encouraged land management systems that combine production, environmental services (biodiversity, carbon sequestration, nutrient cycling and water quality) and social benefits, and this has created a new interest in agroforestry systems.
The agricultural crops (cereals, forage, legumes) or biomass plants, grown between the rows of woody trees thus become a distinctive element of the landscape. In the initial phase the environmental conditions are favourable to agricultural crops that require full light; as the trees grow, the shading and the competition for water and nutrients increases, while decreasing temperature and wind action (Fig. 27 and 30). Plant trees as contour lines of fields can significantly reduce the erosion of the soil and the leaching of nutrients, in favour of surface water quality in the surrounding area. The fine roots and the litter produced by leaves enriches the soil with organic matter, increasing the microbial activity and availability of nutrients, which leads to faster nutrient turnover, and reduces compaction of the soil.

Figure 30 *- Agroforestry system in the initial phase favourable to agricultural crop.*

For wood species such as poplar it has been observed that growth is faster than in specialized plantations, as the plants are more spaced and can use part of the residual fertility of agricultural crops (Paris et al., 2014; Facciotto et al. 2015).
Regarding the wood suitability for industrial uses, it should be noted that in some cases there may be limitations, particularly for plantations arranged in rows or in any case having very “unbalanced” patterns, with the distance between plants within rows very different from the distance between rows. In these cases, the trunks of some clones can take on an elliptical shape and can form bands of tension wood. Both cases can

reduce the uniformity and technological quality of the poplar wood, with end uses of lesser value as sawlogs instead of traditional veneer logs. Although in the rural development plan agrosilviculture is currently included as a component of greening, further investigations and experiments on the cultivation practices and the most suitable poplar clones are necessary for an objective transfer and diffusion on a large scale, also with the purpose of a better understanding of the aspects connected to the characteristics of the poplar wood.

In France, agroforestry using poplar is locally popular even if the areas concerned remain small and localised. A technical guide has recently been published.

5.3 Certification schemes for sustainable management

The Forest Stewardship Council (FSC) and the Programme for the Endorsement of Forest Certification Schemes (PEFC) have defined specific requirements to verify effects related to the restoration, improvement and maintenance of ecosystem services. These instruments, which are voluntary, can support promotional statements on ecosystem functions, thus providing access to the emerging market in environmental services. Certification of the sustainable management of wood plantations has been carried out in Italy for more than a decade and involves about 15% of specialized poplar cultivation. In particular, sustainable plantation management, promoted by the schemes of the Forest Stewardship Council (FSC) and the Programme for the Endorsement of Forest Certification Schemes (PEFC), is a tool for the valorisation and traceability of wood production. From this point of view, certification also provides a way to reduce the risks of illegal wood trade, helping to implement European and Italian regulations on due diligence and the EU Timber Regulation (EUTR).

The PEFC and FSC certification schemes recognize polyclonality as one of the fundamental criteria for the sustainable plantation management. Although they do not refer specifically to improved MSA clones, they each impose a mandatory minimum percentage of a different clone from the main one: PEFC requires the use of another clone for at least 10% of poplars farmed on areas exceeding 20 ha, while FSC imposes a percentage of 20% for poplar plantations of more than 30 ha.

In France, the demand for certified wood by industry has been growing for years. For poplar, this certification is essentially PEFC. Indeed, due to its land structure (small properties of a few hectares), the French poplar grove is not adapted to the current FSC certification. For the past 10 years, within the framework of the reforestation aid proposed by the industrialists, called the "Thank you poplar" charter, registration with PEFC has been a condition for access to the aid.

In Spain, currently nearly around 12.000 ha of the poplar plantations follow FSC and PEFC certification schemes.

5.4 Environmental aspects of sustainable poplar plantations

Poplar culture has lower environmental impact than agricultural crops, with positive implications also for conservation and protection of the landscape; however its sustainability could be improved further with an appropriate choice of clones and the use of cultural practices with lower environmental impact. The cultural practices indicated in these guidelines for sustainable poplar cultivation, based both on the use of clones that are resistant to the main biotic adversities (MSA clones) and on the reduction of soil tillage and phytosanitary interventions, lead to a reconsideration of the possibilities of growing poplar for productive purposes in riparian areas and areas designated for nature conservation. The natural affinity of the Salicaceae for riparian and floodplain areas and the most recent cultivation guidelines for eco-sustainable cultivation of poplar, suggest that poplar cultivation can have a positive impact with respect to other agricultural crops. Thus in addition to being a source of timber supply, poplar cultivation has important landscape and environmental functions: poplars can be used as windbreaks, are part of the ecological network, absorb carbon dioxide, buffer polluting substances in the groundwater, reduce erosion of riparian soils during flood events, and can be used for phytoremediation of polluted areas (Bergante et al. 2015).

Acquired knowledge suggests that the carbon footprint of poplar cultivation is more than positive thanks to poplars' high capacity to absorb CO_2 and accumulate it in wood (up to 25 t ha^{-1} y^{-1}) (Chiarabaglio et al. 2014; 2020). In this sense poplar production, including industrial material and biomass for energy, can contribute to reducing emissions of climate-altering greenhouse gases (Tedeschi et al. 2005). The long duration of the plantations on agricultural land, with lower soil disturbance, results in an increase of organic content and fertility in comparison with annual agricultural crops. Poplar cultivation can adapt well to scenarios of global changes, with productivity gains under conditions of higher concentration of atmospheric CO_2 (Miglietta et al. 2001; Liberloo et al. 2005; Luo et al. 2006). Finally, the storage of carbon in poplar wood has a long life cycle thanks to the use of wood in furniture and other products that can be further recycled (Lovarelli et al. 2018).

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

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

Figure 31 *- Rural landscape with intensive poplar culture in a floodplain area*

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

Cultivated poplars diversify the agroforestry environment, form part of the ecological network in the often monotonous and relatively low-biodiversity landscape of agricultural areas, create niches with conditions favourable for the survival of animal and plant organisms, and can serve as windbreaks (Fig. 31).

Examples of high-density poplar plantations with phytoremediation purposes have been implemented in Northern Spain, in areas of former mining use (Castaño-Díaz et al. 2018). Currently, a public-private consortium in which INIA-CSIC participates is also exploring the possibility of irrigation with wastewater from the agri-food industry in a circular economy context (Pradana et al. 2020).

6. CONCLUSION AND OUTLOOK

Poplar research and experimental activities carried out for several time in European and non- European Countries, have allowed the development of cultivation practices suitable for obtaining significant quantities of poplar wood to be used for both industrial and energy purposes. Furthermore, breeding works and some biological characteristics of the species such as rapid growth, rooting capacity and easy vegetative propagation have contributed to this, which have led to the development of a highly specialized sector of considerable economic importance, based on the close integration of different production chains. Nonetheless, the urgent action to fighting climate change and its impact and the need to ensure the continuity of wood supplies obtainable from plantations outside the forest, require the adoption of new possibilities for innovative cultivation models and forest reproductive materials (FRM) with greater adaptability and resilience, to be proposed and disseminated as an alternative to conventional ones.

The indications given in these guidelines aim at the use of new selected genotypes (FRM), more resistant to biotic and abiotic stress, to be tested also in non-highly specialized plantations based on clonal mixtures or in polycyclic and polispecific stands, also in order to improve the biodiversity and ecosystem services, made more available with these new planting systems.

Although the results obtained so far are certainly interesting and encouraging, the validation of these materials and methodologies requires further investigations with the possibility of carrying out comparative tests in several environments and counties in EU, with different pedological and climatic characteristics, as well as the possibility of a better comparison of the results obtained in different sites for studies and in-depth analysis on possible future scenarios.

In perspective the adoption of cultivation models more environment-friendly and less-energy consuming, besides the selection of clonal varieties well adapted to climate change are a priority objective of many public institutions and private companies of the forest sector.

The Sustainable Forest Management will have a key role in reaching the European Green Deal objectives by year 2050 and poplar cultivation offer great opportunities to build a green economy and to face the challenges of climate change and in Europe.

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