Populus L. (*Populus alba* L. and *Populus nigra* L.)

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Propagation

Seed propagation

Populus alba (white poplar) and *Populus nigra* (European black poplar) are heliophilous (shade-intolerant) forest tree species. *P. alba* shows optimal growth in temperate climates, on well-drained, deep, silty or sandy-silty soils. *P. nigra* thrives on deep, nutrient rich, medium-textured soils with a pH of 5.5–7.5 (Richardson et al., 2014). Both species are dioecious thus requiring outcrossing. Their reproductive structures consist of inconspicuous flowers in pendulous catkins. Male catkins are reddish-purple, while female catkins are greenish; both primarily are located in the upper crown. Anthesis precedes foliar development, typically between February and April, depending on climate. Pollination is anemophilous. The fruits are oblong-conic capsules, approximately 4 mm in length, maturing from March to June. Seed are dispersed by wind and water, with mature trees producing seeds annually.

Seed collection is conducted from March to June, employing various methods including long-handled cutting tools, ground collection, or whole-tree harvesting. Timing is critical, as collection must coincide with the onset of capsule dehiscence, necessitating careful field monitoring due to rapid seed dispersal. Premature collection is contraindicated, as seeds must reach full maturation. A recommended practice involves harvesting branches bearing early-ripening catkins and rapidly transporting them to a greenhouse (Vujnović et al., 2023). The cut ends are placed in water-filled containers and the branches are covered with a breathable cotton sheet to contain the seeds following capsule opening. Under semicontrolled greenhouse conditions, where day temperature ranged between 15°C and 34°C, and adequate humidity was maintained, catkin dehiscence and seed release occurred within 24 h. A single meter-long branch may yield four to seven catkins, each containing an average of 15 seeds per capsule (Vujnović et al., 2023). Postharvest maturation of *P. nigra* catkins at room temperature for 3–5 days facilitates capsule dehiscence and seed release.

P. nigra seeds have white silky hairs (Fig. 11.33), facilitating wind dispersal over long distances (Barsoum, 2001). While removal of the silky hairs is optional, it simplifies seed handling. Seeds can be separated from the hairs through mechanical abrasion using a 2.38 × 2.38 mm mesh sieve and compressed air (Vujnović et al., 2023). Although *P. nigra* seeds exhibit high germination and vigor, their limited energy reserves restrict longevity to days or weeks (Moss, 1938; Muller et al., 1982; Johnson, 1994; Van Splunder et al., 1995; Braatne et al., 1996; Karrenberg and Suter, 2003). Due to their rapid loss

Figure 11.33 Upon maturation, *Populus nigra* capsules split open to disseminate their short-lived, pappus bearing seeds with cottony hairs. *(Zvonimir Vujnovič.)*

of viability at ambient temperature and humidity, seed processing should be completed within 1 week after collection.

Seeds of *Populus* spp. are classified as suborthodox (Bonner, 2008) or intermediate (Suszka et al., 2014; Michalak et al., 2015). Seed viability can be maintained for ~4 weeks at 4°C under non-drying conditions (Gosling, 2007). For long-term storage (several years), seed moisture should be reduced to 5%–8% and stored in airtight containers at 4–5°C. Ultra-long-term storage requires temperatures below 0°C (e.g., −18°C) with 6%–8% moisture content. Rehydration of long-term stored seeds must be gradual to prevent imbibitional damage. Germination under controlled conditions requires no pre-treatment, with an optimal temperature of 20–25°C. Seed characteristics of *P. nigra* and *P. alba* are summarized in Table 11.48.

Vegetative propagation

Populus species are easily propagated vegetatively using hardwood and root cuttings. Optimal cuttings should be harvested from healthy, vigorous mature branches located in the lower part of the tree crown or from new shoots. Cuttings are typically 10–15 cm in length, containing 10 internodes, or 10 cm in length with five internodes.

Table 11.48 Characteristics of seed lots of *Populus nigra* and *Populus alba*.

Species	Purity (%)	No. seeds/kg	Germination capacity (%)
P. nigra	85–99 (92)	1,000,000–1,100,000 (1,050,000)	77–95 (86)
P. alba	85–99 (92)	1,600,000–1,800,000 (1,700,000)	60–95 (78)

Mean values in brackets.
Piotto et al. (2001), Bonner (2008), Prada et al. (2008), Suszka et al. (2014), Michalak et al. (2015).

For *P. nigra*, cutting diameters should range from 8 to 20 mm (Sabatti et al., 2001), with a general length of 20–30 cm (Fig. 11.34). Cuttings can be harvested both in winter and summer. Winter cuttings are collected from December to March, with early spring collection (February–March) in Mediterranean climates. Cuttings are stored in a cool, humid environment, either in cold storage, buried in sand, or within sawdust to maintain moisture (Bonner, 2008) until planting in the ground or pots in March.

Auxin application is generally unnecessary for propagating *Populus* cuttings. For *P. alba*, propagation success is highly influenced by ortet genotype (Prada et al., 2008), with substantial mortality when propagating diverse clonal material (Sekawin, 1975). For recalcitrant genotypes, rhizogenesis can be enhanced by using internodal material immediately below a node. This material should be subjected to a water pretreatment at 16°C under darkness until root initiation (Phipps et al., 1983), followed by transplanting to a rooting bed at 20°C. The enhanced root development observed in nodal-proximal regions likely results from localized concentration of endogenous root-promoting phytohormones.

Propagation using current-year shoots (green cuttings) collected in July and August requires careful moisture management (Barsoum, 2001). These cuttings are highly prone to desiccation and root poorly if not handled properly. Immediate immersion in water is

Figure 11.34 Hardwood cuttings as a potential source for valuable *Populus nigra* genotype propagation. *(Zvonimir Vujnovič.)*

crucial to maintain turgor and prevent desiccation. Green cuttings show the highest rooting for *P. alba*, probably because mother trees are in optimal physiological condition for vegetative propagation at that time (Harfouche et al., 2007).

Populus species can also be propagated via root segments, which can form roots, be used directly for plant production, or serve as green cuttings.

In vitro propagation of *Populus* spp. is feasible using catkins, stem segments, and axillary leaf buds (Ahuja, 1987). This technique involves cultivating tissue explants under controlled laboratory conditions to generate new plants. While in vitro methods facilitate the mass production of genetically uniform individuals (Bonner, 2008), the high costs in time, labor, and resources limit its practicality for large-scale forestry (Suszka et al., 2014; Michalak et al., 2015).

Seedling cultivation

Vegetative propagation is the main method for *Populus* spp. cultivation in nurseries, as it is easier than seed propagation, ensures genetic uniformity (a crucial factor for timber production), and enhances plant survival. Where greenhouse facilities are available, cutting cultivation can start in early December, coinciding with the initiation of preparing cuttings from mother stock plants. In nurseries without heated greenhouses, cuttings can be stored in cold storage or buried outdoors in soil. To prevent desiccation during storage, cuttings should be wrapped in damp jute bags. Greenhouses should be maintained at optimal temperatures, with supplemental heating during cold, low-light periods, along with adequate moisture, to promote root development.

Bareroot plants

Cuttings should be planted vertically in rows, with one-third of the cutting (containing one to three buds) remaining above the ground. Care must be taken to avoid damage to the apical bud and bark. Spacing is critical for plant development. For establishing mother plant fields, high planting density with reduced inter-plant distances are recommended. Rueda Fernández (2013) suggest densities ranging between 25,000 and 50,000 plants/ha for timber with *Populus* clones coppiced up to 2 or 3 years. For *P. nigra*, Maestro-Tejada and Alba Monfort (2013) recommend a spacing of 2 × 3 or 3 × 3 m for mother plant fields coppiced up to 8 years. Wider spacing is recommended for plants used for forestation. Excessively high densities result in etiolated growth, characterized by slender stems with reduced mechanical strength, making plants more susceptible to bending and wind damage after transplanting. Row spacing commonly ranges from 1 to 2 m, with intra-row spacing of 30–40 cm.

Supplemental irrigation is essential, particularly during extended dry periods, to ensure timely plant development. Irrigation frequency, typically every few days, depends on the weather conditions and plant size. In greenhouse settings, selective pruning of lateral branches may be implemented to promote apical dominance and enhance plant vigor, improving their resistance to stress in field conditions after transplanting.

Fertilization should be tailored to correct nutrient deficiencies or suboptimal growth. Specific formulation, application rate, and frequency must be determined based on visual diagnosis and site-specific soil analysis. For field-grown plants, an initial application of balanced NPK fertilizer (e.g., 10-10-10) at a rate of 50–100 g/plant is recommended for plant establishment. Annual spring applications of 100–150 g/plant should continue in subsequent years, with an optional mid-season fertilization in late spring or early summer to boost growth. Mature trees ($\geq$5 years) typically require fertilization every 2–3 years at a rate of 300–500 g/plant.

Following leaf emergence, management of defoliating insect populations may be necessary. Insecticide selection, application rate, and frequency should be determined based on local pest pressure and established recommendations. Pyrethroid insecticides, including Cypermethrin (0.5–1 L/ha), Permethrin (0.5–1 L/ha), and Deltamethrin (0.05–0.1 L active ingredient/ha; equivalent to a 0.05%–0.1% solution with 100 L/ha), demonstrate efficacy against a broad spectrum of defoliating insects, such as poplar leaf beetles, tent caterpillars, and aphids. Biological insecticides like *Bacillus thuringiensis* (2.5–5 L/ha) are specific to larvae. To prevent herbivore damage, nurseries should be enclosed with a robust fence.

During harvest, roots should be thoroughly buried in moist soil (Božič et al., 2021), and plants should be covered with a shading net to minimize desiccation. Typically, 1 + 2 or 2 + 3 plants are used for forest planting.

Seed propagation requires seed sowing immediately after collection, without pretreatment. Direct seeding uses approximately 3000 seeds/m^2 on mechanically prepared seedbeds to facilitate sowing. Seeds with intact white silky hairs are preferred, as these structures aid adhesion to the moist substrate. After germination, adequate hydration is crucial for seedling establishment. Initial nutrient requirements are relatively low, as seedlings can effectively take up soil nutrients. Seed size influences germination success and seedling development. Seeds should not be covered or, if pressed into the substrate, should not be buried deeper than 2–3 times their diameter. Germination typically occurs within 12–24 h after sowing. Seedlings are highly vulnerable to drought stress during the first month.

Container plants

Containerized cultivation provides advantages over bareroot methods, particularly for out-of-season planting or challenging site conditions. For container-grown cuttings, container size is a critical factor. Initially, planting in smaller containers may require subsequent transplanting to larger containers to facilitate robust root system development. The final container volume depends on the production objective. Generally, a minimum volume of 6 L is necessary to provide enough space for roots to grow in all directions. Container depth should be at least 30–40 cm to facilitate unrestricted root growth.

A suitable growing medium for cuttings can be a 1:1:1 mixture of peat (pH near 7), fine-grained sand, and perlite, which promotes moisture retention and aeration (Vujnović et al., 2023). Commercial growing media mixtures are also available. Consistent irrigation is essential for successful rooting of cuttings. If rooting hormones are employed, Indole-3-butyric acid (IBA) can be applied at concentrations of 1000–3000 mg/L to stimulate root primordia formation (Harfouche et al., 2007). As with bareroot stock production, cuttings should be planted vertically in the growing medium with approximately one-third of the cutting containing one to three buds remaining above the ground.

For seed propagation, starting cultivation in small pots (up to 70–75 cm^3) is recommended. Once established, seedlings can be transplanted into larger containers ranging from 300 mL to 3.5 L (Vujnović et al., 2023). Under semicontrolled conditions, seedlings grow rapidly and develop dense root systems. The same substrate used for cuttings can be employed for seedling cultivation. *P. nigra* seed germination typically occurs rapidly (within 24–48 h) given adequate moisture (Siegel and Brock 1990; Van Splunder et al., 1995). However, seedlings are shade-intolerant (Gage and Cooper 2005), making sufficient light crucial for successful germination. Postemergence, high humidity and temperature predispose seedlings to fungal diseases, necessitating timely fungicide applications.

Nutrient leaching from substrates is a concern; therefore, supplemental fertilization is recommended. During the early rooting stage, a balanced or moderate amount of N is necessary to support initial growth, with NPK (relative proportions of 1:1:1 or 2:1:2). During active vegetative growth, we recommend that the relative proportion of N, P, and K in the fertilizers to be 3:1:2 or 4:1:2, as higher N supports shoot development, and higher P promotes root growth. Finally at the plant maturity stage, the relative NPK proportion should be 2:1:3 or 1:1:2, where increased K enhances stress and disease resistance, and general plant health. When flowering and seed production occur, an NPK ratio of 1:2:2 or 1:3:2 supports reproductive processes, with increased P and K facilitating flowering and fruiting.

Controlled-release fertilizers offer a single-application approach for season-long nutrient provision in containerized production and are typically incorporated into the substrate at a rate of 3–5 g/L.

Field establishment

Preplanting hydration is crucial, particularly during dry winters. Soaking bare roots in water for 1–2 days prior to planting is recommended. Timing during spring planting should coincide as closely as possible with anticipated rainfall, ideally within a 15-day window. Briefly immersing seedling roots in a muddy slurry before planting can increase establishment (Božič et al., 2021). However, autumn planting is generally preferred due to the increased frequency and severity of dry springs in many regions. If immediate planting is not feasible, plants must be protected from desiccation. Bareroot seedlings should be heeled in by covering the roots with soil, while container seedlings can be stored above ground, protected from direct sunlight, and watered as needed.

Populus alba is a heliophilous species, adapted to full sunlight, which thrives on neutral to alkaline substrates and is tolerant of heavy soils and moderate salinity. It forms dense stands or grows sparsely in lowland or swampy riparian zones. In cooler climates, it cooccurs with *P. nigra*, while in warmer or coastal regions, it becomes the dominant species due to its thermophilic nature. Weed competition management is crucial during the initial 1–2 years postplanting, particularly in specific natural site conditions. Rotary cutting and manual removal of climbing plants (e.g., wild hops and clematis) using hand shears can help to minimize damage to young plants (Sallmannshofer and Ruhm, 2021).

Before planting, it is advisable to analyze soil pH, nutrient levels, and texture (sand, silt, clay) to optimize site selection and preparation as poplars thrive better on loamy soils with optimal drainage and a pH between 5.5 and 7. Correction of nutrient imbalances by adding fertilizers or organic amendments based on test results is suggested Although poplars tolerate wet conditions, proper drainage is necessary to prevent root rot. In compacted soils, using a subsoiler to break up the soil to a depth of at least 30–40 cm is recommended. Fertilization should be tailored to different growth stages. Before planting, a balanced fertilizer (e.g., 10:10:10 NPK), typically, a rate of 50–100 kg/ha is recommended. After planting, during the first year, a fertilizer enriched in N can be especially beneficial for root and shoot growth, with a dose of 50–100 g/tree. Fertilization should take place in early spring (before or at planting) and additional fertilization can be supplied in early summer. We recommend avoiding late-season fertilization (late summer or fall), as it can promote late-season growth, increasing plant vulnerability to frosts. For mature trees, fertilization may not be necessary unless soil nutrients are low. However, periodic maintenance fertilization every 2–3 years can help maintain health and productivity.

Deer herbivory presents a significant threat to poplar establishment, with damage manifesting as bark stripping and foliage and bud browsing. Mitigation strategies include physical and chemical deterrents. Electric fencing, while effective in North America (Brenneman, 1982), requires maintenance to ensure integrity, including vegetation control to prevent grounding. High-tensile woven wire fencing, although offering a robust physical barrier (Dickman and Lantagne, 1997), entails high initial investment costs. In certain regions, such as Croatia, localized protection methods involve wrapping individual seedlings in reeds secured with wire. Although more affordable than woven wire fencing, this method demands increased labor for individual plant treatment.

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