THE PRACTICE AND PHYSIOLOGICAL BASIS OF COLLECTING, STORING AND PLANTING POPULUS HARDWOOD CUTTINGS

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Abstract.--Producing healthy hardwood cuttings for *Populus* plantation establishment requires attention to the management of clonal nurseries, timely collection of cuttings, adequate grading of cuttings, storage temperature and conditions, preplanting treatments, and planting operations. Recommended nursery practices are outlined, along with their grounding in such biological factors as stem anatomy, moisture content, induction of dormancy, availability of carbohydrate reserves, and freedom from insects and pests.

Hybrid *Populus* plantations can be successfully established with hardwood cuttings of selected, fast-growing clones. Nursery managers and foresters in Europe and North America have a wealth of experience and knowledge about collecting, storing and planting hardwood cuttings, yet our understanding of the biological reasons for these practices is not nearly as thorough. However, physiological studies have offered many generalizations about cutting production that have further refined nursery practices. The empirical knowledge of each of the practices involved in producing healthy cuttings and the physiological bases for these practices are summarized in this paper, drawn principally from the literature on *Populus* and on our experiences at the Forestry Sciences Laboratory in Rhinelander, Wisconsin.

The recommended production practices are a sequence of activities, beginning with the establishment of clonal nurseries, as represented in Figure 1. All of these practices are directed toward the ultimate objective of producing trees that have high survival rates and maximum vigor and height growth, particularly during the first growing season. With early rapid growth, the time is reduced that costly weed control treatments are required and that terminal shoots are out of reach of browsing deer.

The findings reviewed in this paper are limited to hardwood cuttings of *Populus* clones that root easily from hardwood cuttings. Because of their stem anatomy, roots begin to emerge from the bark of these cuttings within several days of

Figure 1.--Required practices and factors affecting the production and establishment of healthy cuttings.

CLONAL NURSERIES ⟶	COLLECTION ⟶	CUTTING SELECTION ⟶	STORAGE ⟶	PRE-PLANT TREATMENTS ⟶	PLANTING OPERATIONS ⟶	HEALTHY PLANTATIONS
Establishment Nutrition of Parent Plant Pest Management	Time of Year Equipment	Diameter Position Absence of Disease or Wounds	Duration Temperature Conditions Moisture Pathogens	Duration Soaking in Water Fungicide Dips	Site Preparation Soil Moisture Planting Equipment Weed Control	

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soaking in water. One-year-old stems and some older wood of poplars (Populus sections Aigieros and Tacahamaca), willows and other species have performed root primordia, which generally originate in ray tissue of the secondary phloem (Braun 1963, Haissig 1974, Hartmann and Kester 1975, Swingle 1929, and Smith and Wareing 1972a). These adventitious roots only need to increase in length and size. Wound roots may also be produced from the base of the cutting, sometimes following callus formation. These wound roots are relatively unimportant in species with preformed root primordia, but become the adventitious roots in species and plant material that lack preformed root initials. Cuttings of the Leuce section of Populus have few preformed primordia, and are much more difficult to root (Farrar 1977, FAO 1979). Many Populus clones can also be propagated from roots, suckers, or grafts (FAO 1979, Hartmann and Kester 1975, and Williams and Hanks 1976). Softwood (or greenwood or tip) cuttings taken from non-dormant rapidly-growing shoots have received most of the attention in empirical and physiological studies of cuttings. Research efforts on softwood cuttings, and on hardwood cuttings of species or plant material that lacks preformed root primordia, have been directed toward altering environmental conditions and applying chemicals (usually hormones such as auxin) that promote root initiation.

Clonal Nursery Management

Managers who plan to establish large plantations or who want to control the quality and availability of hardwood cuttings should install and maintain their own clonal nurseries. Each hectare of Populus plantations established at spacings of 1 m^2/tree requires 10,000 cuttings (4,000/acre), and 2500 cuttings for spacings of 4 m^2/tree (1,000/acre), so large numbers of cuttings must be produced and handled.

Generally, 4 to 10 whips are produced from each rootstock, and 5 to 8 20-cm cuttings can be obtained from each whip (depending on the clone and shoot condition), thus each healthy rootstock could yield from 20 to 80 cuttings annually. A clonal nursery established with 1 or 0.5 m between trees within rows and 1 m between rows allows plenty of room for tractors and equipment used for harvest of cuttings (Hansen, Moore, Netzer, Ostry, Phipps and Zavikovski 1982). About 10,000 rootstocks could be maintained per hectare, and about 200,000 cuttings produced per hectare annually. Additional acreage must be allotted to roads and irrigation lanes, and some consideration given to the failure of rootstocks to resprout. For Populus plantations established in the southern United States, McKnight (1970) recommended that clonal nurseries be established with 0.3 m spacings within rows and 1 m between rows, to maximize production of unbranched whips. Many clonal nurseries are also established at wider spacings, typically 1 m between trees within rows and 3 m between rows, which facilitates cultivation and increases the number of whips produced per rootstock. Spacings of up to 3 m between rows reduce incidence of some diseases such as Septoria canker and allow sanitation practices such as disposal of infected residues and soil cultivation to be undertaken more easily (Hansen et al. 1982).

Maintenance of healthy nursery plants is essential, since cutting vigor has been related to nutrition of the parent shoot (FAO 1979, Hartmann and Kester 1975). Clonal nurseries at Harshaw Experimental Farm (10 miles west of the Forestry Sciences Laboratory, Rhinelander, Wisconsin) have been established from disease-free hardwood cuttings, fertilized, irrigated, and maintained weed-free by mechanical cultivation and herbicides. McKnight (1970) recommended that a well-drained site be chosen, and that nursery beds be fumigated if cottonwood had been grown there previously. The Food and Agriculture Organization publication Poplars and Willows (1979) recommends that nurseries be established on fertile, well-drained soils; fertilized; maintained free of weeds; and protected against insects and disease. Clones which are particularly susceptible to diseases should be removed from the clonal nursery.

After 1 or 2 years, the planted trees are cut back to within 15 cm of the ground, and the resultant coppice growth harvested annually thereafter for cuttings. Rootstocks can normally be maintained for 4 to 8 years until sprouting vigor is markedly reduced. Although the author knows of no study on the longevity of Populus nursery rootstocks, there have been some studies on the effect of season of harvest and cutting method on coppice regeneration of plantations. DeBell and Alford (1972) reported that sprouting vigor was greatest when harvests were made during the dormant season, as would be the case for cutting production, and that cutting height and angle had no effect on initial sprouting of stumps established from P. deltoides cuttings. Hansen et al. (1982) recommend that stumps be cut 15-20 cm above the ground each year. Phipps (personal communication) offered the observation that some sprouts grow nearly horizontal to the ground when stumps are cut nearly at ground level. Lust and Mohammady (1973) suggested that rupture of the bark and bursting of the stool be avoided, that the cutting surface be as close to the soil as possible so that some shoots develop their own root systems, and that the cut be smooth and angled so that water can run off. Crist and Mattson[2/] found that stump mortality was

[2/] Crist, J. B., J. A. Mattson and S. A. Winsauer. 1983. Effect of severing method and stump height on coppice growth. This publication.

significantly greater for *Populus* 'Tristis #1' trees severed in February with a shearing head than for stumps sawn with a chain saw, with some mortality caused by shearing head's damaged to adjacent stumps.

Collection of Cuttings

Collecting and sorting cuttings is still labor-intensive, and there are many opportunities for reducing labor requirements and costs of processing cuttings. At the Harshaw Experimental Farm, a side-mount sickle bar mower is used, that has a sharp bar and is in good operating condition, to minimize ragged cuts, splitting, and other damage to stumps. The mower is followed by a tractor-drawn wagon, onto which two workers load the harvested whips. Harvest systems are being developed that will cut whips, tie them in bundles and load them onto wagons for transport to the processing area (Hansen *et al*. 1982).

Hardwood cuttings must be collected after shoots achieve some degree of dormancy and before the end of dormancy is reached in the spring. Most commercial nurseries collect hardwood cuttings from December to early March, as displayed in Table 1.

In regions where snow cover and cold temperatures hamper the ability of field crews to collect cuttings in mid-winter, cuttings may be collected in late fall. In the fall of 1980, hardwood cuttings of 7 hybrid *Populus* clones (whose parentage is listed in Table 2) were collected monthly from the Harshaw Experimental Farm from mid-September to mid-December. Cuttings were stored over the winter at temperatures from 2 to -20°C, and planted in mid-May (Fege and Phipps 1982). A similar study was conducted the following year, with cuttings of 3 clones collected in mid-October and mid-December, stored at 3 temperatures, and planted in May. As shown in Table 3, survival was poor for all cuttings collected in September. Survival and height of cuttings collected in mid-October were not significantly different from cuttings collected in November or December for any of the clones, with the exception of clone group 5262 collected in mid-October and stored at -20°. Bud set was 2 weeks later for clone group 5262 than clone group 5334 or clone 5260, and this suggests that plant material of clones 5262, 5263, 5272, and 5377 was not sufficiently hardened by mid-October to withstand -20° temperatures. In the 1981-82 study, overall height growth was much less for all treatments and clones because of lower temperatures in June and poor weed control in the plots, but survival patterns were similar. Whereas overall survival of clone 5260 was poor in the 1980-81 study, its performance paralleled that of clone 5334 in 1981-82.

Some studies of effects of collection date must be interpreted cautiously, since cuttings were planted in greenhouses immediately after they were taken from the field. Field managers would not be able to plant cuttings in January or February. Yet, these studies offer additional insight into the physiological conditions of parent material during the winter. Allen and McComb (1956) found greater survival and rooting of cuttings collected in March and planted immediately, than those collected and planted in November or December. Farmer (1966) found that *Populus deltoides* cuttings collected in Mississippi in early February rooted better than those cut in December, January or early March, when planted immediately after collection. Phipps and Netzer (1981) collected cuttings of 4 clones monthly from November to March and planted them immediately in a greenhouse, and found that rooting and bud break occurred more rapidly in the later-collected cuttings, and that the lowest rate of rooting was for cuttings collected in November. Cuttings collected in November and stored at 2.8°C for 5 months had the same rate of rooting as March-collected cuttings, suggesting that proper storage may permit earlier collection of cuttings with no loss of rooting ability.

Some degree of dormancy must be achieved before cuttings are harvested. Physiological changes accompanying the process of dormancy induction include cessation of growth, increase in stored reserves, development of cold hardiness, and leaf fall. Our studies have shown differences in carbohydrate content in dormant *Populus* shoots throughout the winter.[3/] Starch content is greatest in early fall, and declines progressively to minimum levels in December through early March. Content of total sugars increased from September to December, maintaining high levels until early March. Although a direct relation between carbohydrate content and field performance has not been established, we assume that these carbohydrate reserves provide the energy for early growth and emergence of functioning roots.

Selection for Cutting Size and Position

Entire whips are generally sawn into cuttings of about 20 cm in length, then sorted and bundled. After entire whips are brought in from the field, branches are clipped from the mainstem and discarded, then 4 to 6 whips are held together and sawed into 20-cm lengths with a band saw. The small-diameter shoot tip and any portion of the stem base which is less than 20 cm in length is

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3/ Fege, A. S. and G. N. Brown. 1983. Carbohydrate distribution in dormant *Populus* shoots and hardwood cuttings. In preparation for *Forest Science*.

Table 1. Commercial nursery practices for collection and storage of Populus hardwood cuttings.[1/]

	Collection Date	Storage Conditions	Planting or Shipping Date
1.	January and February	Stored as cuttings, covered with moist peat moss, at 1 to 2°C, or uninsulated barn as low as -7°C.	May
2.	Late winter, while still dormant	(Planted as soon as possible; kept in cellar until planting.)	
3.	Mid-December through February	Stored as cuttings in wet peat moss or shingletoe in wooden crates lined with plastic (10 bundles of 100 cuttings/bundle in each crate) at -3 to 0°C.	Late April to June
4.	February and March	Bundles of 15-cm cuttings dipped in Chlorox, put in wet peat/sand mixture, at 1 to 2°C in 100 percent humidity room.[2/]	After last frost (May)
5.	January and February	Bundles of 150 15-cm cuttings dipped in Captan-Benlate solution, and 6 to 8 bundles stored in 30-gallon plastic trash bags at -1°C.	May
6.	Mid-December to late February	Stored as cuttings in plastic bags held in cardboard boxes at -2°C (bud break occurs in cuttings stored at 0 and 2°C).	Late March to late May
7.	November and December	Stored as bundles of 12-cm cuttings placed in wooden flats with basal ends in moist sphagnum moss. Held at 10 to 15°C for 2 weeks to initiate callus formation and roots, then stored at 1°C.	Mid-May
8.	December	Stored as entire whips in humidity-controlled room, at -2°C until March. Whips sawed into cuttings, bundles dipped in fungicide and stored at 1°C in mulch until planting.	Late April
9.	December	Whips harvested in December, sawed into cuttings in January, and stored in plastic bags below 0°C.	April and May
10.	December and January	Stored as 32-cm cuttings in plastic bags in unheated barn. In late February, cuttings moved to cold storage at -1°C.	May and June
11.	During dormancy[3/]	Stored as cuttings at -2 to 0°C, bundles set in 5-7 cm of moist sand, covered with wet burlap. If cuttings taken immediately before planting, cuttings are held in aerated ponds for 3 days or more.	December to early March (southern U.S.)

1/ Nurseries located in Maryland, Michigan, Minnesota, Montana, Ohio and Pennsylvania.

2/ Mention of commercial products does not constitute endorsement by the University of Minnesota or the U.S. Department of Agriculture.

3/ From McKnight (1970).

Table 2. Parentage of hybrid Populus clones.

Original Number	North Central Number	Parentage[1/]
---	5260	(P. tristis x P. balsamifera) 'Tristis #1'.
NE-387	5262	P. 'Candicans' x (P. x berolinensis)
NE-386	5263	P. 'Candicans' x (P. x berolinensis)
NE-1	5272	(P. nigra x P. laurifolia) 'Strathglass'
NE-252	5334	P. deltoides var. angulata x P. trichocarpa
---	5377	P. x euramericana 'Wisconsin #5'
---	9922	Populus spp.

1/ From Hansen et al. (1982). Names according to Dr. Donald Dickmann, Department of Forestry, Michigan State University, East Lansing, MI. 48824.

Table 3. Field performance of hardwood Populus cuttings, by date of collection and storage temperature.

Date of Collection	Percent Survival 2	-3	-10	-20	Height of Surviving Trees (cm)[1/] 2	-3	-10	-20
1980-1981 Study								
5262 group[2/]								
September	76	0	1	0	87	-	-	-
October	86	92	94	14	111	107	115	-
November	100	93	93	97	111	106	113	111
December	95	96	95	96	97	114	111	115
5334 group[3/]								
September	77	7	0	0	78	-	-	-
October	87	90	88	78	101	97	103	82
November	72	62	53	78	77	65	75	80
December	97	90	82	88	85	108	95	92
Clone 5260								
September	7	10	23	0	-	-	-	-
October	30	3	100	93	-	-	61	74
November	17	7	93	97	-	-	68	59
December	53	37	97	63	-	-	71	49
1981-1982 Study[4/]								
Clone 5262								
October	65	70	20	-	33	45	-	-
December	82	85	75	-	57	45	42	-
Clone 5334								
October	92	88	75	-	35	36	25	-
December	98	92	82	-	45	37	35	-
Clone 5260								
October	92	80	100	-	21	26	36	-
December	90	86	80	-	20	22	29	-

1/ Generally for treatments with greater than 60 percent survival.

2/ Clones 5262, 5263, 5272 and 5377.

3/ Clones 5334 and 9922.

4/ Cuttings held at 2, -3 and -10°C in 1981-1982 study.

discarded. At most nurseries and research stations, teams of workers sort cuttings manually. Careful labeling of the clone number for each batch of cuttings is essential. At Harshaw Experimental Farm, cuttings that do not meet the following grading standards are discarded: (1) diameter greater than 0.95 cm, (2) no evidence of mechanical damage such as stripped bark, split or crushed ends, or broken or missing buds in the top third of the cutting; (3) no signs of disease or insect infestation such as fruiting bodies, galts, lesions, eggs, or borers; and (4) green inner bark and no dessicated or shrivelled outer bark. The acceptable minimum and maximum diameter values vary by clone and generally are set to exclude the terminal cutting and cuttings made from the upper portions of small-diameter whips. All cuttings should be oriented in the same direction, to eliminate the need for such orientation by the planting crew.

Two well-accepted generalizations may be made about cuttings: larger cuttings perform better than smaller cuttings, and cuttings taken from the shoot terminus root poorly. However, it is difficult to separate the effects of cutting diameter, cutting length, and position of the cutting within the parent shoot. Larger-diameter cuttings had higher survival rates and produced taller shoots and shoots with greater dry weight, in studies with 20-cm cuttings in Michigan and Wisconsin (Dickmann, Phipps and Netzer 1980). Clonal response differed greatly, with shoot height differences of 14 percent between largest- and smallest-diameter cuttings for one clone, and 250 percent for another clone. For 3 of the clones tested, survival was 20 to 40 percent less for cuttings with diameters of less than 6 mm, suggesting that this may be a minimum diameter for cuttings used in field plantings of many clones. Bowersox (1970) found that height growth was correlated with cutting diameter for the first 2 years after planting, but height after 3 years was not related to cutting diameter.

Rooting and field performance of planted cuttings varies with distance from the shoot tip. Bloomberg (1963) observed that rooting capacity of *Populus* clones increased with distance from stem tip, and reported that basal cuttings of 3 *Populus* clones had significantly greater root number, total length and weight of roots than cuttings taken from the second 15-cm length from the tip. Hansen and Tolsted (1981) found that cuttings taken from branches, 1-year-old and 2-year-old stemwood of a difficult-to-root clone (*P. alba*) had comparable survival rates for any given diameter class as cuttings taken from the main stem (Table 4). Cutting survival increased as cutting diameter of both stem and branches increased, and was essentially due to the effects of position. They recommended that branch material be selected on the basis of diameter, but stem material be selected on the basis of both diameter and position, since some of the smaller-diameter basal cuttings still had high survival rates. Height growth increased with cutting diameter for the first 2 months that plants were grown in the greenhouse, but no further effect on height growth was observed. Allen and McComb (1956) found that, with constant cutting diameter, cutting survival and number of roots decreased with age of the parent shoot. They found no survival differences for cuttings of three diameters (0.52, 1.12, and 2.1 cm).

The effect of diameter and stem position on field survival may be attributed to many anatomical and physiological factors. Smith and Wareing (1972a) have shown that preformed root primordia develop acropetally in 1-year-old *Populus* x *robusta* coppice shoots throughout the summer and fall, thus root primordia in basal regions develop earlier. Bloomberg (1962) has shown that the anatomy of the basal region of 3 *Populus* hybrids had wider and fewer vessels than the top region, wider sieve tube zones, and a thicker periderm, thus is more favorable for water storage, retention and translocation. Total carbohydrate reserves are also greater in larger-diameter cuttings. Bud development varies widely along 1-year-old *Populus* stems with poorly developed buds at the stem base. In addition to developing into the new shoot, these buds also affect root development. Smith and Wareing (1972b) found that removing buds from *Populus* x *robusta* cuttings decreased the emergence of root primordia.

Table 4. Relation of cutting numbers and survival to cutting diameter, after 3 months.[1/]

	Stem and Branches		Stem		Branches	
	#Cuttings	% Survival	#Cuttings	% Survival	# Cuttings	% Survival
All cuttings	357	29	144	39	213	22
Greater than 9 mm	102	53	85	53	17	53
Greater than 15 mm	20	65	–	–	–	–

[1/] Hansen and Tolsted (1981).

Cuttings are commonly 20 cm (8 inches) in length, although longer cuttings are known to survive better than shorter cuttings under such conditions as moisture stress in the field. On shallow soils, shorter cuttings are generally recommended, and on deeper soils, greater survival will be achieved with 50- to 80-cm cuttings inserted to a depth of 30 to 40 cm (FAO 1979). McKnight (1970) advocated 50-cm cuttings for establishing Populus deltoides plantations in the South. Allen and McComb (1956) found that survival, number of roots and shoot growth of 45-cm cuttings was at least double that of 15-cm cuttings.

Parent stems and cuttings should be examined for disease signs, since pathogens causing blackstem, cankers and rusts may be disseminated on planting stock. Blackstem (caused by the fungi Phomopsis, Cytospora and infrequently Dothichiza) can cause deterioration of cuttings, killing them directly in storage or reducing their vigor after planting. Ostry and McNabb (1982) have reported that the presence of each pathogen differed on cuttings collected in Iowa and Wisconsin. The incidence of many Populus diseases and insect pests varies widely by region and locality. Marssonina and Septoria and insect eggs and borers can be present in cuttings, and entire plantations infected if diseased or infested cuttings are planted.

Storage Temperature and Conditions

Most commercial nurseries store cuttings successfully just below or at 0°C for 2 to 4 months before planting (Table 1). Our experience has been that sprouting and root emergence occurs if cuttings are stored just below or above freezing for 5 to 8 months before planting time. For these longer storage periods, cuttings should be held at -10°C or lower to avoid root and shoot development before planting. Cuttings are commonly stored in bundles in one of three microenvironments: (1) moist sand or peat moss around the basal quarter to half of the cutting, covered with moist burlap or held in a humidified environment; (2) in plastic bags in environments where humidity is not controlled; or (3) as entire whips in humidity-controlled rooms.

Generally greater survival and field performance have been achieved by storing cuttings at temperatures several degrees below freezing. For those cuttings stored considerably below 0°C, certain pre-planting treatments may be required for satisfactory growth. Phipps and Netzer (1981) found that cuttings of 4 clones collected in early November rooted and flushed more rapidly if cuttings were stored at 2.8°C than if they were stored at -17.8°C or -3.9°C. This growth retardation was overcome in cuttings stored for one year at -7°C by pre-conditioning the cuttings for 1 or 2 weeks at 2°C then soaking the cuttings until roots began to emerge (Phipps, Hansen and Fege 1983). Phipps and Netzer (1981) found that cuttings of 3 Populus clones stored for 4 months at -18°C and -6°C rooted slower than those stored at either 3°C for 4 months, or at 7°C for 2 months followed by 3°C for 2 months. Nearly 100 percent of the cuttings rooted within 22 days of planting, regardless of storage temperature. Cram and Lundquist (1982) found no significant differences between height of cuttings of the Walker clone (Populus x deltoides Bart. cv. 'Walker') stored at -2°C and 2°C over the winter. However, they reported 82 percent "rooting capacity" of cuttings stored at -2°C from mid-November to mid-May, compared with 73 percent after storage at 2°C and 60 percent after heeling-in outdoors over the winter.

In our studies of 7 Populus clones collected in mid-October or later and stored at temperatures from 2°C to -20°C in 1980-81 planted in 1981, and 3 clones stored from 2°C to -10°C in 1981-82, there were no statistically significant survival or height differences by storage temperature, except that some clones collected in October and stored at -20° or -10°C did not survive (Table 3). The pre-planting treatments of "warming" and soaking may have obscured the differences between cuttings stored at various temperatures. For the 1980-81 and 1981-82 studies, cuttings stored at -10°C and -20°C were transferred to 2°C about 3 weeks and soaked in water 1 week prior to planting; cuttings stored at 2°C or -3°C were soaked only 1 day since shoots and roots had begun to grow during storage. Since cuttings stored at the two lower temperatures achieved the same height growth as cuttings stored at near-zero temperatures, the -10°C and -20°C storage temperatures would be advantageous for field operations, since they allow nursery managers greater flexibility in soaking cuttings and scheduling planting.

Minimizing the incidence of disease is an advantage of storing cuttings at freezing temperatures. Development of molds and other organisms on hardwood cuttings and seedlings during storage reduces field survival. Generally, damage is more common when plants are collected early in the fall, storage temperature is above freezing, temperature of storage chamber is allowed to fluctuate, free moisture is present on plant surfaces, and/or storage period is extended several months (Venn 1980). Ostry and McNabb (1982) have shown that incidence of blackstem fungi is lower and survival of cuttings of two hybrid Populus clones is higher when cuttings were stored at -3°C rather than at 1°C. Cytospora was associated with lower bark moisture in these cuttings.

Cuttings can be bundled and packed in moist sand or peat moss if the storage room has high humidity or if damp burlap covers the cutting bundles. Otherwise, cuttings should be kept in plastic bags during storage. In a study of 5 hybrid Populus clones stored at two locations, cuttings were stored in mulch or plastic bags, or stored as entire whips. For the 3 clones, survival and height growth did not differ significantly between locations or treatments.[4/] For the other 2 clones, there were no differences in either survival or height growth between treatments, with the exception that none of the cuttings stored in the less-controlled environment at Harshaw Farm survived. Cram and Lindquist (1982b) observed that Populus cuttings covered with vermiculite or stored in polyethylene bags at temperatures of -5°C or -1°C showed greater rooting than those stored as bare cuttings, whereas there was no difference between the 3 storage methods at -18°C.

Moisture content in cuttings is influenced by storage conditions. Ostry and McNabb (1982) observed that cuttings stored in plastic bags retained more moisture than those stored unbagged, and resulted in better field survival. In our study of 5 Populus clones stored at 2 locations, moisture content averaged 148 percent for cuttings stored in mulch, 118 percent for those stored in plastic bags, and 84 percent for those stored as entire whips. Cram and Lindquist (1982a) found moisture content to be 136 percent in November-collected cuttings heeled-in outdoors during the winter, with 108 to 123 percent moisture content in cuttings stored at 2°C in plastic bags and 108 percent in cuttings stored at -2°C in plastic bags. It is common practice in France to dip both ends of cuttings in paraffin wax to reduce dessication, with colored wax used to identify the cuttings of different clones (FAO 1979).

Pre-Planting Treatments

The bottom half or three-quarters of cuttings should be soaked in water at about 15°C for 7 to 10 days before planting, until root primordia begin to emerge from the bark and cuttings are fully imbibed. Cuttings may be soaked outdoors in the shade, or in an equipment shed. If cuttings have been stored in plastic bags, the bottom and top of each bag may be punctured to admit water. If roots have begun to emerge and shoots begin to grow during storage, cuttings should be soaked only one day before planting so that moisture content is increased but shoots and roots do not develop further. In order to determine the number of days of soaking needed for root emergence to begin, small tests should be conducted with each clone and storage treatment about a month before planting is scheduled. Nursery managers should soak the cuttings until roots appear as small bumps under the bark surface and begin to break through the bark.

Soaking increases early root growth, essentially extending the growing season. Soaking cuttings for 10 days would be equivalent to a 10 percent increase in the 100-day growing season in northern Wisconsin (Phipps, Hansen and Fege 1983). Petersen and Phipps (1976) found that presoaking stimulated rooting and increased field survival of hardwood cuttings of 3 Populus clones. Root length, root dry weight, percent flush and shoot length increased with duration of soaking (Phipps, Hansen and Fege 1983). In studies of Populus and Salix poles (1.4 to 2.7 m long), Edwards and Kissock (1975) reported that water uptake was most rapid in the first 1-3 days, then followed a logrithmic decline, and that water uptake was maximized by soaking stems vertically rather than horizontally. Shoot and root growth and drought resistance was increased by soaking. Soaking P. deltoides cuttings for 24 hours prior to planting is cited as a method for reducing Dothichiza (FAO 1979), presumably due to the increased moisture content at planting.

Generally, root development proceeds faster at temperatures of about 15°C and under conditions of saturated moisture content. For cuttings which are partly immersed, water should be changed every 2 days or aerated, since oxygen is required for root development. Bloomberg (1963) found that roots produced by cuttings which had moisture content adjusted to 100 percent saturation within polyethylene bags had 5 to 10 times more roots, about twice the total length of roots, and up to 9 times the root dry weight of those produced by cuttings at 50 percent moisture content. When Phipps, Hansen and Fege (1983) made comparisons between soaking 20-cm cuttings to depths of 3 or 15 cm, no significant difference was found for 3 clones, and slightly greater root length and dry weight for only 1 clone, when soaked to 15 cm. Water uptake, bud break, and the emergence of roots proceeded faster in cuttings which were soaked in the dark at 16°, compared with those soaked at 4°C. Bloomberg (1963) held cuttings in polyethylene bags which had moisture content adjusted to fully saturate the cuttings, and found that root number, length and dry weight after 10 days were much lower when cuttings were kept at 5°C, than if they were kept at 15°C or 25°C.

Following observations that soaked cuttings performed far better than unsoaked cuttings when spring weather was exceptionally warm and dry, Phipps and Hansen (1983) evaluated the effects of soil moisture tension on cutting development. Soaking for 4 to 10 days accelerated bud flush over the range of soil moisture tensions (0 to -0.6 bars), with increased shoot length at the high soil moistures. None of the unsoaked cuttings at -0.5 bars flushed by 10 days after

4/Fege, A. S. and H. M. Phipps. 1983. Effect of collection date and storage conditions on field performance of Populus hardwood cuttings. In preparation for Can. J. For. Res.

planting. In field studies of cuttings planted at various dates from snow melt to frost, tree height of soaked cuttings was 13 percent greater than unsoaked cuttings during a wet spring. Allen and McComb (1956) observed 0-20 percent survival in soils at or below field capacity and 61-80 percent survival in soils at moisture contents up to full saturation for 47 days, for unsoaked cuttings. Soaking 50-cm _Populus deltoides_ Bartr. cuttings significantly increased field survival, but the advantage of soaked over unsoaked cuttings were much greater when field conditions were less desirable (Krinard and Randall 1979).

There is some flexibility in the number of days that cuttings can be soaked before planting, depending on the winter storage temperatures and field moisture conditions. When cuttings have reached the proper stage for planting, they may be stored on crushed ice for up to 2 weeks to delay further root extension and shoot development (Phipps, Hansen and Fege 1983). Shoot growth for 4 weeks following planting in soil with adequate moisture was not affected by allowing soaked cuttings to dry for 8 hours at 24°C before planting. After allowing _Populus_ cuttings to dry out for 8 to 14 days (lowering moisture content by 22 to 24 percent), then soaking cuttings in water for 1 day before planting, Bogdanov (1965) reported survival levels of 60 to 75 percent of cuttings which had not been allowed to dry out. In our studies with 7 _Populus_ clones during 2 growing seasons, the cuttings stored at 2°C or -3°C had emergent roots and some flushed buds. Soaking for more than 1 day or delaying planting would have increased mortality of these cuttings. McKnight and Biesterfeld (1968) reported that two companies in the South stored entire whips for a few days in bulldozed trenches filled with water at the planting site, with whips cut into 50-cm lengths just before planting. The basal ends of cuttings were sometimes placed in ditches for a few days before planting, with wet burlap sacks covering them.

When cuttings have been soaked too long and roots have emerged, the process of planting cuttings will break off or damage many of these initial roots. After removing 75 percent and 100 percent of the roots emerging from _Populus trichocarpa_ cuttings which had been incubated in darkness in moistened plastic bags, Bloomberg (1963) reported significantly less shoot growth and fewer roots in the first 9 months, when compared with cuttings planted with all the initial roots intact. Cuttings with 75 percent of their roots removed suffered no greater mortality and had the same root dry weight as cuttings with all their roots intact.

Treatment with fungicides may lessen disease incidence, and indeed, several commercial nurseries included in Table 1 dip their cuttings in fungicides before storage. Hartmann and Kester (1975) recommend that cuttings be dipped in 5 percent benomyl or 24 percent captan after cuttings are made. Two clones known to be susceptible to blackstem injury in early trials were treated with 2 fundicides (1200 ppm) and stored from early March to early June at -20°C, -3°C, and 1°C. Average survival was 58 percent for untreated controls, 70 percent when treated with thiram and 81 percent when treated with benomyl (Ostry and McNabb 1982). Blackstem damage was much lower in cuttings stored at -3°C than those stored at 1°C, and storage of cuttings at -3°C eliminated the need for fungicide use. Ostry and McNabb (1982) also reported that fungicide dips increased survival at 2 sites where adverse growing conditions were found, but that there were no differences at 2 other sites where growing conditions were favorable. Since blackstem develops only on stressed cuttings, they conclude that fungicide dips are not necessary if healthy cuttings and proper handling and storage practices are used, and sufficient water and nutrients are supplied after planting.

There have been various reports of more rapid rooting when auxins are added to the soaking water. Only limited benefit would be achieved in most clones that have performed root primordia since roots emerge after cuttings are soaked in water for a week, but there is evidence that rooting is stimulated in clones which have fewer preformed root primordia (Hartmann and Kester 1975).

Planting Cuttings

Hardwood cuttings should be planted vertically with only 1 or 2 cm of the top of the cutting exposed, and soil well-packed around the cutting. In tests designed to determine the effects of cutting length and planting depth, the least number of main shoots were produced when 20-cm cuttings were planted flush with the ground surface in a silt loam soil. However, first year shoot height was less than that of cuttings planted at shallower depths of either 10 to 15 cm (Hansen _et al_. 1982). Horizontal planting of cuttings has also been evaluated for various species, but is not generally recommended for _Populus_. Bloomberg (1963) found that significantly more roots were produced by _P_. x _regenerata_ and _P_. x _robusta_ cuttings when placed in upright rather than inverted or horizontal positions, but there was no effect of planting position on _P. trichocarpa_ cuttings.

Cuttings are planted in the spring, after the frost has left the ground and site preparation is completed. This may be as early as March in warmer climates and as late as early June in the northern U.S. Over 3 years, Hansen _et al_. (1982) found that cuttings planted in mid-May grew consistently more during the growing season than those planted in April, but that differences between planting dates from April to early June were slight. Fall planting was successful in only 1 of the 3 years due to frost heaving; snowpacks were light in both years that fall planting failed.

Research foresters at the Harshaw Experimental Farm have established up to 8 ha annually with 2 modified planting machine systems. The first consisted of 4 semi-mechanical transplanters model CT-5 mounted on a 15-ft tool bar, pulled by a 85-hp farm tractor. Each of the 4 units can plant about 1200 cuttings per hour at a 1-meter spacing. In a time study of this system, 30,400 cuttings were planted in a 2.9 ha Populus plantation at 1 x 1 m spacing (Mattson and Miyata 1982). The actual planting required 5.6 hours and the estimated planting costs were $98/ha, with lower costs projected for wider spacings. The second planter consisted of 2 Holland transplanter units Model 1525. This was also pulled by a 85-hp tractor. Each unit planted approximately 500 trees per hour. Engineers at the Forestry Sciences Laboratory in Houghton, Michigan, have modified the planter by adding an audible system to control within-row spacing, redesigned the packing system, added larger and stronger planting shoes, and added protective shields for the operators (Hansen et al. 1982). Spacings must be precisely maintained, particularly between rows, in order to facilitate cultivation and minimize damage to stems whenever equipment is maneuvered between the planted rows. For planting 50-cm P. deltoides cuttings, the Southern Forest Experiment Station developed a slit-planting machine that opens a trench with a subsoil chisel, with one worker riding the machine and manually inserting cuttings to the bottom of the trench at the proper within-row intervals. The machine was mounted on a 3-point hitch and drawn by a tractor of at least 85 drawbar horsepower (McKnight and Biesterfeld 1968). During field operations, moisture content of unplanted cuttings should be retained by covering cuttings with moist burlap or by leaving cuttings in plastic bags, and holding cuttings in the shade.

The survival and growth of planted cuttings depends greatly on the availability of soil moisture in the soil or the supplementation of soil moisture by irrigation. In a growth chamber study, Phipps, Hansen and Fege (1983) found that the time required for bud break and early shoot growth increased as soil moisture tentions decreased. Whereas adequate soil moisture is particularly important in the weeks following planting, field performance during the first growing season depends also on adequate moisture, control of competition, soil nutrient levels, and pest management.

Conclusions

Hardwood cuttings are routinely collected, stored and planted by many nurseries in Europe and North America to establish Populus shade trees and plantations. For all the activities required for cutting production, from managing clonal nurseries to planting the cuttings, there are recommended practices based on both practical experiences and knowledge about physiological processes. There is considerable flexibility in some of the practices, particularly in the clonal nursery design, date of cutting collection, sawing and sorting procedures, and duration of soaking cuttings. On the other hand, planting stock vigor and survival can be markedly reduced if storage temperature and duration are not considered together, if there is inadequate soil moisture, and if cuttings are infected with blackstem diseases. These practices are only recommendations--each nursery must tailor their operations to their region, site, field workers, and Populus clones.

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