Sprouting and Growth of *Paulownia tomentosa* Root Cuttings

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Two studies were completed to determine (1) number and diameter distribution of root cuttings obtained from 1-yearold field-grown paulownia — Paulownia tomentosa *(Thunb.) Steud.— seedling sprouts, and (2) sprouting success and growth of these cuttings under field and greenhouse conditions. The seedling sprouts yielded an average of 7.7 root cuttings ranging in size from 1.3 cm (0.5 in) to more than 5 cm (2 in) in diameter and from 7.6 cm (3 in) to 22.8 cm (9 in) in length. Sprouting success of the root cuttings was 95% in the greenhouse and ranged from 19 to 58% in the field. Variation in field-sprouting success was associated with soil moisture conditions at planting time and incipient root cutting rot. First-year height growth ranged from 21 to 112 cm (8.2 to 43.7 in), showing significant differences among field sites, but not among root cutting diameter classes.* Tree Planters' Notes 45(3):95100; 1994.

Plantations of *Paulownia tomentosa* (Thunb.) Sueud. can be established using many types of planting stock, including seeds, bareroot seedlings, containerized seedlings, and root cuttings (Beckjord 1982, Graves and Stringer 1989). Although containerized seedlings are the most widely used planting stock in the United States, their production and use can be expensive. Producers often ship nondormant containerized stock during the early part of the growing season, requiring large amounts of care after outplanting. Root cuttings are preferred for vegetative propagation of *Paulownia* spp. in many parts of the world (Stephen 1988). Because they require minimal effort for storing, transporting, and planting, root cuttings may also provide a viable planting stock for plantation establishment. Although root cuttings can be obtained from wild trees, producing cuttings in paulownia plant beds can be an effective method of ensuring a source of planting stock. Plant bed techniques and seedling densities for producing 1- and 2-year-old nursery stock have been established (Stringer 1986). These techniques can also be employed to produce root cutting beds.

This paper presents results from two studies. The first study was aimed at determining the number and size of root cuttings from field-grown 1-year-old paulownia *(Paulownia tomentosa)* trees. The second study compared the sprouting success of paulownia root cuttings of different diameters and the subsequent growth of the sprouts relative to planting site and root cutting diameter.

Methods

Study 1: Root cutting yield. In a greenhouse, 100 2-monthold half-sib containerized paulownia seedlings were grown from seed collected from a naturalized tree located at lat. 37° 30' N. and long. 84° 30' W. Seedlings were grown in 2-L (2.1qt) containers for 2 months prior to outplanting. Coppiced containerized root systems were outplanted in May 1989 in a field located in the outer bluegrass region of Kentucky (lat. 38° N. and long. 84° 50' W.). The field was dominated by Kentucky 31 tall fescue *(Festuca elatior* var. KY-31). The soils in the field, located adjacent to a small stream, were classified as Ashton silt loam (fine-silty, mixed, mesic Mollic Hapludalfs) with a rooting depth greater than 1 m (3.3 ft), and capable of yielding a *Quercus rubra* site index of 90 ft, base age 50 years (McDonald et al. 1983). This soil series has been classified as "suited" for paulownia establishment and growth (Stringer and others 1994). Prior to planting, competing vegetation was treated with a 2% glyphosate solution (Roundup®) in a 0.5-m (l.7-ft) radius around each planting spot. Planting spots were arranged on a 3- by 3-m (9.8- by 9.8-ft) grid. Each planting hole was dug 40 cm (15.6 in) wide and 50 cm (19.5 in) deep, then backfilled after planting with extracted soil. Seedling sprouts were allowed to develop throughout the 1989 growing season and then to overwinter. They were excavated by hand spade on April 12,1990. Primary roots 1m (3.3 ft) long and lateral roots 30 cm (11.7 in) long were divided into cuttings using hand shears. Cuttings were grouped into four diameter classes: small (1.3 to 2.5 cm, or 0.5 to 1.0 in), medium (2.6 to 3.8 cm, or 1.0 to 1.5 in), large (3.9 to 5.1 cm, or 1.5 to 2.0 in), and the remaining root collar (>5.1 cm, or >2.0 in). An attempt was made to divide the root system into cuttings with little variation in diameter along their length; a typical cutting scheme is shown in figure 1. Although the length of cuttings varied among size classes, minimum length was 7.6 cm (3 in). Number and length of cuttings in each class was then determined.

Study II: Sprouting success and sprout growth. This study involved determining (1) sprouting percent of paulownia root cuttings of four different diameter classes (treatments), and (2) annual height of the sprouts for each root cutting diameter class.

Site descriptions. Test sites included both field and greenhouse environments. Sites I, II, and III were fields dominated by Kentucky-31 fescue. They were located in the outer bluegrass region of Kentucky (in Woodford County, at lat. 38° N. and long. 84° 50' W.), but did not coincide with the site used in Study I. Sites I and II, which adjoined each other at the top of a 10% north-facing slope, were originally planned as a single test site. But on April 12, 1990, heavy rainfall interrupted planting, which only resumed after the soils had drained for 10 days. This created differences in planting conditions and times between plantings;

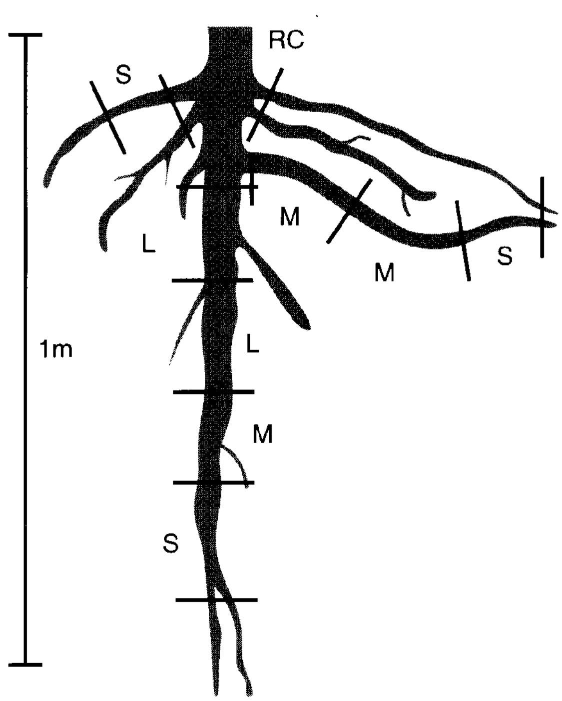

Figure 1—*Typical division of the root system of 1-year-old Paulownia tomentosa seedling sprouts. RC = root collars (>5.1 cm), L = large-diameter cuttings (3.9-5.1 cm), M = medium-diameter cuttings (2.6-3.8 cm), S = small-diameter cuttings (1.3-2.5cm).*

accordingly, the area planted was treated as two separate sites. Site III was located 1,000 m (3,280 ft) from Sites I and II at the top of a 10% west-facing slope.

Soils at all three sites were classified as Faywood silt loam (fine, mixed, mesic Typic Hapludalfs). They were moderately deep, well-drained soils with a 15-cm (5.9-in) dark grayish-brown silt loam surface layer and a yellowish brown silty clay or clay subsoil extending down to limestone bedrock at a depth of 76 cm (29.6 in). Supporting a *Quercus rubra* site index of 70 ft, base age 50 years (McDonald and others 1983), this soil series has been classified as "questionable" for paulownia establishment and growth (Stringer and others 1994). The range of characteristics associated with this series includes soils well suited for paulownia growth as well as those with clay content above that considered acceptable.

Site IV was located in a greenhouse in Lexington, Kentucky. Four-L (4.2-qt) pots were filled with sterilized potting media consisting of equal parts of perlite, top soil, and sand.

Test site design and establishment. A complete block design with split plots was used for field plantings. Field sites were made up of linear replicate blocks (corresponding to rows) spaced 3 m (9.8 ft) apart. Each block (or row) consisted of 5 linear plots, each of which contained 7 root cuttings planted 3 m (9.8 ft) apart along the row. Within each block/plot combination, all four cutting diameter classes (treatments) were planted. Due to the unequal number of cuttings available for each diameter class, each plot consisted of 1 root collar and 1 large-, 2 medium-, and 3 smalldiameter cuttings randomly distributed in the 7 planting spots. Root cuttings were obtained from Study 1. The number of blocks, plots, and root cuttings by diameter class for each field site are shown in table 1.

Ground cover at all field sites, which consisted primarily of Kentucky-31 tall fescue, had been treated in fall 1989 with a 2% glyphosate (Roundup®) solution in a circle 0.7 m (2.3 ft) in diameter around each planting spot. Each spot was prepared by digging a hole about 40 cm (15.6 in) wide and 50 cm (19.5 in) deep using a tractor-mounted posthole digger.

Root cuttings were excised from the root systems on April 12, 1990, and dried for 10 days prior to planting. At planting time, the cut ends were dry to the touch. Cuttings were oriented vertically in the holes, with the basipetal end approximately 2.5 to 5.0 cm (1 to 2 in) below the surface. Root collars were planted with the distal end of the cutting 2.5 to 5.0 cm (1 to 2 in) below the surface. The holes were then backfilled with

Table 1 -*Number of blocks, plots, and root cuttings by diameter class for each field site*

			Cuttings by diameter class			
Site	Blocks	Plots	Small	Medium	Large	Root Cellar
I (north slope)	6	30	90	60	30	30
II(north slope)	3	15	45	30	15	15
III(west slope)	9	45	135	90	45	45

extracted soil. Planting of Site I was completed on April 23,1990, when soils were wet; a saturating rain halted further planting. After the soil had been allowed to drain for 10 days, Sites II and III were planted. In the interim between plantings, cuttings were stored in a ventilated shed. Other than the initial application of herbicide, no cultural treatments were applied to the field sites.

Root cuttings were planted in the greenhouse (Site IV) on April 22, 1990. Five root collars and 5 large-, 10 medium-, and 15 small-diameter cuttings were placed in individual pots with the same orientation as described for Site 1. Plants were watered thoroughly every other day.

Analysis. On July 27, 1990, sprouting percent, sprout survival, and total height were determined at all sites. In January 1991, sprout survival and total height were determined at sites I, II, and III. Arc sin transformation of sprouting percent data (Steel and Torrie 1980) along with untransformed data of the other variables were subjected to Wilk-Shapiro/rankit plots to test for normality. Statistical analysis using ANOVA (Type III SS) (Shaw and Mitchell-Olds 1993) and LSD pairwise *t*-test were used to determine differences among the various sites and root cutting diameters in sprouting percent as well as in sprout growth and survival (P

Results and Discussion

Study 1: Root cutting yield. Ninety-eight of the 100 coppiced containerized seedlings survived, averaging 1.86 m in height. Root cuttings per root system averaged 7.7, for a total of 753 cuttings from the 98 sprouts. Average yield of cuttings per root system was 1 root collar and 1 large-diameter, 2.1 medium-diameter, and 3.6 small-diameter cuttings (table 2). Cutting length varied by diameter class, ranging from 7.6 to 22.8 cm (3 to 9 in) (table 2). Where trees are allowed adequate growing space and given proper care, root cutting yield per seedling sprout should be

Table 2-*Diameter distribution of root cuttings from 1-year-old Paulownia tomentosa seedling sprouts*

		Number of cuttings[1]	
Diameter class (cm)	Cutting length (cm)	Total	per tree
Root collar (>5.1)	7.6-12.7	98	1.0
Large (3.9-5.1)	7.6-17.8	98	1.0
Medium (2.6-3.8)	7.6-17.8	205	2.1
Small (1 .3-2.5)	7.6-22.8	352	3.6

1 Ninety-eight 1-year-old seedling sprouts produced a total of 753 cuttings.

comparable to that obtained in this study. However, root cutting yield from similar-aged trees may not be this great if grown where competition is present or where soil-site factors are less than favorable for paulownia growth.

Study II: Sprouting success and sprout growth. There were differences in sprouting percent among sites, but no significant differences among cutting diameter classes. Sprout survival was excellent at all sites. Both midseason and first-year sprout height growth varied greatly among sites, but there was little difference in height growth among cutting diameter classes.

Sprouting percent and sprout survival. Data pooled by diameter class showed a significant difference (P sprouting percent among test sites (table 3). The 95% sprouting of root cuttings planted in the greenhouse (Site IV) was significantly greater than at any of the field sites. Fifty-eight percent of the cuttings at Site II produced sprouts, a significantly higher percentage than at Site I or III, where cuttings sprouted at rates of 19 and 23%, respectively. Although cuttings with larger diameters tended to have a higher sprouting percent, no statistical difference in sprouting percent was found among diameter classes within sites.

The sprouting percent obtained for cuttings planted into drained soils at Sites I and IV were comparable to

Table 3—*Sprouting percent of* Paulownia tomentosa *root cuttings*

Diameter class	Site I	Site II	Site III	Site IV
Root collar	22.3	66.7	14.0	100.0
Large	16.7	60.0	36.0	100.0
Medium	23.3	53.3	24.4	96.7
Small	14.6	53.3	18.0	83.3
Mean[1]	19.5 a	58.3 b	23.1 a	95.0 c

[1] Significant differences, as determined by ANOVA (Type III SS) and LSD at $P < 0.05$, among sites for survival are indicated by different letters.

those found by Rin (1979) for Taiwan paulownia (*Paulownia taiwaniana*) cuttings of similar size. In sprouting studies of Taiwan paulownia cuttings, Fang and Hwang (1979) found that root collars did not perform as well as true root cuttings. In the present study, however, the percentage of root collars producing sprouts was similar to that of other cutting diameter classes. Examination of cuttings 1 month after planting revealed that unsprouted cuttings were entirely rotten, whereas unrotted or partially rotted cuttings were either developing buds or in the process of sprouting. Examination of the cuttings in the greenhouse found little evidence of rot.

Sprout survival was excellent. One hundred percent of the established sprouts survived the first growing season at Sites II, III, and IV, and 96% survived at Site I. Accordingly, overall plantation mortality can be attributed to a lack of initial sprouting. Observational evidence suggests that failure to sprout resulted from rot developing in the cuttings prior to sprout development. It may be possible to prevent rot development by reducing the time the cuttings are in the soil prior to shoot development. This could be accomplished by pretreating the cuttings to initiate budding, or by planting late, after soils have warmed. It may also be possible to reduce rot by treating root cuttings with a fungicide solution prior to outplanting. The results of this study suggest that prescriptions for dipping paulownia whole-root systems in fungicide (Beckjord 1984) should be applied to root cuttings as well.

Sprout growth (midseason). Within diameter classes, midseason height growth differed significantly ($P \leq 0.05$) among sites (table 4). Greenhouse-grown sprouts (Site IV) were taller than field-grown sprouts across all cutting diameter classes. But midseason sprout height was generally only weakly related to cutting diameter. Simple linear regression of sprout height and cutting diameter yielded an $r^2 = 0.58$ ($y = -9.064 + 28.207^{-} X$). Analysis of data pooled over all sites indicated no significant differences among diameter classes for sprout height. The only significant intrasite difference among diameter classes was found at Sites I and IV (table 4). At Site I, small-diameter cuttings had shorter sprouts (averaging 27.4 cm, or 10.7 in) than medium-diameter cuttings (which averaged 46.0 cm, or 17.9 in). At Site IV, small-diameter cuttings had significantly shorter sprouts (averaging 61.0 cm, or 23.8 in) than other diameter classes, and root collars produced significantly taller sprouts (averaging 91.3 cm, or 35.6 in) than other diameter classes. Still, the general lack of growth differential

Table 4—*Midseason heights (cm) of sprouts from* Paulownia tomentosa *root cuttings (measured July 27,1990)*

Site	Root collar	Diameter class[1] Large	Diameter class[1] Medium	Diameter class[1] Small	Mean
I (north slope)	36.5 ab	39.6 ab	46.0 a	27.4 a	35.8 a
II (north slope)	46.0 a	54.9 a	45.0 a	45.0 b	46.5 b
III (west slope)	24.4 b	30.5 b	30.4 b	21.3 a	25.7 a
IV (greenhouse)	91.3 c	76.2 c	73.2 c	61.0 c	71.0 c
Mean[2]	49.6	50.3	48.7	38.7	—

Note: Values within a column with the same letter are not significantly different using ANOVA (Type III SS) and LSD at $p < 0.05$.

[1] No statistical differences were found among diameter classes within a site, except for Site I, where sprouts from small cuttings were shorter than those from medium cuttings, and Site IV, where sprouts from small cuttings were shorter and those from root collars larger than those from other diameter classes ($p > 0.05$).

[2] No statistical difference was found among diameter classes for data pooled across all field sites.

among diameter classes within field sites was unexpected.

Observation of the sprouts showed that height growth within a cutting diameter class was positively related to the amount of rot present in the cutting. Smaller sprouts were found where much of the cutting had rotted, whereas larger sprouts were from cuttings with little or no rot. Rot may have reduced the amount of carbohydrates available for root and shoot development. Variation in rot development in the cuttings may have masked differences in height growth relative to cutting diameter. However, the performance of the small- and medium-diameter cuttings was favorable, because a planting bed can produce a greater number of smaller cuttings than larger ones.

Sprout growth (annual). In early September 1990, hail damaged approximately one-half of the leaves and broke the tops out of approximately 15% of the sprouts. The damage may have affected total height growth, but it was consistent across all cutting diameter classes and sprout sizes, and damaged sprouts (except for those with top damage) were used in the analysis.

As was the case at midseason, significant differences in height growth among sites within diameter classes were found (table 5). After the first growing season, sprout height growth from cuttings planted at Site II (which averaged 93.6 cm, or 36.5 in) exceeded growth at Site I (which averaged 65.7 cm, or 25.6 in) by more than 25 cm (9.8 in). Height growth varied greatly within each diameter class across sites, with standard deviation approaching 50% of total height. But no statistical difference in total height was found among root cutting diameter classes within sites at the end of the first growing season.

Analysis of data pooled over all diameter classes showed that Site III had significantly less height growth (26.5 cm, or 10.3 in) than Sites I and II, despite identical slope, elevation, and soil series. The primary difference was aspect: whereas Sites I and II faced north, Site III faced west. The greater height growth at Sites I and II may reflect increased moisture availability due to the northerly exposure of the slope. Results suggest that planting trials are necessary to determine suitability of a potential plantation site where the mapped soil series has a range of characteristics, portions of which are not recommended for the species.

Management Implications

Given reasonable planting conditions, root cuttings are a viable planting stock for establishing paulownia plantations. However, when cuttings are planted under conditions that would be acceptable for bareroot seedlings, rot may develop, and lower sprouting percent or sprout height growth may result. Avoiding extremely wet soils and planting into relatively warm soils should decrease the danger of rot. This might best be accomplished by planting at the beginning of the growing season, a time considered late for bareroot seedling establishment. In addition, using fungicide dips and pretreating cuttings to stimulate sprouting before outplanting may help to reduce rot.

Table 5 -*First-year height growth (cm) of sprouts from* Paulownia tomentosa *root cuttings (measured January 1991)*

Site	Root collar	Diameter class[1]			Mean
		Large	Medium	Small	
I (north slope)	54.9 a	67.1 a	91.4 a	51.8 a	65.7 a
II (north slope)	85.39 a	112.8 a	82.3 a	97.5 b	93.6 b
III (west slope)	21.3 b	30.4 b	30.4 b	24.4 c	26.5 c
Mean[2]	53.8	70.1	68.3	57.9	—

Note: Values within a column with the same letter are not significantly different using ANOVA (Type III SS) and LSD at $p < 0.05$.

[1] No statistical difference was found among diameter classes within sites.

[2] No statistical difference was found among diameter classes for data pooled across all field sites.

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