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Transplant Timing Affects First-season Root Growth of Turkish Hazelnut (*Corylus colurna* L.)

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Abstract. **Rapid posttransplant root growth is often a determining component of successful establishment. This study tested the effect of transplant timing on first-season root growth dynamics of bare-root Turkish hazelnut trees. Trees were either harvested and planted in the fall (F-F), harvested in the fall and planted in the spring after holding in refrigerated storage (F-S), or harvested and planted in the spring (S-S). All trees were transplanted into 51-L containers, adapted with root observation windows. Root growth began in F-F and F-S trees 1–2 weeks before spring budbreak, but was delayed in S-S trees until ≈3 weeks after budbreak. Budbreak was 6 days earlier for fall-harvested than for spring-harvested trees. No new roots were observed before spring. Root length accumulation against observation windows (RL) was delayed for S-S trees, but rate of increase was similar to F-F and F-S trees soon after growth began. Seasonal height, trunk diameter growth, and RL were similar among treatments. Surface area of two-dimensional pictures of entire rootballs was not correlated with seasonal RL.**

Rate of recovery from posttransplant water stress is directly proportional to the rate at which new roots regenerate (Nambiar et al., 1979). Regeneration rate is partly due to the innate capacity of a species for root regrowth. For example, the easy-to-transplant green ash (*Fraxinus pennsylvanica* Marsh.) will regenerate roots from severed root ends in as few as 17 d (Arnold and Struve, 1989), whereas the more difficult-to-transplant red oak (*Quercus rubra* L.) takes at least 24 d (Struve and Rhodus, 1988). Field-grown Leyland cypress (X*Cupressocyparis leylandii* Dallim.) had over four times the dry weight of new roots outside rootballs 10 weeks after transplanting than did laurel oak (*Quercus laurifolia* Michx.) (Harris and Gilman, 1991). Another important component of quick-to-establish transplants is the growth of intact (not severed) lateral roots (Mullin, 1963; Ritchie and Dunlap, 1980). Intact laterals of dormant green ash begin elongation as early as 7 d after placement in a warm greenhouse (Arnold and Struve, 1989).

Rootball fibrosity may affect early transplant establishment. Ritchie et al. (1993) determined that rootball density of Douglas-fir [*Pseudotsuga menziesii* (Mirb) Franco] seedlings of similar trunk diameter was positively correlated with posttransplant growth. Easy-to-transplant species have often been observed to have more fibrous root systems than do difficult-to-transplant species (Fare et al., 1985; Harris et al., 1994). Fibrosity probably bestows transplant success in part because of large numbers of intact lateral roots. A fibrous root system will also have more absorptive area than coarser root systems of similar or, to a degree, greater dry weight (Harris and Gilman, 1993).

Fall transplanting improves posttransplant growth and survival of some species (Harris and Bassuk, 1994; Harris et al., 1996) but not of others (Kelly and Moser, 1983; Watson and Himelick, 1982). Many nursery operators buy bare-root trees to outplant and grow to a marketable size. These newly planted trees (liners) are typically harvested in the fall, placed in refrigerated storage, and sold for outplanting the following spring. However, nursery growers usually have a less hectic work schedule in the fall than in the spring, and lining out trees in the fall may result in increased first-season growth (Hinesley, 1986).

The purpose of this research was threefold. First, the effect of fall vs. spring transplanting on first-season root growth dynamics was determined for Turkish hazelnut trees. Second, since refrigerated storage may negatively alter physiology (Ritchie, 1987) and reduce vigor (Bates and Niemiera, 1997; Bates et al., 1994), we also included a fall-harvested, but spring-transplanted, treatment to test the effect of refrigerated storage on first-season growth. Third, we wished to determine if rootball density at planting affected first-season growth.

Materials and Methods

Three transplant-timing treatments were randomly assigned to 30 four-year-old Turkish hazelnut trees on 5 Nov. 1998. All trees were field-grown until harvest at the Urban Horticulture Center, near Blacksburg, Va. (U.S. Dept. of Agriculture zone 6a) in a Groseclose silt loam soil (clayey, mixed, mesic Typic Hapludults; pH = 6.2). Beginning mean tree height (SE in parentheses) was 2.2 (0.06) m and trunk diameter (mean of two measurements made in opposite directions 15 cm from ground level) was 4.1 (0.08) cm. Treatments were: 1) harvested and transplanted in the fall (F-F); 2) harvested in the fall, placed in refrigerated storage, and transplanted in the spring (F-S); and 3) harvested and transplanted in the spring (S-S). F-F trees were both harvested and transplanted on 5 Nov. 1998, just after leaf drop. F-S trees were harvested on 5 Nov. and immediately placed in refrigerated storage [2.5 °C (±1); 86% to 98% relative humidity]. Rootballs were covered with wet sawdust until planting on 19 Mar. 1999. S-S trees were harvested and planted on 19 Mar. 1999. Rootballs were hand-dug, washed free of soil, and trimmed to 40-cm diameter and depth. As had been observed in the past with similar and larger-sized rootballs of this species, there were very few intact lateral roots. Transplanted trees were planted in a completely randomized design into 51-L containers (B-15, 43.8-cm top width × 40.6-cm height, Lerio, Mobile, Ala.) in a pot-in-pot (PIP) production system, also at the Urban Horticulture Center. All trees were irrigated with a microirrigation system once per day as needed so as to maintain substrate moisture near container capacity throughout the experiment. Container substrate was 100% milled pine bark (pH = 5.1). All trees were fertilized with 168 g of encapsulated slow-release fertilizer (18N–2.6P–9.9K; Osmocote, The Scotts Co., Maryville, Ohio) on 2 Apr. 1999. Bark physical properties were: air space = 24.3%; bulk density = 200 $kg \cdot m^{-3}$; total porosity = 79.8%; container (water holding) capacity = 55.5%. The PIP system consisted of 51-L socket containers, spaced 1.2 m on center in rows 1.5 m apart. The area between containers was covered with black landscape fabric, and an underground drainage system assured that containers were not in standing water. Each production container was fitted with a 28 × 28-cm clear polycarbonate sheet 6.4-mm thick (GE Worldwide Manufacturing Sites, Mount Vernon, Ind.) as a window through which root growth could be observed (rhizotron). A 25 × 25-cm square was marked with lines in 5-cm increments (grid) on each window.

To determine the effect of rootball density on first-season growth, each rootball was photographed from two directions against a white sheet with a digital camera. Image contrast was computer-enhanced (Adobe Photoshop, ver. 3.0; Adobe Systems, Mountain View, Calif.) and surface area of the two-dimensional image (shadow) was calculated utilizing computer software (SigmaScan/Image, ver. 1.2; SPSS Science, Chicago). The mean area of the two shadows for each rootball was the shadow area of each rootball.

Soil temperature was monitored with a thermocouple placed 20 cm deep in a nearby bare-ground bed. Beginning 28 Jan. 1999, container substrate temperature was also monitored with a thermocouple placed 20 cm deep

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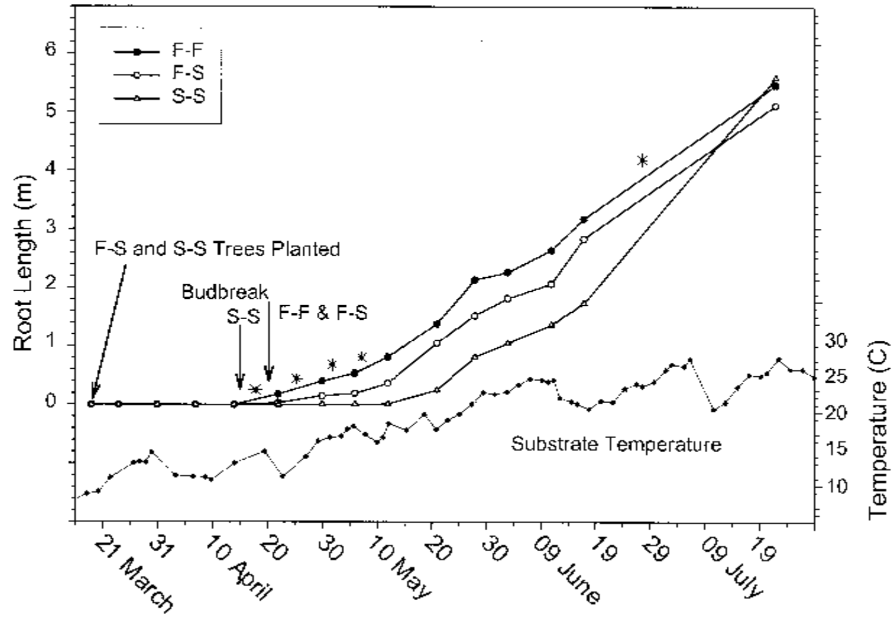

Fig. 1. Root length as measured against rhizotron windows of Turkish hazelnut trees harvested and planted in the fall (F-F); harvested in the fall, placed in refrigerated storage, and planted in the spring (F-S); or harvested and planted in the spring (S-S). Asterisks indicate significant treatment effect for the time period indicated according to repeated measures analysis of variance. (See Table 1 for specifics.) Substrate temperatures are shown in the lower quadrant with the ordinate on the lower right. n = 9 for F-F, 10 F-S and S-S.

Table 1. Single degree-of-freedom contrasts for change of root length against rhizotron windows during the specified time periods according to repeated measures analysis of variance for Turkish hazelnut trees (*Corylus colurna* L.). Trees were harvested and planted in the fall (F-F), harvested in the fall, placed in cold storage, and planted in the spring (F-S), or harvested and planted in the spring (S-S). n = 9 for F-F, 10 for F-S and S-S.

	Pr > F				
Treatment	22–30 Apr.	30 Apr.–6 May	6–12 May	12–21 May	17 June–22 July
F-F vs. S-S	0.008	0.001	0.002	0.007	0.037
F-F vs. F-S	0.025	0.066	0.033	0.278	0.962
F-S vs. S-S	0.595	0.045	0.209	0.074	0.036

and 1 cm from the sidewall in a growing container.

Rhizotron pots were checked frequently for the presence of new root growth. Root length against the rhizotron windows was estimated periodically (22, 30 Apr.; 6, 12, 21, 28 May; 3, 11, 17 June; 22 July; and 30 Oct. 1999) with the line-intersect method (Marsh, 1971; Newman, 1966). Final tree height and trunk diameter were measured on 27 Oct. 1999.

Spring budbreak was determined by estimating the percentage of buds on an individual tree that were open and had visible leaves. When 50% of the buds were estimated to be open, that tree was considered to have achieved spring budbreak.

Root length against rhizotron windows was plotted over time to reveal early-season root growth patterns. Change in root length was analyzed with repeated measures and single degree-of-freedom contrasts (Littell, 1989) within the GLM procedure of SAS (ver. 6.08, SAS Institute, Cary, N.C.). Final seasonal root length against rhizotron windows (RL), height growth, trunk diameter growth, and days between first root growth and budbreak were analyzed with the GLM procedure of Minitab (Minitab ver. 12, Minitab, State College, Pa.). The relationship between area of rootball shadow and total seasonal root length against rhizotron windows was determined by correlation analysis with Minitab.

Results and Discussion

Tree survival was 100% for all treatments. Only one tree, an F-F, had noticeable branch dieback. Since dieback was severe (>25%), this tree was excluded from further analysis. The first roots appeared against rhizotron windows on an F-F tree on 26 Mar. Fall-transplanted Turkish hazelnut in upstate New York (Harris and Bassuk, 1995), and fringe tree (*Chionanthus virginicus* L.) in southwestern Virginia (Harris et al., 1996) also failed to regenerate roots until spring. Median day for first sighting of new roots for all F-F trees was 16 Apr., 162 d after planting. At fall planting, soil temperature in a nearby bed was 8.3 °C. Substrate temperatures were probably limiting for root extension (Harris and Fanelli, 1999; Harris et al., 1995) until late March, when they remained near or above 10 °C (Fig. 1). Although roots were first noticed 14 d later (9 Apr.) for F-S trees, median day was the same (16 Apr.) for F-S and F-F trees. Root extension in F-S trees lagged somewhat behind that in F-F trees (Fig. 1; Table 1), but rate of increase was similar beginning 12 May. Roots were visible in F-F and F-S trees a mean of 13 and 5 d, respectively, before budbreak. These differences, however, were not statistically significant ($P > 0.05$). Despite the slight lag in root extension (Fig. 1) in refrigerated trees, median day of first appearance of new roots (16 Apr. for both F-F and F-S) and budbreak (22 Apr. for both F-F and F-S) were unaffected by refrigerated storage. This lag in root extension was not significantly different from that in F-F trees after 12 May (Table 1). Seasonal height, trunk diameter, and RL growth were similar for stored and nonstored trees (data not shown). Refrigerated storage is therefore of no permanent detriment to Turkish hazelnut if liners are handled in a manner similar to our experimental conditions.

Spring-harvested trees broke bud on 16 Apr., 6 d before fall-harvested trees (22 Apr.). New roots did not appear until 30 Apr. (median day = 6 May) in S-S trees. The appearance of new roots on F-F and F-S trees was concomitant with the spring warming of substrate above 10 °C; however, substrate temperatures for transplanted S-S trees were also in a range favorable for root growth. Transplanting stress has been defined as a combination of stress conditions and the process of adaptation and recovery (Rietveld, 1989). Fall-harvested trees in our study had a much longer time for adaptation and recovery. S-S trees broke buds on average 24 d before new roots appeared, significantly earlier ($P < 0.05$) than in F-F and F-S trees, in which roots appeared 13 and 5 d, respectively, before budbreak.

Root extension was not measurable on S-S trees until 21 May (Fig. 1). The change in root length in all treatments was similar thereafter until the period of 17 June to 22 July, when S-S trees had the greatest change in root length. At season's end (30 Oct.), total root length against rhizotron windows, height growth, and trunk diameter growth were similar for all treatments (11.9, 11.3, 15.9 m for F-F, F-S, S-S, respectively), and all trees were visually healthy, well-rooted, and judged to be of high quality.

Our data indicate that either system (F-F, F-S, S-S) may be employed for nursery production if growing conditions can be as closely managed as the PIP system used in this study. Nursery producers can therefore use the system that is the most convenient and economical. However, fall transplanting may be advantageous when planting into uncertain landscape conditions where the chances of drought stress are heightened. Early root growth would confer a larger soil water reservoir, and new root growth before budbreak may also help insulate developing shoots from sudden drought. Delayed root extension, especially after budbreak, makes posttransplant irrigation management especially critical for spring-transplanted trees. The trees in this experiment were transplanted into an intensively managed system. An automatic irrigation system and daily monitoring insured that the container substrate was never dry. Few landscape settings have this level of posttransplant management.

Surface area of root shadows (data not shown) correlated with beginning trunk diameter ($r = 0.52$; $P = 0.003$), indicating that larger trees generally had rootballs with greater shadow area. However, variability of rootballs was high. Shadow areas ranged from 468 to 1635 cm^2 (mean = 859.5 cm^2), or a range of 250%, whereas trunk diameters ranged from 3.5 to 5.3 cm (mean = 4.1 cm), or a range of only 50%. Rootball shadow area was not correlated with seasonal root length against rhizotron windows ($r = 0.28$; $P = 0.13$). Others have shown that increasing root length within rootballs does not always increase posttransplant growth. Harris et al. (1998) reported no increase in growth of sugar maple (*Acer saccharum* Marsh.) with larger rootballs. Sands (1984) concluded that prolonged posttransplant water stress of radiata pine (*Pinus radiata* D. Don) was due to poor root : soil contact, not loss of roots at harvest. Increased fibrosity of sycamore maple (*Acer pseudoplatanus* L.) from root wrenching did not lead to increased growth (Hipps et al., 1996). The shadow method, presented here for the first time, does not measure overall root length, surface area, or weight, the traditional destructive methods of rootball analysis (e.g., see Gilman et al., 1996; Harris and Gilman, 1993), but is similar to the nondestructive method that has been used to estimate tree canopy leaf area (Lindsey and Bassuk, 1992). If fibrosity is assumed to be fairly constant within a species, the rootball shadow method should be a reasonable measure of relative root length density. Other nondestructive methods include the root number (Marshall and Gilman, 1997) and water displacement (Harris and Gilman, 1993) methods. A destructive harvest of entire root systems in the current experiment may have revealed a closer correlation between rootball shadow and posttransplant root growth.

Conclusions

Fall-transplanted, bare-root Turkish hazelnut trees begin root growth earlier and shoot growth later than do spring-transplanted trees. Spring-transplanted trees begin shoot growth without the benefit of new root growth, whereas fall-transplanted trees begin root growth ≈2 weeks before budbreak. New root growth is slightly delayed in trees harvested in the fall and placed in refrigerated storage until spring, although extension rate of new roots is soon similar to that in trees not stored. Since total first-season root and shoot growth are similar among treatments, nursery growers can choose either transplant timing and produce a similar-sized tree, as long as irrigation is carefully monitored. However, fall transplanting may be an advantage on sites where irrigation is uncertain. Spring-transplanted trees in the present experiment were transplanted 42 d before new roots were first noticed on rhizotron windows. This may be close to the minimum time required for this species. Since very few intact lateral roots were observed on rootballs at planting, most posttransplant root growth would originate from severed roots, increasing the time required for new roots to appear. Kelting et al. (1998) reported that red maple (*Acer rubrum* L.), transplanted in early April in southwestern Virginia, required 38 d after transplanting before new roots were visible against root observation windows. Future research should investigate how additional transplanting dates affect budbreak and early root growth for Turkish hazelnut and other species.

Literature Cited

Arnold, M.A. and D.K. Struve. 1989. Green ash establishment following transplant. J. Amer. Soc. Hort. Sci. 114:591–595.

Bates, R.M. and A.X. Niemiera. 1997. Effect of cold storage and pre-transplant desiccation on root growth potential and bud break of bare-root Washington hawthorn and Norway maple. J. Environ. Hort. 15:69–72.

Bates, R.M., A.X. Niemiera, and J.R. Seiler. 1994. Cold storage method affects root and shoot water potential of bare-root hawthorn and maple trees. J. Environ. Hort. 12:219–222.

Fare, D.C., C.H. Gilliam, and H.G. Ponder. 1985. Root distribution of two field-grown *Ilex*. HortScience 20:1129–1130.

Gilman, E.F., T.H. Yeager, and D. Weigle. 1996. Fertilization, irrigation and root ball slicing affects Burford holly growth after planting. J. Environ. Hort. 14:105–110.

Harris, J.R. and N.L. Bassuk. 1994. Seasonal effects on transplantability of scarlet oak, green ash, Turkish hazelnut and tree lilac. J. Arboricult. 20:310–317.

Harris, J.R. and N.L. Bassuk. 1995. Effects of defoliation and antitranspirant treatment on transplant response of scarlet oak, green ash and Turkish hazelnut. J. Arboricult. 21:33–36.

Harris, J.R., N.L. Bassuk, and T.H. Whitlow. 1994. A window into below-ground growth of landscape trees: Implications for transplant success. HortTechnology 4:368–371.

Harris, J.R., N.L. Bassuk, R.W. Zobel, and T.H. Whitlow. 1995. Root and shoot growth periodicity of green ash, scarlet oak, Turkish hazelnut, and tree lilac. J. Amer. Soc. Hort. Sci. 120:211–216.

Harris, J.R. and J. Fanelli. 1999. Root and shoot growth periodicity of pot-in-pot red and sugar maple. J. Environ. Hort. 17:80–83.

Harris, J.R. and E.F. Gilman. 1991. Production method affects growth and root regeneration of Leyland cypress, laurel oak, and slash pine. J. Arboricult. 17:64–69.

Harris, J.R. and E.F. Gilman. 1993. Production method affects growth and post-transplant establishment of 'East Palatka' holly. J. Amer. Soc. Hort. Sci. 118:194–200.

Harris, J.R., P. Knight, and J. Fanelli. 1996. Fall transplanting improves establishment of balled and burlapped fringe tree (*Chionanthus virginicus* L.). HortScience 31:1143–1145.

Harris, J.R., P. Knight, and J. Fanelli. 1998. Effect of root severance on growth of field-grown sugar maple. HortScience 33:21–23.

Hinesley, L.E. 1986. Effect of transplant time on growth and development of Fraser fir seedlings. HortScience 1986:65–66.

Hipps, N.A., K.H. Higgs, and L.G. Collard. 1996. The effect of irrigation and root pruning on the growth of sycamore (*Acer pseudoplatanus*) seedlings in nursery beds and after transplanting. J. Hort. Sci. 71:819–828.

Kelly, R.J. and B.C. Moser. 1983. Root regeneration of *Liriodendron tulipifera* in response to auxin, stem pruning, and environmental conditions. J. Amer. Soc. Hort. Sci. 108:1085–1090.

Kelting, M., J.R. Harris, J. Fanelli, and B. Appleton. 1998. Humate-based biostimulants affect early post-transplant root growth and sapflow of balled and burlapped red maple. HortScience 33:342–344.

Lindsey, P.A. and N.L. Bassuk. 1992. A nondestructive image analysis technique for estimating whole-tree leaf area. HortTechnology 2:66–72.

Littell, R.C. 1989. Statistical analysis of experiments with repeated measures. HortScience 24:37–40.

Marsh, a'B. 1971. Measurement of length in random arrangement of lines (short communication). J. Appl. Ecol. 8:265–267.

Marshall, M.D. and E.F. Gilman. 1997. Production method and irrigation affect root morphology of live oak. J. Environ. Hort. 15:84–87.

Mullin, R.E. 1963. Planting check in spruce. For. Chron. 39:252–269.

Nambiar, E.K.S., G.D. Bowen, and R. Sands. 1979. Root regeneration and plant water status of *Pinus radiata* D. Don seedlings transplanted to different soil temperatures. J. Expt. Bot. 30:1119–1131.

Newman, E.I. 1966. A method of estimating the total length of root in a sample. J. Appl. Ecol. 3:139–145.

Rietveld, W.J. 1989. Transplanting stress in bareroot conifer seedlings: Its development and progression to establishment. North. J. Appl. For 6:99–107.

Ritchie, G.A. 1987. Some effects of cold storage on seedling physiology. Tree Planters Notes Spring:11–15.

Ritchie, G.A. and J.R. Dunlap. 1980. Root growth potential: Its development and expression in forest tree seedlings. N.Z. J. For. Sci. 10:218–248.

Ritchie, G.A., Y. Tanaka, R. Meade, and S.D. Duke. 1993. Field survival and early growth of Douglas-fir rooted cuttings: relationship to stem diameter and root system quality. For. Ecol. Mgt. 60:237–256.

Sands, R. 1984. Transplanting stress in radiata pine. Austral. For. Res. 14:67–72.

Struve, D.K. and W.T. Rhodus. 1988. Phenyl indole-3-thiobutyrate increases growth of transplanted 1-0 red oak. Can. J. For. Res. 18:131–134.

Watson, G.W. and E.B. Himelick. 1982. Seasonal variation in root regeneration of transplanted trees. J. Arboricult. 8:305–310.