here may develop growth-limiting container moisture levels earlier than found here, and should benefit more from cyclic microirrigation than reported.

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Effect of Drought and Phenological Stage at Transplanting on Root Hydraulic Conductivity, Growth Indices, and Photosynthesis of Turkish Hazelnut[1]

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Abstract

A single drought episode was applied to two groups of container-grown *Corylus columa* L. (Turkish hazelnut) seedlings which had concomitantly reached distinct phenological stages; 1) buds opening and no new root growth visible and 2) shoot extension well underway and new root growth just beginning. Two days after rewetting, root hydraulic conductivity was lower for plants exposed to drought, but there was no phenological stage effect. No differences in root hydraulic conductivity were apparent among well-watered plants of stage 1, 2 and a third stage, 3) shoot extension complete (buds set) and root growth well underway. Twenty five days after return to daily irrigation, those plants subjected to the drying treatment had smaller diameter trunks, but total plant height and dry weight of root-balls were similar. No differences in photosynthetic rate or stomatal conductance were evident 25 days after transplanting.

Index words: *Corylus columa* L., transplant shock, plant establishment.

Significance to the Nursery Industry

Since container-grown plants are by necessity grown in well-drained media, root-balls are susceptible to rapid drying unless frequent, often daily, irrigation is applied. Perhaps the most drought vulnerable stage in the transplanting process is after plants are delivered to the landscape job, but before the actual planting occurs. Unless these plants are quickly planted, exposure to increased heat loads and wind can create high evaporative conditions, and root-balls can quickly desiccate. In addition, plants are often delivered to the site dry, and irrigation is usually unavailable until after they are planted.

The results of this experiment indicate that a single severe drying episode at transplanting will result in plants with a decreased conductance of water through root systems and smaller stem diameters. It is therefore important that pro-

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duction liners and landscape plants are not allowed to dry out at transplanting. Since even a short drought episode results in an increased resistance to water flow through roots, the probability of transplant shock is much increased. Plant establishment may therefore be slower, and the chance of failure will be increased. Comparison between plants that had just begun to grow and those that were in the active shoot extension stage revealed that drought impacts both growth stages in a similar manner. Actively growing plants may, however, reach drought stress sooner.

Introduction

The growth of woody nursery plants is often curtailed immediately after transplanting. Post-transplant symptoms include reduced shoot extension, smaller new leaves, scorched older leaves, stem daybook or even death. These conditions are collectively referred to as transplant shock (19). Transplant shock is thought to occur as a result of an inability of a reduced root system to supply sufficient water to the rest of the plant (11), desiccation during handling (1, 6), increased need for irrigation of container-grown transplants due to drainage from the rootball (13), or disruption of the rootball when removing fabric containers (10). Exposure to drought at transplanting may result in decreased photosynthetic rates because of reduced stomatal conductance or damage to the photosynthetic apparatus itself (10). Drought also decreases the capacity for water uptake by existing root systems (1, 14).

Ramos and Kaufmann (14) investigated the effect of previous water stress on the hydraulic conductance of rough lemon and found that short periods of moderate drought stress resulted in greater root hydraulic resistances. These results were attributed to increased suberin deposits in cell walls or to increased resistance across cell membranes. These conclusions were supported by the work of Cruz et al. (5), who reported an increased deposition of lignin and suberin in the hypodermis and endodermis on roots of drought stressed sorghum. Sands et al. (16) found that conductance of water through white unsuberized roots was 4 times greater than that through older suberized roots, and Brissette and Chambers (2) reported that a small increase in new root growth of beans resulted in a large increase in root water absorption capability. Columbo and Asseltine (3), however, found that as roots began to grow on black spruce seedlings, root hydraulic conductivity increased to a point, but then leveled off, and Wan et al. (18) found that conductance was only substantially higher for white verses brown roots when the soil was dry for the drought tolerant shrub *Gutierrezia sarothrae.*

One of the advantages of planting container-grown plants is that they can be planted during the growing season, whereas plants grown in other production systems transplant poorly at this time (9). Container-grown plants are therefore planted at all seasonal growth stages (phenologies). Plant response to rapid drying at different phenological stages is therefore of much interest to nursery growers and landscapers. Little information, however, is available in the literature on the effect of phenology on transplant response, and apparently none on the effect of phenology on root hydraulic conductivity of hardwoods. The purpose of this research, therefore, was to investigate root hydraulic conductivity and transplant response to rapid drying of Turkish hazelnut at different phenological stages.

Materials and Methods

One hundred germinated seedlings of *Corylus colurna* L. Turkish hazelnut were produced at Watson's Nursery, West Valley, NY, in the spring of 1992 and shipped to the Cornell University campus, Ithaca, NY. All plants were immediately potted into 200 ml (0.85 pint) containers in a topsoil:perlite:peat medium (1:1:1 by vol), grown outside throughout the summer and overwintered in unheated cold frames. The container dimensions were 6.5 cm (2.6 in) diameter top, 4.5 cm (1.8 in) diameter bottom and 8.5 cm (3.3 in) deep. Mean plant height, stem diameter 30 mm from the soil line and volume of washed roots determined by water displacement (s.e. mean in parentheses) at leaf drop (75% of leaves dropped) were 48.4 (1.4) cm (19.1(0.6) in), 6.2 (0.3) mm (0.24 (0.01) in) and 18.6 (1.7) ml (0.4 (0.04) pint), respectively, for n = 6.

The general procedure used for root hydraulic conductivity was to establish the pressure:flow relationship of root systems placed in a pressure chamber (3, 12) and to pick a single pressure within the region where the relationship was linear for conductivity determination (4, 7, 15). On May 13, 1993, the hydraulic conductivity of two replicates was measured to determine linearity. Tops were cut below the first branch junction, 60 mm from the soil line, and bark was removed from the cut stem. The containers were gently removed from the rootball and placed into a pressure chamber (Soil Moisture Equipment, Santa Barbara, CA) which had been fitted with a plastic sleeve and filled with vigorously shaken deionized water. The water within the pressure chamber was changed and again vigorously shaken to facilitate oxygenation between measurement of each replicate. The pressure chamber was then slowly pressurized with compressed air to 0.2 MPa. After 15 minutes, the cut end of the exposed stem was fitted with a pre-weighed section of tygon tubing which had been filled with absorbent cotton. Exudate was collected for 15 minutes, and the volume of the exudate was calculated from the weight gain of the tubing. This procedure was repeated at increased pressures of 0.2 MPa increments up to 2.0 MPa. After treatment, the volume of the root systems were determined by water displacement and flow per minute per ml of root volume (hydraulic conductivity) determined for each replicate. Hydraulic conductivity was determined to increase linearly with applied pressures of 0.2–2.0 MPa.

On April 15, 24 trees were chosen at random and placed into cold storage (5C (41F)). On May 15, the 24 plants in cold storage and 30 plants chosen at random from the unheated cold frames, were placed in a completely random design in a growth chamber and irrigated daily until June 16. This resulted in plants with two distinct phenological stages of development, one with buds opening but with no visible new root growth (stage 1) and one with shoot extension well underway and a few white root tips present (stage 2). The growth chamber was set at 16 hours light (PAR = 330 μmol m^{-2} sec^{-1}) at 22C (72F) alternating with 8 hours dark at 15C (59F). Twelve plants from each phenological stage were randomly selected for drought treatment. Irrigation was withheld from these plants until the mean pre-dawn xylem potentials (Ψ) of three randomly chosen subsamples from each phenological stage, determined with a pressure chamber, reached –2.0 MPa. Critical xylem potentials were recorded on June 26 for phenological stage 2 and June 28 for stage 1. Plants which did not receive the dry down treat-

Table 1. **Means and probabilities > F for hydraulic conductivity (J_v), hydraulic conductivity of well watered stages 1–3 (J_vB), height growth (Ht gain), trunk diameter growth (Cal gain), post-transplant dry weight of roots (Root wt), rate of photosynthesis (Ps) and stomatal conductance (G) for three phenological stages and drought and no drought treatments.**

	Mean[Z]						
	J_v (µl min^{-1} ml^{-1})	J_vB^Y (µl min^{-1} ml^{-1})	Ht gain (cm)	Cal gain (mm)	Root wt (g)	P_s (µmol m^{-2} sec^{-1})	G (mol m^{-2} s^{-1})
Stage 1	0.239	0.40	4.59	0.44	17.3	3.92	0.054
Stage 2	0.385	0.52	3.21	0.50	17.2	4.32	0.064
Stage 3		0.34					
Drought	0.167		4.79	0.35	17.3	4.58	0.067
No drought	0.457		2.86	0.61	17.2	3.56	0.051
	Pr > F						
Stage	0.163	0.407	0.377	0.619	0.255	0.472	0.302
Treatment	0.009		0.236	0.042	0.470	0.101	0.111
Stage × Trt	0.802		0.452	0.105	0.278	0.526	0.577

[Z]n = 6 for each stage × treatment.

[Y]Phenological stage 1, 2 and 3. No drought.

ment were irrigated daily. After reaching the mean critical xylem potential, all droughted seedlings were irrigated and allowed to equilibrate for 48 hours, after which 6 replicates from each of the two treatments for each phenological stage (6 drought, 6 no drought for each of 2 phenological stages) were moved into a dark lab for hydraulic conductivity measurements the next morning. Hydraulic conductivity was determined as discussed above except that pressures were slowly (0.2 MPa per minute) raised to 0.6 MPa and exudate collected at that pressure only. The other 6 replicates were planted into 1 liter (1 qt) containers in topsoil:perlite:peat medium (1:1:1 by vol) and returned to the growth chamber in a completely random design. Container dimensions were 13 cm (5 in) top diameter, 10 cm (4 in) bottom diameter and 9 cm (3.5) deep. Conductivity was measured as discussed above for the 6 plants which remained in the growth chamber in the 200 ml containers on August 22 (99 days after placement into the growth chamber). These plants were always well watered, and no fertilizer or drought treatment was imposed. Hydraulic conductivity determination coincided with bud set and active new root development (phenological stage 3).

Twenty seven (stage 2) and 25 (stage 1) days after return to the growth chamber (July 23), photosynthesis rates were measured (Licor 6200, Licor, Lincoln, NB) on all repotted plants (12 stage 1 and 12 stage 2). All plants were moved outdoors in the early morning of the day of measurement, and measurements were made that afternoon between 1400 and 1600 HR. Air temperature ranged from 28–31C (82–88F) and PAR always exceeded 600 µmol m^{-2} sec^{-1}. Photosynthesis rates were determined in-situ by placing a 34 mm by 26 mm section of recently matured leaf (3–5 leaves from the apex) into a ¼-liter sample chamber. Photosynthetic rates for each replicate were the mean rates of 3 consecutive 10 second periods. Stem diameter 30 mm from the soil line, height and root dry weight were then measured. Root dry weight was determined by drying clean tissue to a constant weight at 70C (158F). All data were subjected to analysis of variance.

Results and Discussion

Phenology had no effect on hydraulic conductivity (Table 1). This is contrary to reports on well-watered conifers (2, 3), where new root growth resulted in increased conductivity through root systems. The absence of a phenological effect may have been the result of morphological features of root systems of broad-leaved container plants. Root system morphology differs dramatically for trees produced in containers compared to those produced directly in the ground (10). Turkish hazelnut is a very coarse-rooted tree when field grown (8), but the root system of the container-grown trees used in this study appeared much more fibrous. It is possible that the large absorptive capability conferred by the fibrous root system of these well developed root balls obscured any increase in absorption resulting from the production of new roots. This may not have been the case if the plants had been field-grown and transplanted with the customary removal of a major part of the root system at harvest.

Drought significantly reduced root hydraulic conductivity independently of phenology ($p = 0.009$). A single drought episode was therefore equally effective in reducing root hydraulic conductivity for both phenological stages tested. These data indicate that even a single drought episode impacts the future quality of the transplant. Small potted liners that are commonly used in container production are particularly vulnerable. Such plants, especially if actively growing, are very susceptible to rapid drying because of high transpiration rates and a limited water reservoir. Although this study indicates that plants at different phenological stages respond in a similar manner to equal internal drought stress ($\Psi = -2.0$ MPa), rapidly growing plants can achieve that drought stress more quickly if not carefully maintained. Unlike stem diameter, plant height and root weight, 27 days after transplanting, were not affected by phenological stage or drought.

Data from this report indicate that drought at transplanting impacts root hydraulic conductivity independently of the two phenological stages tested and results in plants with smaller stem diameters. Increased resistance to water flow through root systems could affect growth by the reduction of turgor pressure in expanding cells, reducing leaf size, or the reduction of photosynthetic rates through stomatal closure. Struve and Jolly (17) reported that photosynthesis rate on a per leaf basis was similar on transplanted versus untransplanted red oak (*Quercus rubra*) seedlings. Transplant shock was instead mediated by a reduction in total leaf area. Although total leaf area differences between treatments or phenologies were not assessed in the present study, similar results may have occurred, possibly as a result of reduced hydraulic conductivity. This may help explain differences in stem diameter.

Future research should document growth indices, root hydraulic conductivity and photosynthetic rates throughout the production cycle following a drought episode. This would help clarify the mechanisms by which growth is reduced following the drought. Growth indices should be followed on transplants to determine the lasting effects. Finally, investigation into the differences between root hydraulic conductivity of container grown and field grown transplants may be insightful as to differences in transplant response between the two production methods.

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