SHORT AND LONG-TERM EFFECTS OF TREESHELTERS ON THE ROOT AND STEM GROWTH OF ORNAMENTAL TREES

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Abstract. Short-term (aerated solution culture and container nursery) and long-term (landscape) experiments were conducted to study the effect of treeshelters on the root and shoot growth of several ornamental trees (*Sequoia sempervirens* (D. Don) Endl., *Quercus lobata* Née, *Quercus agrifolia* Née, *Lagerstroemia indica* L. 'Watermelon Red', *Ginkgo biloba* L., *Platanus racemosa* Nutt., *Fraxinus latifolia* Benth. and *Populus euamericana* cv. Giacometti). In general, plants grown in treeshelters were taller and some had reduced caliper growth. Treeshelters reduced top dry mass of *F. latifolia, P. racemosa, Q. agrifolia, Q. lobata* and *P. euamericana* and also reduced root dry mass, root:shoot ratio, total root length and total root area for all species/cultivars except *Q. agrifolia*. The results are explained on the basis of the microenvironment in/around treeshelters, photosynthetic partitioning and immobilization of plants growing in shelters. Management challenges and potential usefulness of treeshelters in landscape transplanting are also discussed.

Treeshelters have been used to help improve transplanting success of trees in the landscape. Studies over the past decade have shown that treeshelters increase survival (3), enhance stem growth rates and tree height with relatively little effect on stem caliper and overall biomass (2,6,12). Little attention has been paid to the development of roots or dry matter partitioning of trees growing in shelters. Rendle (15) found that *Quercus Robur* L. trees growing in shelters grew to set heights in shorter periods of time, but did not differ in total dry matter accumulation; however, she did find that dry mass between stems, branches and roots differed depending on whether treeshelters were used or not. More recently, Švihra et al. (18) found that treeshelters reduced the fresh and dry mass of redwood (*Sequoia sempervirens* [D. Don] Endl.) trees growing in the landscape for 4 years.

Dry matter partitioning can be an important factor in the early development of trees in the landscape. If root development is inhibited before or during transplantation, a newly planted tree has a lower probability of becoming well established (9). The objective of this two-year study was to determine the effect of treeshelters on root development and dry matter partitioning of seven tree species common to the western United States.

Materials and Methods

Short-term experiments. A randomized, complete block design experiment (6 blocks, 2 replicates per block) was initiated in May, 1993, in a container nursery whereby each block contained two trees of each species, one in a shelter (122-cm tall, 10-15 cm in diameter, tan Tubex® shelter) and one not in a shelter (control). Seed-propagated liners were used as planting stock including: *Sequoia sempervirens* (D. Don) Endl., *Quercus lobata* Née, *Quercus agrifolia* Née, *Lagerstroemia indica* L. 'Watermelon Red', *Ginkgo biloba* L., *Platanus racemosa* Nutt. and *Fraxinus latifolia* Benth. The trees were grown in 1.8-liter (#1) containers filled with UC (University of California) Mix (1:1:1, by volume, sand:redwood sawdust:peat moss). Thirty g of Nutricote Total (18-6-8 with micronutrients, Type: 180, PlantCo, Inc., Brampton, Ontario, Canada) were added to the soil surface at planting time. Treeshelters, held upright by 1 stake, were placed over the appropriate plants after the containers were moved to the nursery bed. The nursery containers were placed on 40-cm centers. An automated irrigation system (spray stakes) was used to add approximately 500 ml of water each day. Half the blocks were harvested after three months and the other half after six months. Measurements of height, caliper and fresh and dry biomass accumulation were taken at each harvest.

Solution culture experiments. Tip cuttings of *Populus euamericana* cv. Giacometti were rooted in aero-hydroponic units (17) containing de-ionized water. Once rooted, the cuttings were put singly into containers holding approximately 2 liters of Hoagland's Solution 2 plus micronutrients (10) that

Table 1. Mean height increases of seven tree species over time growing with (+) and without (-) treeshelters. (n=8 for 3- and 6-month data, n=20 for 1-year data, n=10 for 2-year data)

	Mean Height Increase (cm)							
	3 months		6 months		1 year		2 years	
Species	-	+	-	+	-	+	-	+
Fraxinus latifolia	27 b	44 a	----	----	162 a	197 a	238 a	233 a
Ginkgo biloba	0 a	0.3 a	1.5 a	4.4 a	13 a	18 a	34 a	51 a
Lagerstroemia indica	27 b	76 a	30 b	76 a	30 b	137 a	98 b	160 a
Platanus racemosa	38 b	64 a	----	----	134 a	173 a	330 a	308 a
Quercus agrifolia	16 b	51 a	27 b	78 a	57 b	144 a	172 a	191 a
Quercus lobata	9 b	31 a	19 b	53 a	71 b	200 a	233 a	261 a
Sequoia sempervirens	11 b	25 a	12 b	38 a	85 a	68 a	123 b	213 a

Values followed by the same letter for each time period are not significantly different from one another at p=0.05 using Scheffe's multiple separation procedure.

were continuously aerated (≈1 L·min^{-1}). Each cutting was held in place in the lid of the container with rubber stoppers that had holes bored through them. This arrangement allowed the rooted cuttings to be held with only their root systems immersed in the aerated nutrient solution. Each container was equipped with an aeration tube, a drip tube capable of distributing fresh Hoagland's Solution 2 and an overflow tube (just under the lid). Treeshelters were attached to the upper surface of the lid of half the containers using hot glue creating an air-tight seal. There were six containers per treatment arranged in a completely randomized design on a bench in a greenhouse kept at 22-28° C. Every day, fresh nutrient solution was added to each container using an automated irrigation system. When the container became filled during each "irrigation", excess nutrient solution escaped through the overflow tube. Plants were measured and harvested six weeks after placing the rooted cuttings in the nutrient solution containers.

Figure 1. Hydroexcavation of tree roots with a high-pressure water and vacuum system.

Long-term experiments. A randomized, complete block design landscape experiment (10 blocks) was initiated in April, 1993, whereby each block contained two adjacent trees of each of the same seven tree species used in the nursery experiments that were planted on 1.8 m centers in rows 1.8 m apart. The trees were irrigated with an automatic drip system distributing ~8.7 L every other day for the duration of the experiment. Trees were fertilized once, four weeks after planting, with Agriform 20-10-5 plus minors fertilizer tablets (Grace/Sierra, Milpitas, CA). The fertilizer tablets were pressed 8-12 cm into saturated soil 6-10 cm from each tree immediately after irrigation. After 12 months height and stem diameter (caliper) were measured and fresh and dry mass were determined for tops (leaves, branches, stems) and roots of trees in half the blocks. Root systems were removed from the ground with a backhoe fitted with a 60-cm wide bucket. The soil attached to the roots was removed with pressurized water so root fresh and dry mass could be determined. A recently rinsed root system of each tree was shaken to remove excess water, weighed (fresh mass), cut into pieces, placed in a paper bag, dried for at least seven days at 70°C and weighed (dry mass). The remaining trees in blocks were harvested after 24 months. Trees were harvested by cutting the trunk at ground level. Twigs with leaves and stems were cut into pieces, weighed (fresh mass), placed in paper bags and dried for at least one week at 70°C to obtain dry mass. Collected biomass data included top (leaves, branches, stems) fresh and dry mass.

Table 2. Mean caliper increases of seven tree species over time growing with (+) and without (-) treeshelters. (n=8 for 3- and 6-month data, n=20 for 1-year data, n=10 for 2-year data)

	Mean Caliper Increase (mm)							
	3 months		6 months		1 year		2 years	
Species	-	+	-	+	-	+	-	+
Fraxinus latifolia	9 a	6 b	---	---	32 a	27 a	83 a	61 b
Ginkgo biloba	2.0 a	1.3 b	2.6 a	2.2 a	3.5 a	3.2 a	9.1 a	6.4 a
Lagerstroemia indica	4.9 a	4.3 a	5.4 a	5.9 a	12 a	10 a	32 a	23 a
Platanus racemosa	7.0 a	9.0 a	---	---	57 a	36 b	138 a	82 b
Quercus agrifolia	3.4 a	3.1 a	4.1 a	5.0 a	13 a	12 a	31 a	22 b
Quercus lobata	1.8 a	2.4 a	2.1 a	2.7 a	16 a	12 a	44 a	32 a
Sequoia sempervirens	3.2 a	1.6 b	4.5 a	5.2 a	24 a	12 b	52 a	36 b

Values followed by the same letter for each time period are not significantly different from one another at p=0.05 using Scheffe's multiple separation procedure.

Root systems were exposed using hydro-excavation techniques (7,8) (Figure 1). A pneumatic conveyor industrial loader vacuum truck (Vactor model 1645, Federal Signal Co., Streator, IL) removed the resulting soil-water slurry. Water was supplied by a nearby hydrant with a flowing pressure of 64 PSI through a 2-½ in. diameter supply line. The hose size was reduced to 1-¾ in. diameter handline with 1-½ in. fittings at the excavation site. A modified "EZ Pup" (Durham Fire and Rescue Specialty Tools, North Tonawanda, NY) was utilized at the end of the handline to reduce operator fatigue and a KK "Thunder fog" nozzle (Task Force Tips, Valpariso, IN) was attached to the "EZ Pup". The water stream delivered under pressure reduced the soil in the root area to a slurry and the Vactor vacuum hose removed it. Using this technique, undamaged roots as small as 1 mm in diameter were exposed. On deeper, more extensive root systems, hydroexcavation continued until roots as small as 1 cm were exposed. They were then cut at the soil interface before removing the excavated portion from the ground. The root systems were air-dried, painted white, suspended above a back-lit background and photographed from above using high-contrast black-and-white film. This set up provided excellent contrast between the shadow-darkened root system and the bright background. Once photographed, the root systems were cut into pieces and dried for at least seven days at 70° C (for dry mass). The black-and-white photographs were used to estimate total root length and total root area. Each root system was photographed with a rod of known length (10, 50 or 100 cm) in the picture. The images of known length and a piece of string arranged into a circular shape (ends not touching) were used to calibrate the video imaging system (AgVision Root and Leaf Analysis, Decagon Devices, Inc.) that made the root length and root area estimations. The string was at least 150 mm in length and produced an image at least 200 pixels long on the computer screen to accurately calibrate the digitized image. By comparing the known length of the string and the known length of the rod in each photograph, the actual dimensions of the root system could be

Table 3. Top dry mass of seven tree species over time growing with (+) and without (–) treeshelters. Dry mass data for 3 months was lost due to a fire in the drying oven. (n=8 for 3- and 6-month data, n=20 for 1-year data, n=10 for 2-year data)

	Top Dry Mass (g)					
	6 months		1 year		2 years	
Species	-	+	-	+	-	+
Fraxinus latifolia	---	---	542 a	463 a	3286 a	2265 b
Ginkgo biloba	3.7 a	3.3 a	11.4 a	6.8 a	23.2 a	17.0 a
Lagerstroemia indica	11.7 b	24.3 a	120 a	177 a	625 a	638 a
Platanus racemosa	---	---	1518 a	720 b	9357 a	3280 b
Quercus agrifolia	22.6 b	48.2 a	113 a	143 a	677 a	533 b
Quercus lobata	7.0 b	12.0 a	162 a	96 a	1346 a	925 b
Sequoia sempervirens	16.5 b	31.3 a	386 a	102 b	1125 a	1288 a

Values followed by the same letter for each time period are not significantly different from one another at ρ=0.05 using Scheffe's multiple separation procedure.

All data for all experiments were analyzed using the General Linear Model (GLM) Procedure of the SAS statistical system (16).

Results

Height increase. All species growing in shelters, except *G. biloba*, showed height increases over control trees of 62-244% after only three months (May to August) of growth (Table 1). This same result occurred in those tree species measured at six months (Table 1). After one year, *L. indica*, *Q. agrifolia* and *Q. lobata* trees growing in shelters were still taller than their unsheltered counterparts, whereas *F. latifolia*, *G. biloba*, *P. racemosa* and *S. sempervirens* trees growing in shelters were no taller than controls. After two years, only *L. indica* and *S. sempervirens* trees growing in shelters continued to be taller than the controls (Table 1). The unsheltered trees of the other five species all had similar heights by then.

Caliper development. Caliper development was only slightly affected by treeshelters after three months in *F. latifolia*, *G. biloba* and *S. sempervirens* (Table 2). At six months none of the tree species showed differences in caliper and long-term (1 or 2 years) effects of treeshelters on caliper were observed in *S. sempervirens* and *P. racemosa* (after 1 and 2 years) and *F. latifolia* and *Q. agrifolia* (after 2 years) (Table 2). At no time during this study were caliper differences between control (unsheltered) and sheltered trees observed for *L. indica* or *Q. lobata*.

Top dry mass. Top dry mass (TDM) varied in treeshelters during the time of the experiment among most of the species. After 6 months *L. indica, Q. agrifolia, Q. lobata* and *S. sempervirens* trees growing in shelters had greater top dry mass than control trees (Table 3). However, after 1 year there was no significant difference between unsheltered and sheltered trees except for *P. racemosa* and *S. sempervirens* where unsheltered trees had higher top dry mass than sheltered counterparts (Table 3). After 2 years *F. latifolia*, *P. racemosa, Q. agrifolia* and *Q. lobata* trees growing in treeshelters had lower dry mass than control trees.

Root dry mass and dry matter partitioning. Except for *Q. agrifolia*, all tree species eventually had reduced root dry mass (RDM) when grown in treeshelters (Table 4). The reduction in RDM occurred most rapidly (3 months) for *F. latifolia*, *G. biloba* and *P. racemosa* and by six months for *L. indica*, *Q. lobata* and *S. sempervirens*. After two years, RDM of sheltered trees ranged from 9 to 71% that of unsheltered trees. Treeshelters reduced the root:shoot ratio of *G. biloba*, *L. indica*, *Q. lobata* and *S. sempervirens* (Table 4). Most dramatic was the response observed in *L. indica* and *S. sempervirens* where the root:shoot ratios for the sheltered trees were 11% and 8% that of the controls.

Total root length and total root area. Treeshelters reduced total root length by 17-39% and total root area by 38-89% compared to controls for all tree species except *Q. agrifolia* (Table 5).

Dry biomass response of Populus trees in aerated solutions. Leaf, stem and root dry mass and root-shoot ratios of *Populus* were lower in plants growing in shelters versus those unsheltered (Table 6). The percent reductions were similar for trees growing in aerated nutrient solutions compared to tree species growing in containers and in the landscape. Figure 2 shows the reduction in root volume of *Populus* trees grown in aerated solutions. The reduction in root system growth is common to most trees studied when grown in shelters. In the aerated nutrient solution experiments none of the root system tissues were lost when the plants were harvested compared to the trees hydroexcavated from landscape sites. Height and fresh mass responses were also similar to those of plants growing in soil (data not shown).

Table 4. Root dry mass over time and final root-shoot ratios of seven tree species growing with (+) and without (–) treeshelters. Some roots <1 cm in diameter remained in the soil after root system excavation. (n=8 for 3- and 6-month data, n=20 for 1-year data, n=10 for 2-year data)

	Root Dry Mass (g)						Root:Shoot (dry mass basis)	
	3 months		1 year		2 years			
Species	-	+	-	+	-	+	-	+
Fraxinus latifolia	46.3 a	17.8 b	259 a	147 b	1473 a	1051 b	0.45 a	0.46 a
Ginkgo biloba	5.3 a	4.0 b	6 a	4 a	34 a	18 b	1.47 a	1.06 b
Lagerstroemia indica	13.3 a	11.3 a	39 a	28 b	1574 a	180 b	2.52 a	0.28 b
Platanus racemosa	40.7 a	27.3 b	673 a	287 b	2394 a	1561 b	0.26 a	0.38 a
Quercus agrifolia	12.2 a	8.4 a	43 a	40 a	165 a	135 a	0.24 a	0.25 a
Quercus lobata	12.5 a	13.8 a	91 a	66 b	664 a	316 b	0.49 a	0.34 b
Sequoia sempervirens	7.3 a	4.0 a	64 a	15 b	404 a	37 b	0.36 a	0.03 b

Values followed by the same letter for each time period are not significantly different from one another at p=0.05 using Scheffe's multiple separation procedure.

Discussion

The reduced root biomass from trees growing in treeshelters was the most striking response observed in this study. Six of the seven tree species growing in soil and *Populus* trees growing in aerated solution cultures showed reduced root biomass, total root length and total root area. Some roots from very large root systems associated with control (unsheltered) trees in the landscape sites were left unexcavated due to their depth and lateral expanse. This means that growth estimates of those root systems are conservative. Still, significant differences were found between sheltered and unsheltered treatments for most of the tree species studied. The reduction in root biomass was likely the result of a reduced overall photosynthate pool (reduced biomass production) and/or a change in photosynthate partitioning between treatments causing a reduction in the root:shoot ratio. Root biomass and root:shoot ratios of trees have been shown to be adversely affected by water and nutrient regimes (5), planting density (14) and light (4), but this is the first report of a long-term reduction in root biomass and root:shoot ratios of several tree species in response to treeshelters. The reduced root biomass found in most of the tree species in this study is most likely due to a combination of environmental factors associated with treeshelters. The light irradiance inside the treeshelter is approximately half that outside the treeshelter (2). This alone would reduce overall available photosynthate.

Top dry mass changes were due either to changes in height or changes in caliper. In no instances were height increases associated with

Table 5. Total root length and total root area of trees growing with (+) and without (-) treeshelters after two years. Some roots <1 cm in diameter remained in the soil after root system excavation. (n=8 for 3- and 6-month data, n=20 for 1-year data, n=10 for 2-year data)

	Total Root Length (cm)		Total Root Area (cm2)	
Species	-	+	-	+
Fraxinus latifolia	1541 a	1099 b	1831 a	1034 b
Ginkgo biloba	273 a	166 b	138 a	52b
Lagerstroemia indica	778 a	636 b	443 a	268 b
Platanus racemosa	2460 a	1713 b	2915 a	1809 b
Quercus agrifolia	485 a	581 a	271 a	276 a
Quercus lobata	730 a	605 b	555 a	353 b
Sequoia sempervirens	692 a	539 b	117 a	195 b

Values followed by the same letter for each time period are not significantly different from one another at $p=0.05$ using Scheffe's multiple separation procedure.

caliper increases and in one case (*S. sempervirens*) increases in height were accompanied with decreases in stem caliper. This is a common occurrence in woody perennials as available photosynthate is partitioned into competing above-ground sinks.

The light environment surrounding a plant shoot can affect its root size and root/shoot biomass ratio and has been widely studied. Individual plant responses are likely under genetic control and "strategies" have been suggested by which a plant invests only enough carbon in roots to support the plant as it develops. Kasperbauer and Hunt (11) found in sweetclover (*Melilotus alba* Desr.) that while photosynthesis regulates carbon fixation and biomass production, photoperiod and spectral distribution regulate biomass distribution (partitioning) and new photosynthate. Wilson (19) has also provided a summary of the effects of light and carbon dioxide on the root:shoot ratios of plants. Changes in light, in particular in light quality or spectral distribution, could explain why root:shoot ratios differ between sheltered and unsheltered tree species studied here. Tubex® treeshelters used in these experiments were tan in color and have been shown to reduce light irradiance (2). While spectral shift analyses have not been conducted for these treeshelters, it is quite probable the absorption, transmission and/or reflection of light inside the shelter is substantially different from incident light outside. Analyses such as these will be necessary to support this contention and help provide an explanation for the dramatic root biomass reductions observed in most trees growing inside treeshelters.

Not all trees responded similarly to treeshelters. For some, height was influenced early and the effect diminished over time (e.g., *F. latifolia*, *P. racemosa* and *Q. lobata*); others were affected for longer periods of time (in this study, two years) (e.g., *L. indica* and *S. sempervirens*); and others, were affected very little (e.g., *G. biloba*). For most tree species in this study, as the tree grew and eventually emerged from the 122-cm treeshelter, the influence the shelter had on growth of the tree diminished. This is to be expected especially when trees had more than half their above-ground biomass outside the treeshelter (e.g., *F. latifolia*, *P. racemosa* and *Q. lobata*). For other tree species this was not the case. *L. indica* and *S. sempervirens* trees maintained their differences in height even though nearly 50% of the tree was out of the treeshelter. There may be other physiological influences of the treeshelter on lower trunk (that part inside the treeshelter) that have

There may be other physiological influences of the treeshelter on lower trunk (that part inside the treeshelter) that have not yet been identified or the early growth of these tree species inside the shelter may predispose them to longer term growth enhancements.

Table 6. Dry biomass response of *Populus euamericana* cv. Giacometti plants growing in aerated solution culture with (+) and without (-) treeshelters.

Dry Mass (g)									
Leaf		Stem		Root		Total		Root:Shoot (dry mass basis)	
-	+	-	+	-	+	-	+	-	+
37.6 a	2.8 b	15.7 a	3.3 b	11.5 a	1.5 b	64.8 a	7.6 b	0.73 a	0.45 b

Values followed by the same letter for each response group are not significantly different from one another at p=0.05 using Scheffe's multiple separation procedure.

Conclusions.

The above-ground responses observed in these tree species are similar to those seen by our earlier work and those of others (1,2,6,12,13,18). That is, trees grown in shelters are taller, tend to have somewhat smaller stem caliper and have reduced fresh and dry mass of above and below-ground biomass. Environmental conditions (reduced light irradiance and increased temperature, relative humidity and CO_2 concentration) inside treeshelters have been associated with most of these growth responses. Treeshelters should not be left around trees once the tree has grown taller than the shelter. This is especially important in windy areas since trunk deformities result (1). The benefits of treeshelters include enhanced stem height, protection from browsing animals and management practices (herbicide applications) and convenient release of predators inside to control of insect pests. The reduction in root mass may not always be a liability to the early development of newly transplanted trees in the landscape depending on the species.

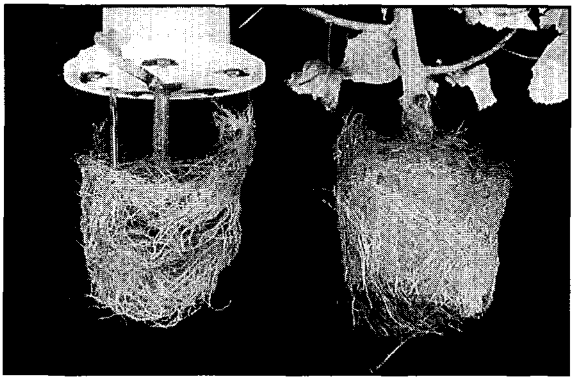

Figure 2. Root development of *Populus euamericana* cv. Giacometti trees grown in aerated solution culture with (left) and without (right) treeshelters.

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Résumé. Des expériences à court et long termes ont été menées afin d'étudier l'effet des ombrières sur la croissance des pousses et des racines des *Sequoia sempervirens*, *Quercus lobata*, *Q. agrifolia*, *Ginkgo biloba*, *Platanus racemosa*, *Fraxinus latifolia* et *Populus euramericana*. En général, les végétaux sous les ombrières étaient plus grands et avaient une diamètre plus petit. Ces résultats s'expliquent sur la base du micro-environnement sous et autour des ombrières, de la photosynthèse fractionnée et de l'immobilisme des végétaux lorsque'ils sont sous les ombrières.

Zussammenfassung. Um den Effekt von Baumschutzhüllen auf Wurzel - und Triebwachstum bei *Sequoia sempervirens*, *Quercus lobata*, *Q. agrifolia*, *Ginkgo biloba*, *Platanus racemosa*, *Fraxinus latifolia* und *Populus euramericana* wurden Kurzzeit- und Langzeitexperimente durchgeführt. Allgemein werden die Pflanzen in den Baumschutzhüllen größer und hatten geringeren Umfangzuwachs. Die Ergebnisse wurden auf der Basis des veränderten Mikroklimas in und um die Baumschutzhüllen und die Immobilisation von Pflanzen in Schutzhüllen erklärt.