Establishment in Treeshelters I: Shelters Reduce Growth, Water Use, and Hardiness, but not Drought Avoidance

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Abstract. We investigated water use and potential drought avoidance of Norway maple (*Acer platanoides* L.) and green ash (*Fraxinus pennsylvanica* Marsh) seedlings grown in protective plastic shelters. Gravimetric tree water use and reference evapotranspiration for fescue turf (ET_o) were monitored for 1 to 3 days during the growing season. Water use of trees was 8% to 14% of ET_o in shelters vs. 29% to 40% for trees not in shelters. Trunk diameter was affected more than whole-tree water relations by lack of irrigation, suggesting that the nonirrigated trees were subjected to only mild water stress. Shelters did not improve drought avoidance, as water potentials were generally more negative and trunk diameter increment was lower for nonirrigated trees in shelters. Maples in shelters were affected more adversely by lack of water than were ash. Higher temperatures in shelters also may have reduced trunk growth. Air temperatures were 13 °C warmer than ambient in nonirrigated shelters, but only 5 °C warmer in irrigated shelters. Tree shelters can reduce transpiration rates by over half, but benefits from reduced water loss may be offset by negative effects of higher air temperatures. Shelters reduced cold hardiness of both species, but maple was affected more than ash.

Tree shelters, developed initially to reduce herbivory on newly planted tree seedlings, increase tree height (Burger et al., 1992; Potter, 1988; Svihra et al., 1993) because greenhouse-like conditions raise temperature and humidity. In addition, shelters block air movement over the foliage, thereby increasing boundary-layer resistance to water movement and reducing overall transpiration rates (Kjelgren, 1994). Reducing transpiration decreases soil–water depletion, potentially improving drought avoidance. In large-scale plantings of small trees, mortality is often high during the first year after planting (Cleveland and Kjelgren, 1994), particularly if trees are not irrigated (Nambiar and Sands, 1991). Tree shelters may help in establishing small trees in large-scale plantings and landscapes when routine irrigation is not possible. In addition, the ability to predict water use in shelters can permit strategic timing of irrigation to conserve water and labor. The objectives of this study were to quantify water use of trees in shelters relative to reference evapotranspiration, and determine if shelters increase water-stress avoidance in bare-root whips during first-year establishment.

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Materials and Methods

Two experiments were conducted on Norway maple and green ash at the Utah State Univ. research farm in Logan.

Expt. 1. To study water use, 0.75-m bare-root seedling whips were planted in early spring in 20-L containers in a 1 peat : 1 perlite mix amended with 200 g of 20N–4.3P–8.3K slow-release fertilizer per container. In early May 1992, shortly after budbreak, 1.25-m-high, 0.1-m-internal-diameter, brown-translucent shelters (Treessentials, St. Paul, Minn.) were placed over four trees of each species, and four others were left uncovered. Characteristics of these shelters are described elsewhere by Potter (1988). The root ball and container of each tree were enclosed within two large plastic bags that were sealed to the tree trunk to eliminate surface evaporation. The bag was sealed to the base of the shelter so that the tree and media surface were exposed to ambient air only through the top of the shelter.

Transpiration was determined over 1- to 3-d periods during July–Aug. 1992 by weighing each tree to 0.1 g before dawn at the beginning and end of each period. The amount of water lost during each period was then replaced, and the bags around the container were opened and allowed to ventilate for 1 d to allow oxygen to the roots. During each period, the trees were placed in holes in existing turfgrass such that the lip of the container was level with the top of the turfgrass canopy. This helped maintain root-zone temperatures equivalent to that in a field soil. Penman-type reference evapotranspiration (ET_o) that described water loss from

a well-watered 0.12-m-high clipped fescue turf (Allen et al., 1989) was measured concurrently with an automated weather station ≈10 m from the study site. In late August, all leaves were harvested and total leaf area measured (model 3100 leaf area meter; LI-COR, Lincoln, Nebr.). Gravimetric transpiration was normalized to unit leaf area by dividing by total leaf area. The mean of the data for four trees for each species was then plotted vs. ET_o for each date.

Expt. 2. To study drought avoidance in the field, we planted bare-root trees of the same size and species, also in Spring 1992, in a split-plot design on a well-drained Millville silt loam (coarse-silty, carbonatic, mesic, Typic Haploxeroll) that had 17% available water content to a depth of 1 m. Main plots were +/- irrigation, and +/- shelters, and species treatments were randomly assigned within each main plot with eight replications (trees). Trees were then randomly assigned to treatments. The soil surrounding the experiment was maintained free of vegetation through the season by hand-cultivation within rows and tillage between rows.

Shelters were placed over treatment trees immediately after planting in mid-May. The irrigated trees were supplied with 23 L of water weekly with a 4 L·h⁻¹ drip emitter. Historically, average weekly ET_o is ≈50 mm in this region from June–August (Ashcroft et al., 1992). One-sided leaf area of these trees was ≈1 m², and assuming tree transpiration at 40% of potential ET_o (Costello et al., 1992), estimated water use would be 20 L per week. Thus, the irrigation rate was sufficient to meet expected tree water requirements. In late August and early September, diurnal air temperature and humidity were monitored in shelters containing a nonirrigated and an irrigated green ash to determine if irrigation affected shelter microclimate. A combination thermistor and humidity sensor (Humicap; Vaisala Corp., Woburn, Mass.) was inserted into the shelter so that the sensor was shielded by foliage from direct sunlight, and readings were recorded (model 900 datalogger; Omnidata, Logan, Utah) every 15 min.

On two dates in August predawn (5:00–6:00 AM) and midday (between 12:00 noon and 2:00 PM), leaf water potential (Ψ) was measured with a pressure chamber (series 3000; Soil Moisture, Santa Barbara, Calif.). A single leaf was excised from each tree before dawn and again at midday, immediately sealed in an aluminum bag (Karlic and Richter, 1979), and returned to the laboratory for measurement with a pressure chamber, usually within 1 h. Midmorning and midday stomatal conductance (g_s) was measured with a steady-state porometer (model 1600; LI-COR) on three representative, fully illuminated, mature leaves per tree. For trees in shelters, g_s was measured through a small window cut into the south side of the shelter at midcanopy. After the window was opened, measurements were taken as rapidly as possible to prevent outside conditions from affecting g_s. The window was taped shut between measurements to prevent air movement into the shelter.

In late summer, 2-cm² disks were removed from five separate leaves per tree, dried at 60 °C for 1 d, then weighed. Specific leaf area (SLA) was determined as cm²·g⁻¹ of leaf tissue. Trunk diameter was measured with a digital caliper at 0.15-m height prior to budbreak in midspring and after leaf drop in the fall. Water potential, conductance, and growth increment means were compared among treatments with analysis of variance appropriate for a split-plot design. Significant differences among means of treatment combinations were determined with F tests at the 0.05 and 0.01 levels of probability. Tree water use for each species with and without shelters was plotted vs. ETo, and standard error of the mean of all measurements was calculated after pooling the variances among replicates. Vapor pressure deficit and air temperatures in irrigated and nonirrigated shelters were plotted vs. time for two study dates.

Results and Discussion

Expt. 1. Shelters substantially reduced water loss from both green ash and Norway maple (Fig. 1). The trees without shelters transpired at 29% ± 3% of potential ETo for maple and 40% ± 4% for ash. These values are in the suggested range of tree water loss as a fraction of grass reference ETo (Costello et al., 1992). As they were planted bare-root, transpiration rates of these trees were probably low due to lack of root establishment. Stomatal conductance of the container-grown trees (data not shown) was about two-thirds of levels reported for non-bare-root broadleaf deciduous tree species (Hinckley et al., 1978). Since g_s in most trees is closely linked to atmospheric conditions due to high boundary-layer conductances (Jarvis and McNaughton, 1986), low g_s reduces the transpiration rate. Transpiration of sheltered trees as a fraction of ETo was 8% ± 1% for Norway maple and 14% ± 2% for green ash; in contrast, Burger et al. (1992) found no decrease in water use in sheltered trees. This reduced transpiration rate was due to restricted air movement in the shelters that severely reduced boundary-layer conductance (Kjelgren, 1994), essentially disconnecting g_s from the outside atmosphere (Jarvis and McNaughton, 1986). Lower transpiration rate in maple as compared to ash was likely due to less open stomata, as seen in field measurements of g_s (Table 1).

Expt. 2. Both irrigation and shelters affected tree growth and water relations in the field study. Nonirrigated trees of both species were subjected to mild water stress (Table 1). June–Aug. 1992 was drier and warmer than average, as the recorded 63 mm of rain and 669 mm of ETo were 85% and 120% of normal, respectively. This rainfall deficit substantially reduced increase in trunk diameter in the nonirrigated trees. Predawn Ψ and midmorning g_s , however, were significantly lower only on the first date of measurement. Growth is more sensitive to water stress than is gas exchange, as growth slows in response to mild water stress before stomata close (Bradford and Hsiao, 1982). Overall, trees in shelters had

more negative predawn Ψ but higher g_s , greater SLA, and smaller increases in trunk diameter than those not in shelters, due in part to low light levels (Kjelgren, 1994); however, higher humidity also may have contributed to higher SLA. Trunk growth of trees in shelters was one-fifth that of nonsheltered trees, probably a result of lack of wind movement (Harris et al., 1976). Conductance levels were lower than previously reported (Kjelgren, 1994), but humidity levels in the shelters appeared to allow higher g_s than in nonsheltered trees.

Shelter microclimate was also affected by irrigation (Fig. 2). As reported in previous work (Kjelgren, 1994; Potter, 1988), shelter air temperatures (T_a) and vapor pressure deficit (VPD) were higher than ambient. In the irrigated shelter, T_a ranged from 28 to 30 °C during the day on both dates, while daily VPD averaged ≈1.5 kPa on 2 Sept., but only 0.75 kPa on 21 Aug. Negligible surface evaporation and lower g_s clearly reduced evaporative cooling and increased T_a and VPD in the nonirrigated shelters compared with the irrigated shelters. During the period from noon to 5:00 PM, air temperature averaged 8 and 5 °C warmer and VPD 1.3 and 0.8 kPa higher in the former on 21 Aug. and 2 Sept., respectively. Indeed, in the nonirrigated shelter, T_a ranged from 35 to 40 °C, substantially warmer than ambient, and VPD ranged from 2 to 3 kPa on both dates.

While shelters reduced tree water loss in the container study, they did not prevent drought stress in the field (Table 1). Nonirrigated trees in shelters experienced greater water stress than those not in shelters, as Ψ values before dawn on 12 Aug. and at midday on 25 Aug. were the most negative of all treatments. By contrast, Kjelgren et al. (1994) reported increased survival and de-

layed onset of water stress in white oak grown in shelters on compacted minesoil in a much more humid and cloudy climate. We did not detect differences in either g_s or Ψ during the other measurement periods. Trunk growth of nonirrigated trees in shelters was lowest of all the treatments (30% of nonirrigated trees without shelters, and 65% of irrigated trees in shelters). Reduced trunk growth and slightly more negative Ψ of nonirrigated trees in shelters may have been more a result of higher T_a than of depletion of soil moisture. While leaf temperature (T_l) was not measured, the 10 to 15 °C higher T_a in nonirrigated shelters probably increased T_l above that in irrigated shelters or outside shelters. Leaf temperatures may have been above the photosynthetic optimum, thus increasing respiration losses and reducing photosynthate available for trunk growth. Lower SLA in nonirrigated shelters would also suggest acclimation to hotter, drier conditions.

Growth and g_s in shelters were more adversely affected in maple than in ash. Sheltered maples had consistently lower g_s than green ash. On 25 Aug., differences in g_s among all maple treatments were negligible, while shelters increased g_s of ash. Differences in trunk growth clearly indicated that maple did not grow as well as ash in the shelters. Trunk growth of nonsheltered maples was greater than that of nonsheltered green ash, but the reverse was true of trees in shelters. Unexpectedly, both species exhibited winter damage in shelters (data not shown). Cambium was clearly discolored in both species, but ash was not affected as much as maple. Shoot elongation in ash the following spring was not vigorous, and some lateral branches died back, while all sheltered maples were killed to ground level.

Tree transpiration was reduced by the buffered conditions in shelters even while stomata

Fig. 1. Transpiration of Norway maple and green ash in shelters and under ambient conditions relative to reference evapotranspiration. Each data point represents the average of four trees, and the legend includes the standard error (vertical bars) based on pooled variances for each treatment.

Table 1. Effect of shelters and irrigation on predawn or midmorning, and midday, water potential, stomatal conductance, trunk growth and specific leaf area (SLA) of Norway maple and green ash grown in the field. I, Sh, and Sp represent irrigated, sheltered, and species treatments, respectively.

	Water potential (Mpa)				Stomatal conductance (mmol·m ⁻² ·s ⁻¹)				Increase in	
	12 Aug.		25 Aug.		12 Aug.		25 Aug.		diam	SLA
	Predawn	Midday	Predawn	Midday	Midmorn	Midday	Midmorn	Midday	(mm)	(cm ² ·g ⁻¹)
	<i>Acer platanoides</i>									
+I –Sh	–1.09	–1.65	–1.05	–2.36	75	44	56	36	7.6	76
+I +Sh	–1.13	–1.84	–1.55	–2.24	88	73	43	32	1.3	138
–I –Sh	–1.16	–1.76	–1.18	–2.21	43	28	43	28	6.0	87
–I +Sh	–1.33	–1.96	–1.56	–2.61	58	35	45	32	1.0	122
	<i>Fraxinus pennsylvanica</i>									
+I –Sh	–1.03	–1.98	–1.09	–2.12	119	93	76	72	5.2	69
+I +Sh	–1.13	–1.74	–1.20	–2.01	245	198	204	192	1.7	142
–I –Sh	–1.04	–1.57	–1.03	–1.99	87	82	52	40	2.5	78
–I +Sh	–1.60	–1.77	–1.34	–2.26	170	124	108	100	1.3	119
Irrigate	**	NS	NS	NS	*	NS	NS	NS	**	NS
Shelter	**	NS	**	NS	**	**	**	**	**	**
Species	NS	NS	**	**	**	**	**	**	**	NS
I × Sh	**	NS	NS	**	NS	NS	NS	NS	**	**
I × Sp	NS	NS	NS	NS	NS	NS	**	*	NS	NS
Sh × Sp	NS	NS	NS	NS	..*	**	**	**	**	NS
I Sh × Sp	NS	NS	**	NS	NS	NS	*	NS	NS	NS

NS, *, ** Nonsignificant or significant at $P \leq 0.05$ or 0.01 , respectively.

were open. This response varied with species, as ash, with greater g_s , lost more water both with and without shelters than did maple. Although shelters reduce water loss, their potential for increasing drought avoidance will probably vary with the environment. In a hot, arid climate with season-long drought characteristic of this study, a prolonged period without rain or irrigation appears to result in oven-like conditions in shelters. In a more mesic region, surface evaporation and tree transpiration would probably remain higher, thus favoring tree growth during an intermittent drought. Winter damage may increase with sunny days and high insolation during the winter in the high desert climate where this study was conducted.

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Fig. 2. Air temperature and vapor pressure deficit in irrigated and nonirrigated shelters and under ambient conditions for two dates in 1992.

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