Tree Seedling Establishment with Protective Shelters and Irrigation Scheduling in Three Naturalized Landscapes in Utah[1]

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Abstract

We investigated the effect of irrigation scheduling and tree shelters on survival and growth of nine tree species during first-year establishment in three naturalized Utah landscapes with divergent soil and climate. Seedlings of nine species were planted at high mountain [MTN; 2180 m (7150 ft)], mountain foothills [FTH; 1350 m (4430 ft)], and alkali desert [DES; 1320 m (4330 ft)] sites. Half the trees at each site were enclosed with transluscent plastic shelters after planting, and all trees were irrigated when water loss, estimated from local evapotranspiration, depleted plant-available soil water. Tree condition was rated through the growing season, water potential was measured once in late season to assess plant water status, and the number of surviving trees were counted. Despite irrigation, tree condition at the DES and FTH sites declined through the growing season but remained high at the MTN site, resulting in final survival of 35%, 25% and 80%, respectively. The effect of shelters on survival was minimal at all three sites. At the MTN site, however, sheltered trees were less water stressed despite receiving 60% less water than those without shelters. Protective shelters and irrigation scheduling can benefit tree establishment in a naturalized landscape by reducing water stress provided soil and climate conditions do not inherently limit tree growth.

Index words: tree, establishment, irrigation, shelters, water stress, naturalized landscape.

Species used in this study: Shantung maple (*Acer tataricum* L.); gingko (*Gingko biloba* L.); honeylocust (*Gleditsia triacanthos* L. var. *inermis*); Rocky Mountain juniper (*Juniperus scopulorum* Sarg.); golden raintree (*Koelreuteria paniculata* Laxm.); pinyon pine (*Pinus edulis* Englm.); Colorado spruce (*Picea pungens* Englm.); burr oak (*Quercus macrocarpa* Michx.); and cottonwood (*Populus deltoids* Bartr. ex Marshall).

Significance to the Nursery Industry

This study demonstrated that manual irrigation can enhance first year seedling survival and can be economically feasible in a naturalized landscape if timing and amount of water applied are carefully scheduled. Addition of tree shelters can add further benefit by reducing tree water loss and hence irrigation frequency. Irrigation scheduling will not work in situations where extreme soil conditions inherently limit tree growth. Shelters can worsen such situations when stress-induced reduction in transpiration reduces evaporative cooling, creating oven-like interior conditions.

Introduction

Naturalized landscapes such as highway right-of-ways, recreational areas, or low-use institutional grounds are expected to meet appearance or utility standards with minimal maintenance. Plants used for such landscapes are typically small, low-cost, seedlings of species, both native and exotic, adaptable to local conditions. In the West, trees are particularly desirable in naturalized landscapes with few or no native tree species because they provide shade and visual interest. The range of tree species adapted to chronic drought characteristic of most of the West is limited, however, and establishing trees under arid conditions is difficult (22). Once established, however, many species may be able to survive on existing rainfall.

First-year survival is critical in establishing a naturalized landscape, particularly in arid climates. Without irrigation, planted tree seedlings are sensitive to drought stress and mortality until roots are established in ambient soil (5). In addition, until seedlings are large enough to withstand browsing, animal depredation reduces first-year survival (18). Herbicides, mulching, altered planting techniques, and repellents can potentially reduce water and animal stress (7, 8, 21, 23), but are not always effective. The surest way to avoid mortality from drought and depredation during establishment is to irrigate and physically shield the seedlings.

Automated irrigation avoids water stress in arid regions (8, 10), but such systems are expensive to permanently install and maintain in a naturalized landscape. Plastic tree shelters physically shield small trees from animal browse (20), and can also increase shoot elongation (16, 9) and reduce transpiration by 40–60% (14, 15). Manual irrigation may be feasible during establishment if frequency and amount are carefully scheduled according to soil water depletion to avoid excess costs, and may be feasible even after establishment if it is a particularly dry site. If irrigation scheduling can be combined with reduced transpiration from tree shelters, the frequency of water application can be sufficiently reduced to become economically feasible. This study investigates the use of irrigation scheduling and tree shelters on growth and survival of seedlings of nine tree species during first-year establishment in three different, arid to semi-arid, naturalized landscapes in Utah.

Materials and Methods

Site background descriptions. Three sites in Utah varying in aridity were chosen for the study (Table 1). The high mountain, semi-arid, site (MTN) was located approximately 50

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Table 1. **Climate and soil characteristics for the Mountain, Desert, and Foothills experimental sites. Weather data, 30-year averages, collected from the closest weather stations located at Park City, Lakeside, and the Ogden City Airport, respectively, that were approximately 12, 16, and 10 km from the respective experimental sites[z].**

	Mountain	Desert	Foothill
Elevation, meters	2176	1323	1353
Latitude, degrees	40°38'	40°11'	40°19'
Longitude, degrees	111°32'	112°55'	112°01'
ETo (June–August), mm	495	515	548
Rainfall (June–August), mm	127	33	68
Rainfall (total annual), mm	732	157	490
Jan mean min temp, C	–9.3	–9.5	–10.6
July mean temp, C	27.6	34.7	32.2
Soil texture	Sandy loam	Silt loam	Sand
Soil series	Rasband	Saltair	Preston
Soil name	fragmented, mixed frigid, typic argixeroll	fine, silty, mixed, mesic, typic salorthids	mixed, mesic, typic xeropsamment
Soil pH	6.8	9.1	7.3
Salinity, dS/m	0.6	2.5	0.5
Sodium adsorption ratio	—	29	1.0
Organic matter content	4.6	1.6	0.6

[z]Ashcroft et al., 1992.

km (30 miles) east of Salt Lake City in an old, irrigated grass pasture located in a drainage that had been dammed for a reservoir. The area immediately around the reservoir was being developed for a state park, and the reservoir itself was being filled during the study. The foothill site (FTH) was located at Hill Air Force Base in Clearfield, UT, approximately 30 km (18 miles) north of Salt Lake City along the base of the Wasatch Mountains in an open field of native grasses and sagebrush (*Artemisia tridentata* Nutt.). The desert site (DES) was located at the Hill Air Force Base Eagle Test Range headquarters near Lakeside, UT, approximately 100 km (62 miles) west of Salt Lake City. The setting was level, open, cheatgrass (*Bromus tectorum* L.) infested range, interspersed with several *Chenopodiaceae* species. Climate data, 30-year averages, were obtained from the Utah Climate Center (Ashcroft et. al., 1992) from weather stations at Park City, Ogden airport, and Lakeside located from 10–16 km (6–10 miles) from the MTN, FTH, and DES sites, respectively. Surface soils at each site were characterized from 0.3 m (4 in) deep cores taken from 5–10 locations at each site before planting. From the combined cores a subsample was analyzed for pH, salinity, sodium absorption ratio (SAR), organic matter content, and textural analysis at the Utah State University Soils Testing Lab according to standard soil testing procedures (19).

Experimental design. The experimental design at each site was a randomized complete block with shelter and species treatments: with or without protective shelters, and nine tree species (*Acer tataricum*, *Gingko biloba*, *Gleditsia triacanthos* var. *inermis*, *Koelreuteria paniculata*, *Juniperus scopulorum*, *Picea pungens*, *Pinus edulis*, *Populus deltoides* 'Siouxland', *Quercus macrocarpa*). Species were selected for cold tolerance to USDA hardiness zone 4 and some reported degree of drought and salt tolerance (6, 12). Each block was one row of 18 trees, nine species and two shelter treatments, randomly assigned within each row, with 10 replicated rows. Trees were planted 1 m (39 in) apart within a row, and rows were spaced 1.3 m (51 in) apart. The experimental layout and the directional orientation was the same at each site.

Experiments were installed at the three sites within a two-week period in late April and early May 1994. Rows were oriented on a north-south axis, and a 0.35 m (1.2 ft) diameter planting hole was power augered to an approximate depth of 50 cm (20 in) for each tree. All plants were 1-year-old seedlings obtained from the State of Utah Plant Consevation Center in Draper, UT, and were harvested bare root except *Juniperus* and *Pinus* that were grown in 150 ml (9 in^3) tubes. Translucent plastic shelters (TreeEssentials, St. Paul, MN), 1.22 m (48 in) high and 0.10–0.15 m (4–6 in) inside diameter, were placed over the trees and pushed approximately 0.03 m (1 in) into the soil surface to seal off air currents and then secured to wooden stakes implanted next to the shelters. All trees were then watered to field capacity. In mid-June a non-selective post-emergent herbicide (Round-up™) was used to control weed competition at the MTN site. Weeds at the other two sites were minimal and thus were controlled with hand cultivation. All trees were kept well watered until June 1 when irrigation scheduling was started at all three sites.

Irrigation schedules for each site were based on applying a fixed amount of water at each irrigation, while varying the interval between irrigations based on estimated depletion of soil water (11). Water amount to be applied was calculated as that needed to replace available soil water in the plant root zone based on soil properties at each site. Plant-available water (field capacity minus permanent wilting point) was estimated from soil texture (24). The fraction of total available water depletable by the plant without water stress was assumed to be 0.6 for the MTN and DES sites (11), and 0.5 for the FTH site due to its very sandy soil. The product of depletable water fraction and plant-available water gave the amount of plant-depletable soil water. We assumed a rooting depth of 30 cm (11.8 in), thus in the root zone of each tree the total depth of depletable water was calculated as the product of plant-depletable water and rooting depth, or total depletable water. Finally, the volume of water in mls to be replaced at an irrigation was the product of depth of total plant depletable water and an assumed radius around the root system of 5.8 cm (2.3 in). This radius approximated the average rooting radius of the seedlings, and created an assumed cylinder of root water extraction. Because of the uncertainty inherent in these assumptions, particularly rooting depth and radius, and to ensure that the soil profile was refilled with water at each irrigation, the estimated volume of water to apply to refill the assumed cylinder was doubled. Rainfall was measured on-site with a rainguage, and measurable rain totals were calculated as irrigations in the irrigation schedules.

The interval between irrigations was based on the number of days until assumed depletable root zone water was consumed through tree water use. Tree water use was estimated from the on-site evapotranspiration rate (ETo). The ETo rate was measured with microevaporimeters (C & M Meteorological Supply, Colorado Springs, CO) calibrated to the FAO Penman-Monteith equation that estimates water loss for a hypothetical 12 cm (4.5 in) high clipped fescue turf (1). A microevaporimeter was installed on a metal post at 2 m (6.6 ft) above the soil surface at each site in early June. Until that time, average daily historical ETo calculated from the weather station nearest each site (2) was used. Tree water use was estimated as 0.4 of ETo (4) for trees without shelters and 0.15 for trees in shelters (14, 15). Microevaporimeters were read in mm of evaporation at every irrigation, which varied from 3–10 days. Tree water loss was calculated for the preceding period after each reading and then subtracted from the depth of total depletable water.

Irrigation water at the DES and FTH sites was pressurized, treated water. At the MTN site low pH, low salt water was obtained from a nearby irrigation ditch. Individual trees were manually watered using a graduated cylinder to apply the calculated water volumes needed. Water was poured into the shelters and allowed to infiltrate, while for trees without shelters basins 0.1 m (4 in) in diameter equivalent to the assumed diameter of rooting were created around the trees to ensure water infiltration into the root zone.

Data collection. Tree condition was evaluated at every irrigation by observing the overall leaf appearance for seedlings with leaves. A five-point scale was used to convert qualitative data into numerical scores for statistical analysis: 5 = Majority of buds breaking or tree leafed out; foliage with healthy appearance, no leaf discoloration; 3 = Majority of leaves obviously stressed, margin burn or chlorosis; 1 = Majority of leaves necrotic or brown. Trees that never broke bud were not included in the analysis to ensure that effects on tree health were a result of the imposed treatments and not due to problems during production, handling or shipment (17). At the end of the 1994 season the number of surviving trees was counted. A tree was considered alive if removal of a small section of bark at the base of the trunk revealed living, green cambium. Tree water status was measured in early September 1994 to assess irrigation scheduling effectiveness during the driest part of the growing season. By this time leaf condition at the DES and FTH sites was so poor that we were only able to measure water potential at the MTN site, where leaf samples were not collected from *Quercus*, *Picea*, and *Pinus* due to insufficient foliage. A single leaf, and a short lateral shoot from the conifers, was collected at midday from four replicates. Foliage was inserted in an aluminum bag to keep the leaf cool and maintain midday water status (13). Leaf water potential was then measured with a pressure chamber within two hours of collection.

A followup study was conducted at the DES and FTH sites to assess how soil properties and transpiring foliage affect shelter interior climate and potential seedling mortality. On August 24, 1995, under full sun, fine-wire chromel-constantan thermocouples were inserted in three shelters at the two sites without trees and three trees. Well-watered *Acer platanoides*, 0.5 m (20 in) high in 19 liter (#5) containers, were used because of availability and to provide a vigorous source of transpiration. A thermocouple was inserted into shelters at 0.6 m (23 in) height at each site, immediately above the foliage in the three shelters with trees, and was shaded by a styrofoam cup. A single thermocouple was placed at 2 m (78 in) height outside the shelters, again shaded by a styrofoam cup, to measure ambient air temperature (T_{air}). Thermocouples were also placed at 0.5 cm (0.2 in) and 2 cm (0.8 in) depths in the soil to measure surface ($T_{surface}$) and shallow soil temperatures (T_{soil}), respectively. Finally, a leveled pyranometer was erected at 1 m (39 in) height to measure incoming solar radiation. Data was recorded as 30 min averages with a datalogger (model CR-10, CSI, Logan, UT).

Data analysis. End-of-season survival percentages were compared with a chi-square independence test between all species regardless of location. Within-site survival was compared only between shelter treatments because each species × shelter survival was was not replicated as it was the percentage survival out of ten trees in a block. Means of numerical evaluation scores for all species at three sites were computed for sheltered and ambient species and plotted against day. Differences in mean scores for each assessment date and for each species were evaluated by paired t-test. Midday water potential assessments between sheltered and ambient trees at the MTN site were made by two way factorial analysis using an F-test. Comparisons of water potential among species and between shelter treatments were made using Duncan's Multiple Range test (SAS for Windows, Statistical Analytic Systems, Cary, NC) when the species × shelter term was significant. Environmental data from the followup climate study were plotted against time. Shelter temperature, the mean of the three shelters per treatment, were also plotted against time.

Results and Discussion

Site environment. Climate and soils were very different among sites (Table 1). The DES and FTH sites had similar historical temperature and evaporation regimes, but historical rainfall at the DES site is approximately half that at the FTH site. The DES site had the highest soil pH, salinity, and sodium adsorption ratio (SAR), nearly double the level suggested for defining a sodic soil (19). While the DES soil had unfavorable chemical properties, the FTH soil had physical limitations, as the very low water holding capacity of the sandy soil was inherently droughty. The MTN site had fewer climatic and soil limitations to growth compared to the other sites. Historical ETo and air temperature at the MTN site were lower and rainfall higher than the two lower elevation sites. High organic matter content, neutral pH, and loamy texture also created more favorable soil growing conditions.

In 1994 the climatic conditions were hotter and drier than historical averages (Fig. 1). Daily high temperature averaged over July and August was 35.7C (96.3F) at the FTH site and 35.2C (95.4F) for the DES site, 12% and 4% above normal, respectively. The higher temperatures at the FTH site were reflected in higher ETo compared to the DES site for June–August, 711 vs 676 mm (27.9 vs 26.6 in), 30% and 31%

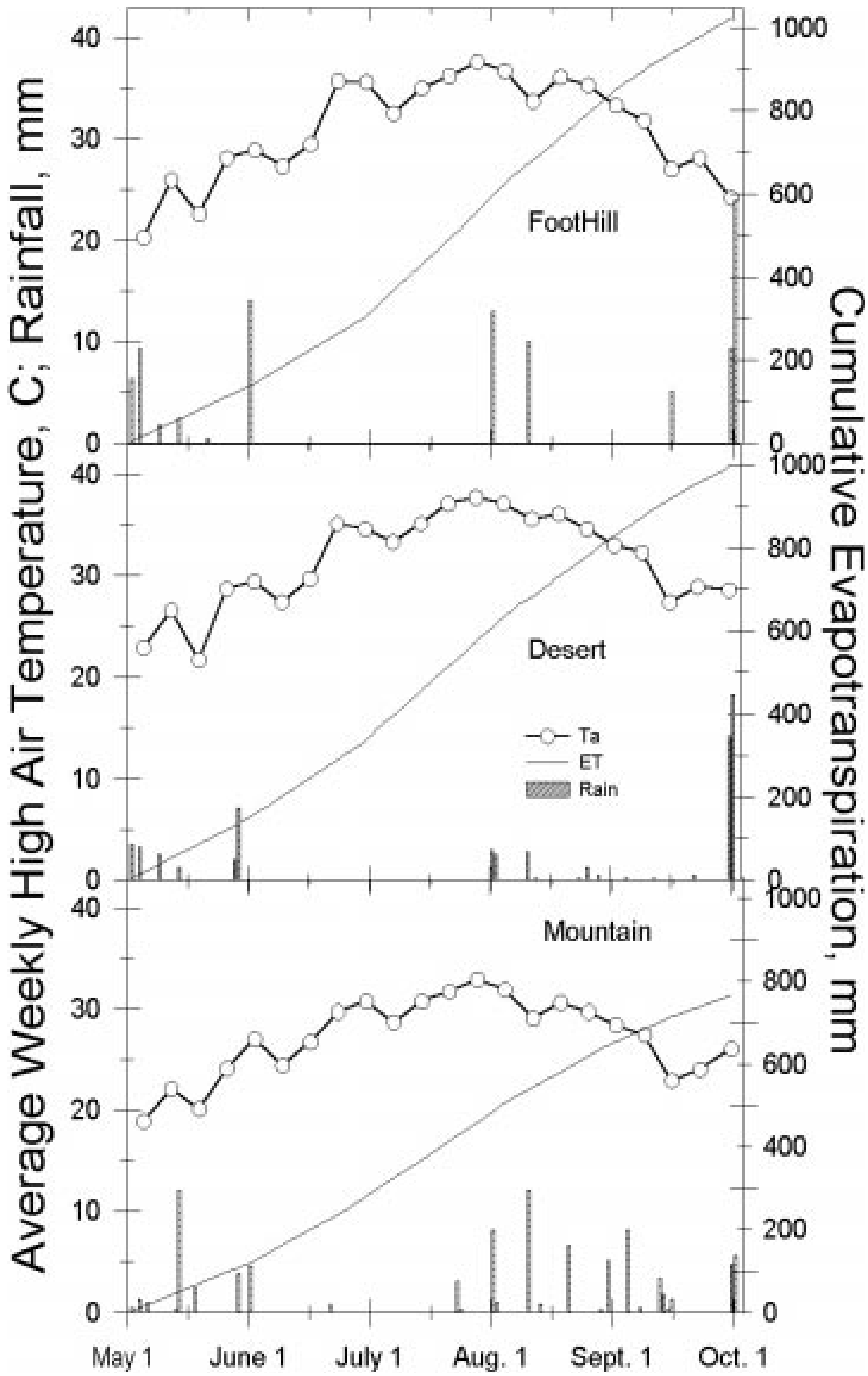

Fig. 1. Average weekly high temperature (Ta), cumulative evapotranspiration (ETo), and rainfall (rain) at Desert, Foothill, and Mountain sites in Utah for the period May 1–September 30, 1994.

above average, respectively. The MTN climate was cooler with less ETo than the other two sites, but again in 1994 was higher than average. Average July/August air temperature was 29.2C (84.6F) and June–August cumulative ETo was 532 mm (20.9 in) both 8% above normal. Cumulative rainfall for the period June–August was also below normal at all three sites. Rainfall was 54 mm (2.1 in), 23 mm (0.9 in), and 11 mm (0.4 in), or 42%, 34%, and 33% of average, for the MTN, FTH, and DES sites, respectively.

Different soil conditions and ETo at the three sites resulted in different irrigation schedules (Table 2). The FTH site had the most demanding schedule, as its low-available-water

Table 2. **Soil water properties and results of irrigation scheduling for three naturalized landscape sites in Utah.**

	Mountain		Desert		Foothill	
	Shelter	No shelter	Shelter	No shelter	Shelter	No shelter
Water holding capacity, mm water/mm soil[z]	0.10		0.18		0.06	
Total depletable water in root zone, mm[y]	18		32		9	
Water volume to be replaced in root zone, ml/tree[x]	190		342		95	
Total seasonal water applied ml, June 1–Sept. 30	2280	5700	3420	8892	2290	5700
Number of applications	6	15	5	13	12	33
Average number of days between applications	20	8	24	9	10	4

[z]Function of soil texture.

[y]Water holding capacity × depletable water fraction (0.6 for DESERT and FOOTHILL, 0.5 for MOUNTAIN) × assumed rooting depth of 300 mm.

[x]Total depletable water in root zone × assumed cylinder of soil 58 mm in radius.

sandy soil resulted in the least amount of water applied per irrigation of the three sites, but the most frequent interval. During July at the FTH site, water was applied every other day to the non-sheltered, and every five days to the sheltered, trees. Irrigation frequency at the MTN and DES sites were similar but for different reasons. The DES site had higher ETo and high total depletable water, while the MTN site had lower ETo, but because total depletable soil water was less, the schedule was the same. Since cumulative MTN ETo was the lowest of the three sites, total water applied was the lowest, while the total amount of water applied at the DES and FTH sites were 44% and 19% higher. The lower estimated transpiration rate used in scheduling irrigations for sheltered trees (14) resulted in approximately 40% less total water used and fewer applications, varying somewhat among sites due to different end-of-season termination dates at each site.

Tree condition varied widely among sites during the growing season (Fig. 2). Most species at the DES site declined from early July, when air temperature was consistently over 33C (91.4F), through the remainder of the season. Nearly all *Acer*, *Gingko*, *Picea*, *Poplus*, and *Quercus* were dead by the end of the season. Only *Pinus* and *Juniperus* exhibited healthy foliage that did not decline in appearance during the growing season. At the FTH site, foliage condition for six of the species started to decline shortly after planting and continued to decline through the growing season. Like at the DES site, *Acer*, *Gingko*, *Picea*, *Poplus*, and *Quercus* were nearly all dead by the end of August. Only *Juniperus*, *Gleditsia*, and *Koelreuteria* at the FTH site maintained live foliage through the season, and of these three *Gleditsia* was the healthiest. At neither the DES nor the FTH sites was the condition of sheltered trees consistently better than those without shelters. *Juniperus* and *Gleditsia* condition rated healthier during late season in shelters, while sheltered *Koelreuteria*, *Gingko*, and *Pinus* had lower condition ratings on several dates.

Trees at the MTN site had a higher rating and showed a more consistent shelter effect than the other two sites (Fig. 2). Tree rating early in June was low for a number of species due to late season freezes that caused leaf damage. By early July, nearly all species exhibited high vigor that was sustained through the season. Three species, *Gleditsia*, *Picea*, and *Populus*, however, had significantly reduced vigor in shelters from early summer on. *Gingko* was the only species whose vigor was higher in shelters. Water relations improved modestly for sheltered trees (Table 3). Late season water potential indicated a significant overall shelter effect ($P < 0.01$, sheltered 2.6 MPa vs. unsheltered 3.2 MPa), and while the shelter × species term was significant ($P < 0.05$), only sheltered *Gleditsia* water potential was significantly less negative than unsheltered. Species variation in water status was substantial, however, as *Gingko* showed the least negative water status and *Acer* the most.

Differences in tree vigor among sites were reflected in end-of-season survival (Table 4). Survival was lowest at the FTH site, while at the MTN site tree survival was over twice the DES and three times the FTH site. Differences in survival among species were most evident at the DES and FTH sites. All *Picea* and *Quercus* died, while more *Juniperus*, *Gleditsia*, and *Koelreuteria* survived than the other species, at both of the lower elevation sites. Trees in shelters did not have a significantly higher survival than those without at the DES and FTH sites. By contrast, the combined survival rate for sheltered trees at the MTN site was significantly lower than unsheltered trees, mostly due to very low survival of sheltered *Picea* and *Populus*.

The follow-up climate study of 1995 showed that sandy soil affected climate inside shelters at the FTH site (Fig. 3). On a very warm and mostly clear day in late August where T_{air} and radiation were similar between the two sites (Fig 3b), the sandy soil at the FTH site retained much more solar energy than the DES site. At the FTH site, T_{soil} at 2 cm (0.8 in) depth was 2–3C (3.6–5.4F) higher than at the DES site, and at the surface 10–12C (18.0–21.6F) higher than DES $T_{surface}$ (Fig 3a). Higher $T_{surface}$ affected air temperature in shelters (Fig 3c). At the DES site, air temperature inside shelters did not differ between those with trees in them and those without. By contrast at the FTH site, shelters without trees were 5–7C (9.0–12.6F) warmer than those with trees, reaching temperatures upwards of 43C (109.4F) before increased cloudiness dropped air temperatures by late afternoon.

The results from the MTN site show that scheduling timing and amount of manual irrigation maintained high seedling survival during a very hot, dry summer. Shelters allowed the interval between irrigations to be increased and the total amount of water applied to be reduced compared to non-sheltered trees. Irrigation of unsheltered trees required 15 applications of 6 liters (1.6 gal) per tree, while sheltered trees required only 6 applications of 2.2 liters (0.6 gal) per tree, and in addition sheltered trees were under moderately less water stress. Because it was double that of the estimated needs, conceivably the total amount of applied water could have been reduced further for greater water savings, although the frequency of irrigation would not have changed. Careful

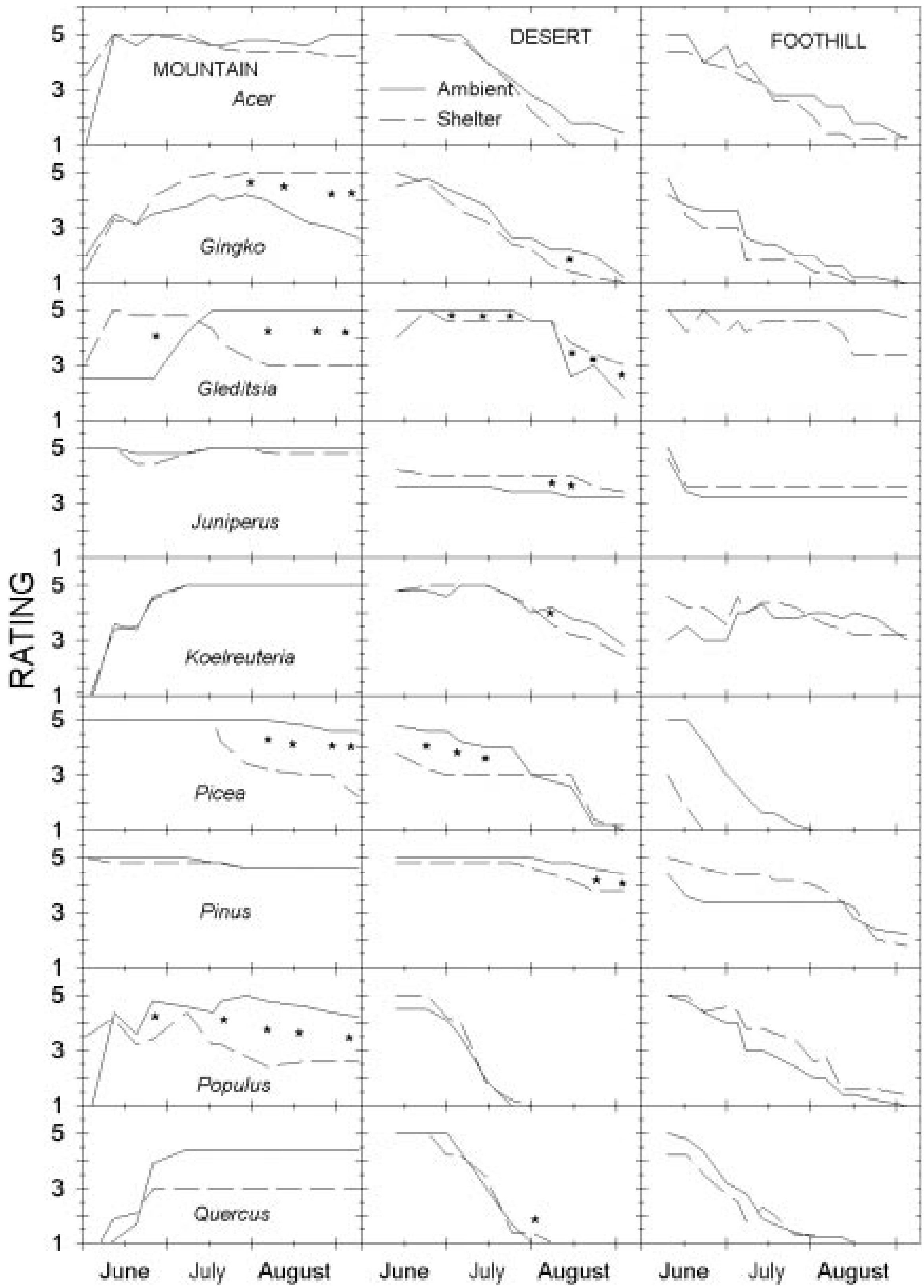

Fig. 2. Condition rating for nine species of trees grown with (solid line) and without shelters (dashed line) at Desert, Foothill, and Mountain sites in Utah, where 5 = no damage and 1 = dead. Dates when statistical differences in the quality of the trees were significant at the 5% level are indicated by a single asterisk.

scheduling with a tighter estimate of water needs can make the logistics of irrigations in a naturalized landscape more feasible when soil conditions are particularly adverse.

However, increased water availability from tree shelters and scheduled irrigations cannot offset the limits unfavorable soil and climatic conditions impose on tree seedlings

Table 3. **Comparison of differences in midday leaf water potential (LWP) among species and between shelter treatment for six tree species at the MTN site on September 9, 1994, when the shelter × species interaction was significant[z,y].**

	Midday water potential, MPa	
Species	**Shelter**	**No shelter**
Gingko biloba	–1.55c	–1.93c
Populus deltoides	–1.77c	–2.70b
Juniperus scopulorum	–2.65b	–2.80b
Koelreuteria paniculata	–2.69b	–2.95b
Gleditsia triacanthos	–3.20b*	–4.15a*
Acer tataricum	–4.02a	–4.20a

[z]a,b,c = significant differences in columns among species at the 5% level using Duncan's multiple range test.

[y]* = significant differences between shelter treatment and no shelter at the 5% level Duncan's multiple range test.

during establishment in naturalized landscapes under arid to semi-arid conditions. At the DES site, the high midsummer air temperatures and less than optimal soil conditions contributed substantially to tree mortality. In addition to being saline and alkaline, the SAR of the silty DES soil was double the threshold for being considered sodic (19). High SAR soils have little structure or aggregation, so water movement into and through the soil would be very slow, and would also impede root penetration and limit root growth into the surrounding soil. We anectdotally observed infiltration of water added to shelters to be about 1–2 mm (0.04–0.08 in)/hr. With moderate temperatures up to early July, evaporative demand and heat stress would not have placed a strain on the root systems. Once temperatures reached 35C (95.0F) in mid July, the combined root and climatic stress (3) appeared to cause declining health, and ultimately death, for most of the species.

While soil conditions were not as limiting as the DES site, the environmental conditions at the FTH site still appeared to constrain seedling growth and survival. Seedling condition of several species, both with and without shelters, declined immediately after planting. This decline may have been due in part to over estimation of the depletable water fraction and total depletable water in the sandy FTH soil, and hence insufficiently frequent irrigation, even though it was every other day by early summer. Another factor may have been heat stress due to high soil temperature. Rapid drainage and surface drying of the sandy FTH soil would result in low thermal conductivity and high $T_{surface}$ (Fig 3a) that would result in higher long-wave flux and convection from the soil surface heating seedlings close to the surface. High heat load can cause stomatal closure that would further increase leaf temperature and decrease stomatal conductance in a feed-forward effect (3) that undoubtedly contributed to poor tree performance at the FTH site. Stomatal closure would reduce transpiration and water demand, but at the cost of reduced photosynthesis and potentially damaging leaf temperatures. Shelters would also have been affected by the high energy load from the FTH soil surface. Since heat and water vapor inside shelters is not readily conducted away due to lack of air movement (14), if stress-induced stomatal closure reduces evaporative cooling, interior shelter temperature will increase, creating oven-like conditions (Fig 3c).

Species varied widely in their survival and growth. Most of the species in this study were poorly adapted to soil conditions at the DES and FTH sites, and did not grow or survive well. The exceptions were *Koelreuteria*, *Gleditsia* and *Juniperus*. *Koelreuteria* is reported to be drought tolerant, and at the seedling stage was superior in this respect compared to the other deciduous species in this study except *Gleditsia*. While considered to be a mostly a riparian in its native habitat, *Gleditsia* is clearly a widely adaptable species that can establish under conditions quite different from its native habitat. *Juniperus* performed unexpectedly well at the DES and FTH sites at elevations below its normal range. At the MTN site, at conditions closer to the natural environmental adapatations of most of the species, survival was the highest. However, *Picea*, *Pinus* and *Quercus*, all considered to be widely adaptable species, did not grow or survive well across the three sites. *Picea* was planted bare root, which may have contributed to its inability to establish well. Similarly, *Quercus macrocarpa* is drought tolerant once established, but it came bare root with a single tap root and almost

Table 4. **Tree seelding survival percentages at the end of the first growing season after transplanting at the Desert, Foothills, and Mountain sites[x].**

	% Survival					
	Mountain		**Desert**		**Foothills**	
Species	**Shelter**	**No shelter**	**Shelter**	**No shelter**	**Shelter**	**No shelter**
Picea	30	60	0	0	0	0
Populus	30	90	20	0	10	0
Gingko	100	40	30	20	0	10
Koelreuteria	91	100	67	50	30	100
Juniperus	90	100	80	70	30	40
Gleditsia	88	100	100	100	80	50
Acer	80	100	20	30	10	20
Quercus	70	100	0	0	0	0
Pinus	80	90	10	20	40	40
Combined species, %	73*[y]	87*	36	32	20	29
Combined site, %	80		34		25	

[x]Percentages based on trees that broke bud.

[y]*, significant differences between shelter treatment and no shelter at the 5% levels by chi-square test.

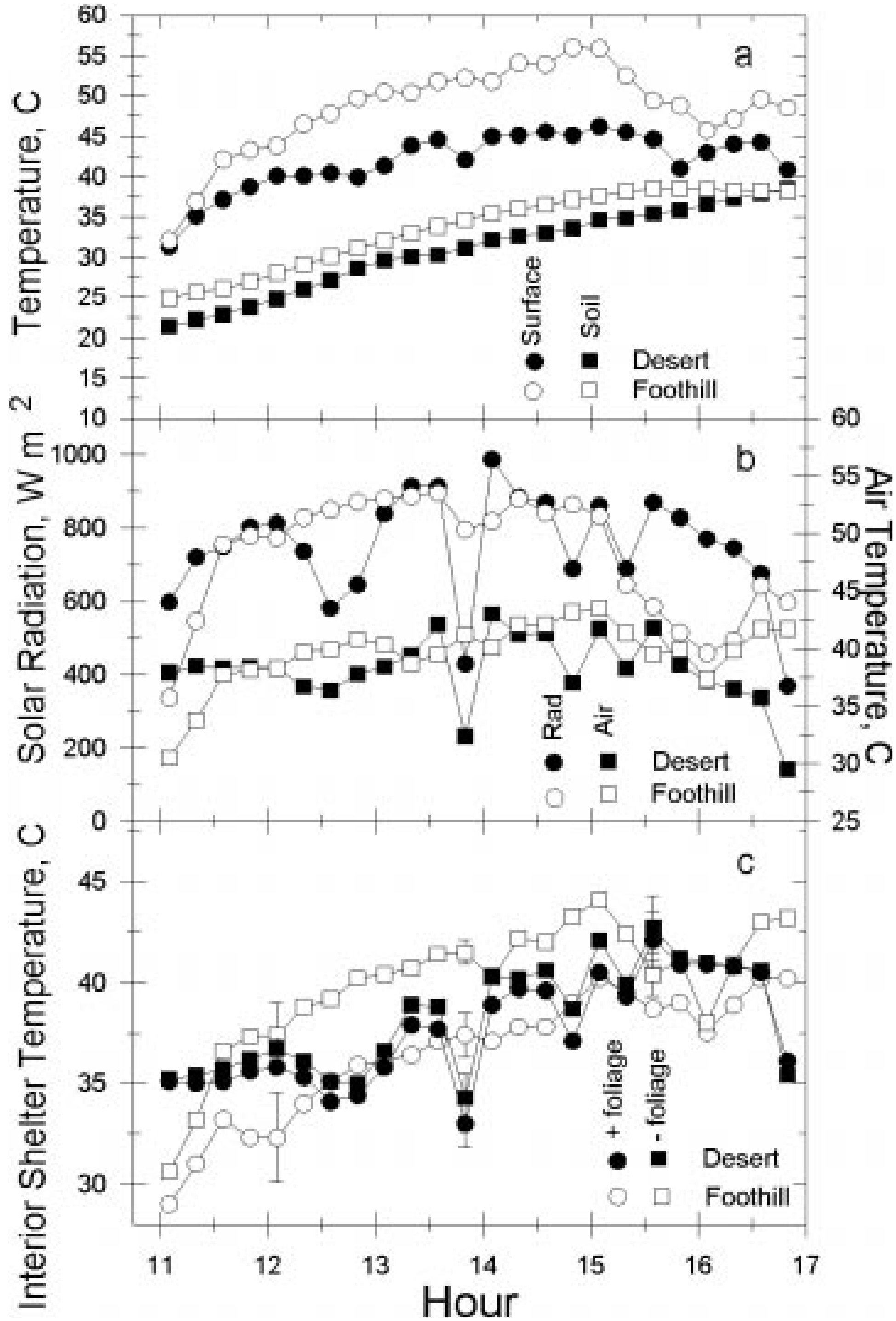

Fig. 3. Shelter interior microclimate at the Desert and Foothill sites measured on August 24, 1995; (a) surface and soil temperature, (b) ambient air temperature and radiation, (c) air temperature in shelters with or without transpiring foliage.

no lateral roots, which may have contributed to its poor performance. Poor performance of *Pinus* is not clear because it is considered to be a very drought tolerant native and was tube-grown with an intact root system.

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