Water Loss Estimates for Five Recently Transplanted Landscape Tree Species in a Semi-Arid Climate[1]

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Abstract

Over three growing seasons (1994–1996), water loss of five recently transplanted, balled and burlaped (B&B) tree species was investigated using below-ground, electronic weighing lysimeters. For each species, actual tree water loss was correlated with reference evapotranspiration (ETo) to create a water loss multiplier. At the beginning of each growing season a single tree was planted into each lysimeter. Selected species were: London planetree (*Platanus* x *acerifolia* 'Bloodgood'), corkscrew willow (*Salix matsudana* 'Tortuosa'), littleleaf linden (*Tilia cordata* 'Greenspire'), Norway maple (*Acer platanoides* 'Emerald Queen'), and green ash (*Fraxinus pennsylvanica* 'Patmore'). Throughout each growing season, trees were well-watered and lysimeter mass and meteorological variables were collected on site. Water loss multipliers for each tree species were calculated as the ratio of water loss (based upon total leaf area) to total daily ETo. Results indicate corkscrew willow and littleleaf linden had the greatest daily mean water loss (5.6 and 4.8 mm, respectively) (0.22 and 0.18 in, respectively), while Norway maple had the least (1.1 mm) (0.04 in). Water loss multipliers were greatest for corkscrew willow and littleleaf linden (1.1 and 0.9, respectively) and least for Norway maple (0.2). Regression analysis indicated total daily ETo had limited influence on total daily tree water loss. This suggests factors other than ETo influence water loss of recently transplanted, B&B trees in a semi-arid climate.

Index words: water loss coefficient, lysimeter, landscape irrigation management, reference evapotranspiration.

Species used in this study: *Acer platanoides* 'Emerald Queen' (Norway maple); *Fraxinus pennsylvanica* 'Patmore' (green ash); *Platanus* x *acerifolia* 'Bloodgood' (London planetree); *Salix matsudana* 'Tortuosa' (corkscrew willow); *Tilia cordata* 'Greenspire' (littleleaf linden).

Significance to the Nursery Industry

In most landscapes, irrigation of recently installed, B&B trees is critical for survival. Nevertheless, because of distribution, abundance, and quality concerns (31), many municipalities limit the amount of water which can be applied to landscape plants. However, even though irrigation limits have been implemented, there has been limited research investigating water requirements of recently planted, B&B landscape tree species. Using in-ground lysimeters, over a three year period we measured total daily water loss of five common, B&B landscape tree species, and related total daily tree water loss to ETo. Our research indicates total daily water use was greatest for *Salix* and least for *Acer*, while *Tilia*, *Fraxinus*, and *Platanus* trees were intermediate. Relating total daily tree water use to ETo indicated water use of recently transplanted *Salix* and *Tilia* trees were greatest, and water use of *Acer* was least. Based upon lysimeter and total daily ETo data, it appears tree species examined can be grouped into low, medium, and high water use categories. With specific site information (tree size, climate, etc.), those working with transplanted B&B trees can successfully estimate tree irrigation requirements, and strive to meet tree water use demands by applying the correct irrigation volume.

Introduction

Freestanding, isolated, trees are an important component of urban landscapes. Isolated landscape trees represent a substantial monetary investment that is sustained by maintaining proper tree health (24). Even though irrigation is often needed, a challenge confronting urban irrigation managers is to conserve water while meeting water requirements of landscape plants (31). Because water requirements of isolated landscape trees are not well known, applying enough water to meet the needs of the tree, while not wasting water, is often difficult.

When transplanting B&B landscape trees, proper irrigation is crucial for success. During transplanting, B&B trees lose a significant portion of their root system (13). Therefore, water deficits frequently develop (25) because the natural balance between root absorptive area and transpiring leaf area is disrupted (20). Until a balance between root absorptive area and transpiring leaf area is restored, gas exchange and apical growth of recently transplanted B&B trees will be reduced (25). To overcome water deficits, most recently transplanted B&B landscape trees are frequently exposed to high irrigation rates (18). Additionally, most landscape irrigation managers are not aware of the amount of water required by recently transplanted B&B trees (27).

Water loss and irrigation requirements of individual landscape trees have been estimated using several methods. Indirect measurement of water loss from isolated trees has been attempted using energy-balance (17, 21) and standard flux equations (7, 26). Lindsey and Bassuk (23) used a comparable model to estimate water needs of mature urban street trees. Although models and equations noted above may pre-

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cisely estimate water use of isolated trees under well-defined conditions, the accuracy of each method on a broad basis limits their usefulness. Several authors report water use of small, containerized tree species. Roberts and Schnipke (28) investigated water requirements and relative water demand of several containerized, seedling tree species. They considered water use of containerized Norway maple (*Acer platanoides*) seedlings to be low and green ash (*Fraxinus pennsylvanica*) seedlings to be high. In addition, Vrecenak and Herrington (32) report daily water loss values for well-watered, containerized Norway maple trees between 0.42 and 0.70 mm/day.

A robust approach to estimate water needs of plants is to define plant water loss factors by a constant, standardized measure of reference water loss which is a function of climatic factors (18). The United Nations Food and Agricultural Organization (UNFAO) has defined ET_O as the rate of evapotranspiration from a hypothetical reference plant (4), and variables needed to calculate ET_O are readily available from automated weather stations.

The UNFAO approach determines plant water loss by parameterizing empirically measured plant evapotranspiration (E_C) as a function of ET_O using a water loss coefficient (K_C). The dimensionless K_C is computed as:

$$E_C = (K_C) \times (ET_O) \qquad \text{[Eq. 1]}$$

where both E_C and ET_O have units of depth of water evaporated (mm)/unit time (1).Water loss of turfgrass is closely related to ET_O (10), therefore in landscape horticulture, K_C values have been developed nearly exclusively for turfgrass.

Because of the great diversity of species and the difficulty of quantifying values, there are a limited number of K_C values reported for woody landscape species (18). Costello et al. (8) suggested woody plant K_C values ranging from 0.1 to 0.9. However, information from their research was primarily based upon field observations, and is subjective data gathered through observation. Garbesi (11) reported isolated trees had acceptable growth and appearance with a leaf-area based K_C value of 0.4. Levitt et al. (22) used lysimeters to estimate K_C values for mesquite (*Prosopis alba*) and live oak (*Quercus virginiana*) trees in 15.0 liter containers. Estimated K_C values for mesquite and live oak were 0.5 and 1.0, respectively.

Little information regarding water requirements of recently transplanted, B&B landscape trees exists. Over several growing seasons, Montague et al. (26) used a standard flux equation to estimate water loss and K_C values for recently transplanted, B&B littleleaf linden (*Tilia cordata* 'Greenspire') and Norway maple (*Acer platanoides* 'Emerald Queen') trees. Water loss coefficients were estimated as 0.4 for littleleaf linden and 0.2 for Norway maple. Sivyer et al. (30) used a model based upon pan evaporation, area under the trees' dripline, leaf area index, and a K_C value of 0.2 to calculate irrigation volume for recently transplanted, 7.6 cm caliper, B&B street trees. According to estimates, recently transplanted pear (*Pyrus calleryana* 'Redspire') and birch (*Betula nigra* 'Heritage') trees required 19.0 liters of water every three days.

Because of the difficulty to produce replicated experiments involving large, recently transplanted, B&B landscape trees, scientific data regarding water requirements of recently transplanted B&B trees is lacking. Therefore, recently transplanted B&B trees may be irrigated in excess (which often results in waterlogged soil, poor plant growth, increased runoff, greater water bills, and wasted irrigation water) or deficit (which often results in poor plant growth, poor plant aesthetics, and plant death) amounts. In either case, performance of recently planted, landscape trees will not meet user expectations. This research investigated water loss of five recently-transplanted, B&B tree species using below-ground, electronic weighing lysimeters under non-limiting soil water conditions. In addition, actual tree water use was correlated with an ET_O to create K_C values for trees during the first year of establishment.

Materials and Methods

Experiments were conducted in Logan, UT (elevation 1,280 m (4,200 ft), U.S. Dept. of Agriculture hardiness Zone 5a). Data were collected during the Summers of 1994, 1995, and 1996. Two below-ground, electronic weighing lysimeters were installed in April 1988. Detailed installation procedures are given by Allen and Fisher (3), but basic lysimeter design is described here. Lysimeters were placed in the center of a 40 ha (99 A) field of a predominately fescue-forage grass mixture which was harvested once each summer for hay and then irrigated and pastured during the remaining summer months. Fetch of similar vegetation was maintained a minimum of 198 m (650 ft) in all directions. Lysimeters were installed 2.0 m (6.5 ft) apart in a north-south direction. Each lysimeter was comprised of rectangular inner and outer tanks made of 4.8 mm (0.19 in) welded steel plates. Tank dimensions provided a 15.0 mm (0.6 in) gap between tanks and an inner tank soil surface area of 0.97 m^2 (10.4 ft^2). Soils were predominately lacustrine clay loams with high organic matter content in the upper 0.3 m (1.0 ft) and precipitated minerals between 0.3 and 1.0 m (0.3 and 3.2 ft). Soil bulk density varied from 900 kg/m^3 at the surface to 1.6 mg/m^3 at a depth of 1.5 m (4.9 ft). Soil layers excavated from lysimeter pits were placed into lysimeters in reverse order of excavation and were lightly compacted to approximate original soil bulk density. A shear beam load cell was mounted in each corner of each outer tank, and the inner tank was suspended from the cantilevered ends of the load cells by tension bolts. Due to electronic malfunctions, the south lysimeter was not used during 1996.

Meteorological sensors were installed on site. Incoming shortwave radiation ($S\downarrow$) was measured with a pyranometer sensor (Model LI-200S; LI-COR Inc., Lincoln, NE). Air temperature (T_A), vapor pressure deficit (VPD), and relative humidity (R_H) were measured with a combination temperature and humidity probe (Vaisalla HMP45C; Campbell Scientific Inc., Logan, UT), and wind speed (ν) was recorded with a 3-cup anemometer (Model 041A; Met One Inc., Grants Pass, OR). Meteorological variables were measured 2.2 m (7.2 ft) above the soil surface. Lysimeter mass was determined each hour. Load cells were scanned every 2 seconds during a 5 minute period beginning 5 minutes before each hour with a data logger (Model 21X; Campbell Scientific Inc.) and a multiplexer (Model AM32; Campbell Scientific Inc.). Lysimeter mass was computed as the average of each 5 minute period. Meteorological sensors were scanned once every minute and averages were recorded every hour.

In mid-April of 1994 and 1995 one B&B tree was planted into each lysimeter. All trees conformed to American Association of Nurserymen Standards specifications (5). In 1994, London planetree was planted in the south lysimeter and corkscrew willow was planted in the north lysimeter. In 1995, littleleaf linden was planted in the south lysimeter and Norway maple was planted in the north lysimeter. Green ash was planted in the north lysimeter mid-April 1996. All trees were grown locally, budded (except corkscrew willow) on seedling rootstocks, annually root pruned in the nursery, and harvested the same year they were planted in lysimeters. Following transplanting, each tree received 19.0 liters (5.0 gal) of a 300 mg/liter N solution of 20N–4.3P–16.6K (Peter's Professional; Scotts Sierra Horticultural Products Co., Marysville, OH). To limit soil water evaporation, 10 cm (4.0 in) of pine bark mulch [1.3–5.0 cm (0.5–2.0 in) in diameter] was placed around each tree. Daily tree water loss was determined as the difference between consecutive mid-night (0000HR) lysimeter mass. To replace water lost through transpiration, daily transpiration volume was calculated (differences in consecutive mid-night lysimeter mass converted from kilograms to liters) and the volume of irrigation was applied by hand the same three days each week (in the event of precipitation, precipitation was subtracted from irrigation volume added). Trees were not pruned throughout the growing season.

Each growing season, a pressure chamber (Model 3005; Soilmoisture Equipment Corp., Santa Barbara, CA) was used to measure weekly predawn leaf water potential (ψ_L) on two leaves from each tree. Predawn ψ_L was measured the day following mid-week irrigation. Tree proportions were measured at time of planting. Trunk area was measured 0.3 m (1.0 ft) above soil level, and crown height was measured near the trunk of each tree with an extension pole. Prior to leaf drop, all leaves were removed from each tree and a subsample of 20 leaves was randomly selected from the total leaf sample. Subsample leaf area was measured with a leaf area meter (Model CI-203 with CI-203A attachment; CID Inc., Vancouver, WA). All leaves were dried and weighed to obtain total foliage dry mass for each tree. Subsample leaf area:dry mass ratios were multiplied by the mass of the non-subsample foliage to calculate total tree leaf area (L_T).

Total daily ET_O was calculated using ET_O calculation software (2). Climatic variables required to calculate ET_O were: total daily incoming S↓ (MJ/m^2/day), maximum and minimum daily T_A (C), maximum and minimum daily R_H (%), and average daily υ (m/second). Reference evapotranspiration was calculated for a well watered, non-stressed, cool-season grass using the Penman-Monteith equation with an assumed crop height of 0.12 m, an albedo of 0.23, and a fixed surface resistance of 70.0 seconds/m (4). Tree water loss (mm) was calculated as:

$$\text{tree water loss (mm)} = \frac{(\text{tree water loss (kg or m}^3))}{(L_T\ (\text{m}^2))} \quad \text{[Eq. 2]}$$

and converted from meters to millimeters. Tree K_C values were calculated by rearranging Eq. [1] such that:

$$K_C = (E_C) / (ET_O) \quad \text{[Eq. 3]}$$

where both E_C and ET_O are in millimeters.

Although all trees were planted in lysimeters in early spring, water loss calculations began after bud set and apical growth ceased. In addition, due to data collection concerns (for example, days with precipitation were not used), the number of days used to calculate tree water loss data were different each growing season. Measurements began mid-July each year, and the actual number of days available to estimate daily tree water loss and calculate K_C values for each species ranged from 25 (green ash) to 51 (maple). Each growing season, daily means, coefficients of variation, and standard errors for climatic variables were calculated. In addition, means, coefficients of variation, and standard errors for climatic variables were calculated from data gathered over the entire three-year period.

Following examples set forth by Wester (33) and Hurlbert (15), we compared daily, mean tree water use and K_C values among trees during different growing seasons. For our research, each tree represented an experimental population and each day's measurements represented a sample from the population. To ensure independent samples, daily tree water loss and K_C values were selected for 20 randomly selected days from each species and growing season. Total daily water loss and K_C value variation from day to day was used to estimate variation inherent in the five populations (33). An F test was used to compare total daily water use and K_C values among these five individual trees in this particular climate. If significant differences were found, means were separated by Fisher's least significance difference procedure ($P \leq 0.05$) (29). This approach is commonly used in applied ecological research (15, 33). In addition, for each day tree water loss was measured, total daily ET_O, tree water loss, and daily K_C for each species were plotted against calendar days. The response of daily tree water loss (mm/day) to total daily ET_O was also examined. Daily tree water loss (dependent variable) and total daily ET_O (independent variable) data were analyzed by regression analysis for each species, and all species combined, and linear or quadratic curves were selected according to significance of the equation and R^2 value (29).

Results and Discussion

Following transplanting, all trees survived and maintained a healthy appearance throughout each growing season. Immediately after transplanting, weekly predawn ψ_L for each species was near –0.5 MPa and remained close to this point for several weeks (data not presented). However, by mid-season, weekly predawn ψ_L recovered to approximately –0.3 MPa and remained near this level for the remainder of the growing season. Tree size and leaf area varied with species. Trunk area ranged from 20.0 cm^2 (3.1 in^2) (littleleaf linden) to 82.0 cm^2 (12.7 in^2) (London planetree) (Table 1). Crown height varied from 3.0 m (9.8 ft) (London planetree) to 4.0 m (13.1 ft) (littleleaf linden and green ash), and total leaf area ranged from 0.8 m^2 (8.6 ft^2) (corkscrew willow) to 3.1 m^2 (33.4 ft^2) (Norway maple).

Coefficients of variation and standard errors for daily means of climatic variables gathered over the entire three-year period indicated little variation from year to year (data not presented). Therefore, tree water loss data among growing seasons could be analyzed and compared, and means for each day are presented. On days tree water loss data were collected, mean, total daily S↓ was 25.4 MJ/m^2/day, mean, maximum T_A was 30.5C (86.9F), mean, minimum T_A was 7.9C (46.2F), mean, daily VPD was 2.0 kPa, mean, daily ν was 1.7 m/second (3.8 miles/hour), and mean, total daily ET_O was 5.4 mm (0.21 in).

Tree water loss varied with species. On a volumetric basis (liters), green ash transpired the greatest amount of water each day (Table 2). London planetree and corkscrew willow had the next greatest total, and Norway maple and linden

Table 1. **Trunk area, crown height, and total leaf area for recently-transplanted, balled and burlaped *Platanus* x *acerifolia* 'Bloodgood', *Salix matsudana* 'Tortuosa', *Acer platanoides* 'Emerald Queen', *Tilia cordata* 'Greenspire', and *Fraxinus pennsylvanica* 'Patmore' trees grown in lysimeters in 1994, 1995, and 1996.**

Species	Year	Trunk area[z] (cm^2)	Crown height (m)	Total leaf area (m^2)
Platanus x *acerifolia* 'Bloodgood'	1994	81.7	2.9	1.6
Salix matsudana 'Tortuosa'	1994	45.4	3.2	0.8
Acer platanoides 'Emerald Queen'	1995	25.5	3.6	3.1
Tilia cordata 'Greenspire'	1995	20.3	4.1	0.8
Fraxinus pennsylvanica 'Patmore'	1996	36.3	4.1	1.8

[z]Measured 0.30 m above soil level.

transpired the least amount of water each day. Transpirational water loss on a depth basis (mm) takes into account volumetric water loss (m^3) and leaf area (m^2) of each tree. Total daily water loss (mm) of corkscrew willow was greatest, followed by littleleaf linden. Total daily water loss was least for Norway maple. Species K_C values followed a similar trend as depth of transpirational water loss (Table 2). Crop water loss coefficients were greatest for corkscrew willow and littleleaf linden, and least for Norway maple.

Throughout each growing season, total daily ET_O, total daily tree water loss, and daily K_C values varied among days and species (Fig. 1). During the 1994 growing season, total daily ET_O ranged from 2.2 to 7.2 mm/day (0.09 in to 0.28 in/day), London planetree water loss ranged from 1.02 to 3.89 mm/day (0.04 to 0.15 in/day), and corkscrew willow tree water loss ranged from 1.9 to 9.1 mm/day (0.07 to 0.36 in/day). London planetree K_C values ranged from 0.19 to 0.68, and corkscrew willow K_C values ranged from 0.48 to 1.8 (Fig. 1). Total daily ET_O during the 1995 growing season ranged from 3.8 to 7.7 mm/day (0.15 to 0.30 in/day). Maple tree water loss and K_C values ranged from 0.18 to 1.77 mm/day (0.007 to 0.07 in/day) and 0.03 to 0.32, respectively, and linden tree water loss and K_C values ranged from 1.86 to 8.05 mm/day (0.7 to 0.32 in/day) and 0.31 to 1.59, respectively. Throughout the 1996 growing season, total daily ET_O ranged from 3.5 to 6.5 mm/day (0.14 to 0.26 in/day). Green ash water loss ranged from 0.54 to 6.8 mm/day (0.2 to 0.27 in/day), and K_C values ranged from 0.11 to 1.19 (Fig. 1).

Regression analysis of tree water loss (mm/day) and ET_O indicate water loss was linear and positively related to total daily ET_O such that daily tree water loss increased as ET_O increased (Fig. 2). Coefficients of determination (R^2) values were low, ranging from 0.06 (maple) to 0.23 (corkscrew willow), but regression equations were significant ($P \leq 0.10$) for each species except green ash.

Throughout each growing season, typical days had high levels of $S\downarrow$, warm T_A, low R_H, high VPD, and high ET_O. Climatic variables were characteristic of summer days in northern Utah (6) and varied little from growing season to growing season. As was the case in our study, water deficit stress often develops when B&B trees are placed into landscapes. Following transplanting, all trees were under water deficit stress (more negative ψ_L), but during the growing season ψ_L recovered to less negative levels. In a similar climate, Montague et al. (25) reports mid-summer ψ_L of non-transplanted, weekly irrigated, field grown Norway maple (*Acer platanoides* 'Schwedleri') and littleleaf linden (*Tilia cordata* 'Greenspire') trees near –0.3 Mpa. Therefore, it is likely trees in this project were not yet established (13) and under water stress conditions (25).

Because of replication and randomization concerns, results from this research must be used with caution before applying to other recently transplanted B&B trees (33). However, our data gives insight into water loss characteristics of these recently transplanted B&B trees in this climate. In our research, Norway maple transpired the least amount of water each day on a volumetric (liters) and depth (mm) basis (Table 2). Green ash lost the greatest amount of water each day on a volumetric basis, but had moderate water loss on a depth basis. In a similar climate, Montague

Table 2. **Daily mean tree water loss (liters and mm) and water loss coefficients (K_C)[z] for recently-transplanted, balled and burlaped *Platanus* x *acerifolia* 'Bloodgood', *Salix matsudana* 'Tortuosa', *Acer platanoides* 'Emerald Queen', *Tilia cordata* 'Greenspire', and *Fraxinus pennsylvanica* 'Patmore' trees grown in lysimeters during 1994, 1995, and 1996.**

	1994 (Aug. 8 to Sept. 15)		1995 (June 28 to Aug. 30)		1996 (July 24 to Aug. 29)
Variable	*Platanus*	*Salix*	*Acer*	*Tilia*	*Fraxinus*
Daily water loss (liters)	4.4b[y]	4.2b	3.2c	3.5c	5.1a
Daily water loss (mm)[x]	2.7c	5.5a	1.1d	4.3b	2.9c
Water loss coefficient (K_C)	0.52c	1.05a	0.19d	0.83b	0.54c
			Significance		
Daily water loss (liters)			0.0077		
Daily water loss (mm)			0.0001		
Water loss coefficient (K_C)			0.0001		

[z]n = 20 days (based upon a random sample of 20 days from each growing season).

[y]Mean separation within rows by LSD, $P \leq 0.05$.

[x](Tree water loss (kg or m^3)) / (Total leaf area (m^2)) and converted from meters to mm.

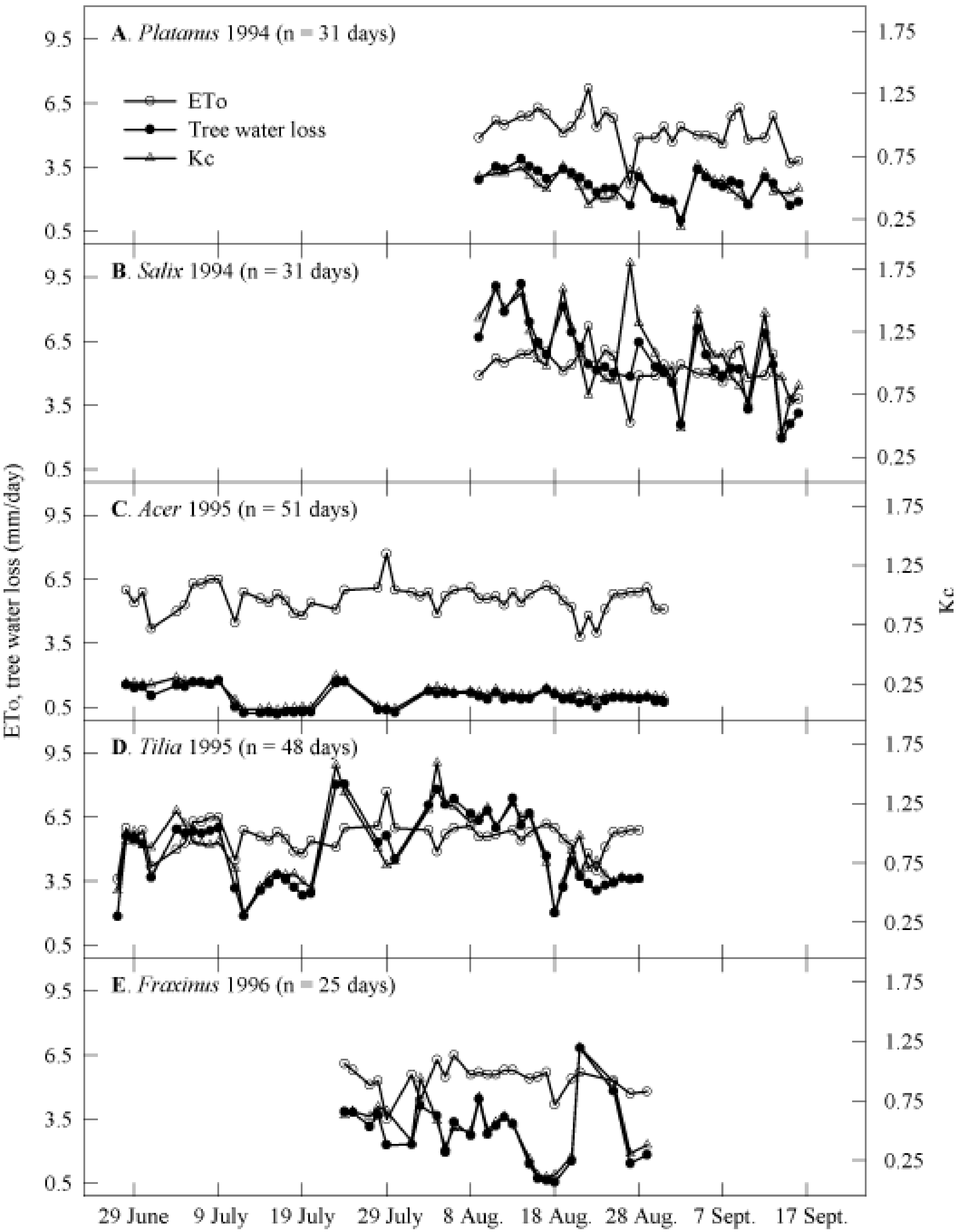

Fig. 1. Total daily reference evapotranspiration (ETo), total daily tree water loss, and daily water loss coefficients (Kc) over three growing seasons (1994, 1995, and 1996) for five recently-transplanted, field-grown, balled and burlaped, landscape trees species (London planetree (*Platanus* x *acerifolia* 'Bloodgood') (A), corkscrew willow (*Salix matsudana* 'Tortuosa') (B), Norway maple (*Acer platanoides* 'Emerald Queen') (C), littleleaf linden (*Tilia cordata* 'Greenspire') (D), and green ash (*Fraxinus pennsylvanica* 'Patmore') (E)) grown in lysimeters.

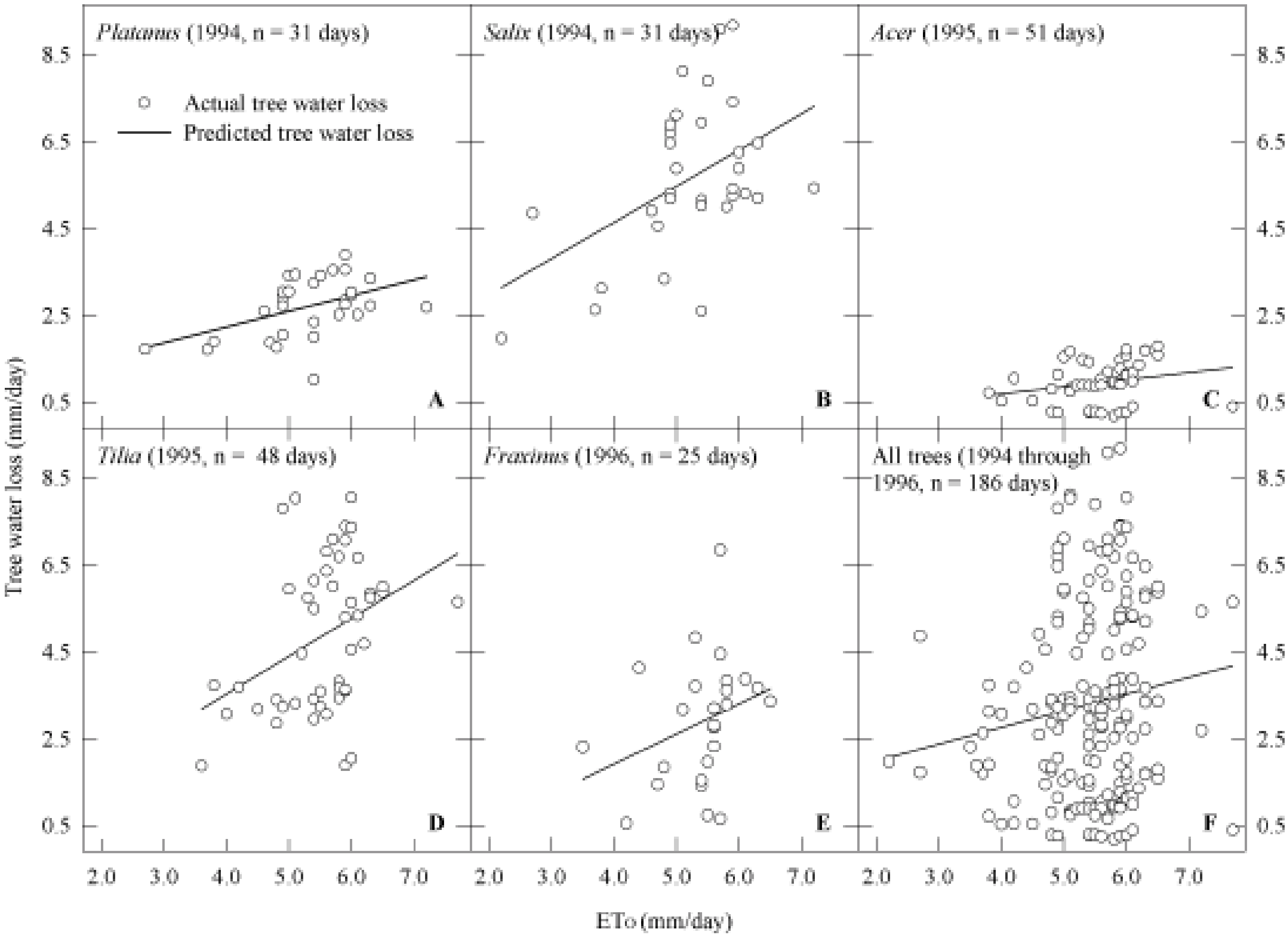

Fig. 2. Influence of total daily reference evapotranspiration (ETo) on actual and predicted tree water loss (WL) for five recently-transplanted, field-grown, balled and burlaped, landscape tree species (London planetree (*Platanus* x *acerifolia* 'Bloodgood'), corkscrew willow (*Salix matsudana* 'Tortuosa'), Norway maple (*Acer platanoides* 'Emerald Queen'), littleleaf linden (*Tilia cordata* 'Greenspire'), and green ash (*Fraxinus pennsylvanica* 'Patmore')) grown in lysimeters over three growing seasons (1994, 1995, and 1996). Predicted regression line equations are followed by R^2 value and significance for the equation: *Platanus* x *acerifolia* 'Bloodgood' (A): WL = 0.79 + 0.36x, R^2 = 0.21, P = 0.009; *Salix matsudana* 'Tortuosa' (B): WL = 1.31 + 0.83x, R^2 = 0.23, P = 0.005; *Acer platanoides* 'Emerald Queen' (C): WL = 0.022 + 0.17x, R^2 = 0.06, P = 0.09; *Tilia cordata* 'Greenspire' (D): WL = 0.04 + 0.87x, R^2 = 0.14, P = 0.0094; *Fraxinus pennsylvanica* 'Patmore' (E): WL = –0.86 + 0.69x, R^2 = 0.10, P = 0.127; All trees (F): WL = 1.22 + 0.38x, R^2 = 0.02, P = 0.058.

et al. (26) used a standard flux equation to estimate water loss for recently transplanted B&B littleleaf linden (*Tilia cordata* 'Greenspire') and Norway maple (*Acer platanoides* 'Emerald Queen') trees grown under landscape conditions. Trees in their study were larger (greater leaf and root area) and more established than trees reported in this research. In addition, water loss estimated by their standard flux equation was not tested by direct measurement. However, they report daily tree water loss estimates for Norway maple (1.04 mm/day) that are similar to daily water loss for Norway maple reported in this study (1.1 mm/day) (0.04 in/day). However, water loss reported for littleleaf linden (1.86 mm/day) was much lower than daily water loss reported for linden in this study (4.3 mm/day) (0.17 in/day). Tree water loss is a function of crown size, leaf area, root volume (21), and atmospheric coupling (14). Thus, it is difficult to compare water loss from trees in different studies. Depth of water loss for trees in our study was likely affected by lack of root and leaf area as a result of our trees being recently removed from the field. Thus water loss for transplanted, B&B trees in our research would likely differ from water loss estimates for established trees (16).

In general, water loss for tree species in our study increased as total daily ETo increased (Fig. 2). This response is similar to the response of turfgrass to ETo (10). However, total daily ETo accounted for a maximum of 23% of the variability for daily, tree water loss rates (corkscrew willow, Fig. 2). This differs from other studies which found a close relationship between tree water use rates and a ETo. Using a model based upon tree growth parameters and climatic data, Lindsey and Bassak (23) estimated water needs of mature, urban street trees. They report a significant regression equation accounting for 85% of the variability in tree water loss for four tree species [serviceberry (*Amelanchier arborea* 'Robin Hill'), Japanese pagoda tree (*Sophora japonica* 'Regent'), basswood (*Tilia americana* 'Redmond'), and white ash (*Fraxinus americana* 'Autumn Purple')]. Others (19, 28, 30) report similar results.

During establishment, water loss for trees in this study was likely influenced by factors other than total daily ETo.

Devitt et al. (9) included tree growth characteristics (trunk diameter, leaf area, canopy volume, and tree height) in water use estimates for containerized (#1, #5, and #15) seedling live oak (*Quercus virginana*) trees. Their results indicate growth characteristics had a positive influence on live oak water loss. Compared to non-transplanted trees, recently transplanted B&B trees have reduced root areas (13), which decreases gas exchange and growth of recently transplanted B&B trees (25). In addition, trees in arid climates are exposed to extreme leaf-to-air-vapor pressure differences, which limit gas exchange and growth of recently transplanted B&B trees (25). Previous reports which found a close relationship between tree water use rates and an ETo investigated trees which were likely under less stress than trees in this research. For example, Lindsey and Bassak (23) investigated water loss of mature, established trees in a humid climate, while others researched tree water loss of containerized trees (19, 28) in humid climates. For trees in our research, it appears water loss rates are not only related to ETo, but possibly to additional factors such as growth characteristics (9), and transplanting (21) or climatic factors (14, 25) which place additional stress on transplanted, B&B trees in arid climates.

We found great variability in daily water use rates, and Kc values, within and among species (Table 2, Fig. 1). Costello et al. (8) estimated water use for selected tree species and grouped tree water use into three categories: high (Kc = 0.7 to 0.9), moderate (Kc = 0.4 to 0.6), and low (Kc = 0.1 to 0.3). They report Kc values for willow species to be high, Kc values for planetree and Norway maple to be medium or high, and Kc values for littleleaf linden and green ash trees to be medium. Montague et al. (26) estimated Kc values for littleleaf linden and Norway maple trees as 0.4 and 0.2, respectively. Our results compare favorably with Costello et al. (8) and Montague et al. (26). We found that in a semi-arid climate, recently transplanted B&B Norway maple would be a low water use species (Kc = 0.19), planetree and green ash would be classified as moderate water use species (Kc = 0.52 and 0.54, respectively), and littleleaf linden and corkscrew willow would be considered high water use species (Kc = 0.83 and 1.05, respectively).

Variability of water loss data is visible among days and tree species (Table 2, Figs. 1, 2). Others have attempted to estimate water loss of individual tree species using a single Kc value (23, 30). However, our research clearly indicates tree species can, and most likely will, have different Kc values (Table 2, Fig. 2). According to Allen (1), species Kc values will vary from day to day due to differences in climatic variables and the plant's response to these variables. Our results clearly show such variability (Table 2, Figs. 1, 2). Therefore, to produce the best estimate of tree water loss, Kc values should be calculated over an extended period and variable climatic conditions (1).

Correct irrigation management of recently transplanted B&B trees is critical for tree establishment and survival. If proper irrigation is not maintained, water stress will limit tree growth and establishment (12, 25). Although, direct inferences arising from this research pertain only to trees in this study (15, 33), our research indicates lysimeter estimated water use of recently transplanted, B&B trees is species specific, and that because of changing climatic conditions, tree water use may differ each day. We also discovered that in this semi-arid climate, water loss of recently transplanted, B&B trees is likely influenced by factors other than total daily ETo. However, despite the limited influence ETo has on tree Kc values, Kc values taken over an extended period of time give insight into water needs of recently transplanted B&B trees. In addition, or research confirms tree species can be grouped into several distinct water use categories. With specific site information (tree size, climate, etc.), those working with transplanted B&B trees can successfully estimate tree irrigation requirements (26), and strive to meet tree water use demands by applying the correct irrigation volume.

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