Determining Water Use and Crop Coefficients of Five Woody Landscape Plants[1]

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Abstract

The water use and crop coefficient of five woody landscape species were determined by growing the shrubs both in 56-liter (15 gal) drainage lysimeters and in above-ground 10-liter containers (#3). Water use per plant, crop coefficient and overall growth parameters differed by species and culture system. Of the five species tested, *Buddleia davidii* 'Burgundy' and *Nerium oleander* 'Hardy Pink' had higher water use per plant in the lysimeters than in the containers. Water use per plant for *Abelia grandiflora* 'Edward Goucher', *Euonymus japonica* and *Ilex vomitoria* 'Pride of Houston' was the same for the two culture systems. Crop coefficient and growth index of *A. grandiflora*, *E. japonica*, and *I. vomitoria* was similar between the two systems. The growth index of *B. davidii* and *N. oleander* was much higher in the lysimeters than in the containers. *Abelia grandiflora* and *E. japonica* had more growth in the containers than in the lysimeters while *I. vomitoria* had slightly larger leaf area in the lysimeters than in the containers. The culture system did not affect the water use per unit leaf area of all species. Therefore, our results indicated that by quantifying the leaf area, the plant water use in the two culture systems is exchangeable.

Index words: container plants, landscape irrigation, lysimeters.

Species used in this study: Abelia (*Abelia grandiflora* Rehd. 'Edward Goucher'), butterfly bush (*Buddleia davidii* Franch. 'Burgundy'), evergreen euonymus (*Euonymus japonica* Thunb.), yaupon holly (*Ilex vomitoria* Ait 'Pride of Houston'), and oleander (*Nerium oleander* L. 'Hardy Pink').

Significance to the Nursery Industry

Conserving water in nurseries and landscapes is of great interest as water prices increase and water availability becomes more limited. Irrigation efficiency can be improved by grouping plants with similar water use and by scheduling irrigation based on actual water requirements. Water use depends on plant species and size. However, little quantitative information of the actual water needs for specific ornamental plants exists. In this study, water use, crop coefficient, and the overall growth of five landscape plants grown in both 3-gal containers (commercial nursery practice) and drainage lysimeters (simulation of landscape conditions) were determined and compared. Water use per plant and crop coefficients were influenced by species and culture system. However, water use per unit leaf area was not affected by the culture system within species. This means that the water use of container-grown plants may be used to predict or estimate the water use of the same species that are grown in a landscape situation, provided that the amount of leaf area can be estimated.

Introduction

The increasing competition among agriculture, industry and municipal water users in arid and semi-arid regions has brought increased attention to water conservation and the improvement of irrigation efficiency. Since landscape irrigation accounts for 40 to 60% of total household water consumption in the Southwest (11), conserving and reducing the amount of water used for landscape irrigation is critically important. Irrigation efficiency is improved by grouping plants with similar water requirements and by scheduling irrigation based on specific plant needs. However, limited information exists on actual water requirements of landscape plants, and in most cases it is given as reference lists based on plant performance in mixed plantings.

Water use of plants is a function of evaporation and transpiration (evapotranspiration, ET); therefore, it fluctuates with climatic conditions such as solar radiation, temperature, humidity and wind. Crop coefficient (K_c) is defined as the ratio of ET of a specific crop to potential evapotranspiration (ET_0) and is widely used for improving irrigation efficiency for many agronomic crops (6). Although a large number of empirical methods have been developed over the last 50 years worldwide to estimate ET_0 from different climatic variables, the United Nation Food and Agricultural Organization (FAO)'s Penman-Monteith method is recommended as the sole ET_0 method for determining ET_0 (1). This method was calibrated in multiple locations worldwide and can be used for estimating ET_0 in a wide range of locations and climates (1).

Methods of estimating actual water use include direct measurement by weighing or drainage lysimeters, gravimetrical method, and soil moisture balance. Lysimeters have been widely used to determine water use for a number of plant species, including turfgrass (8), landscape woody ornamentals (3, 7, 12, 13), and annual bedding plants (16). Planting crops in lysimeters simulates landscape conditions. Levitt et al. (12, 13) used 190-liter (50 gal) lysimeters to determine the water use of three desert landscape trees and compared water use of turfgrass and ornamental trees by using a portable hoist to lift and transport each container to a top-loading balance. Garcia-Navarro et al. (7) used drainage lysimeters (50 gal) to determine water use and K_c of four landscape plants and compared K_c obtained from above-ground containers and lysimeters. They found that differences in relative water use among species in container-grown plants were

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consistent with those grown in the lysimeters. However, only average daily water use of plants from July to October in the lysimeters was presented. The differences in the time course of water use over the seasons between the plants grown in containers and lysimeters were unknown. Plant water use can also be determined from soil moisture reduction (9) and modeling approaches (2).

The water use and crop coefficients of a number of container-grown ornamental woody plants have been determined gravimetrically (4, 13, 16). Although information developed from container-grown plants placed on the ground does not necessarily represent the landscape conditions, it is useful to guide the irrigation of container-grown nursery plants and landscape plants with proper modification. Lysimetry is a preferred method to estimate plant water use, building lysimeters is costly. Among the above mentioned methods, determining the water use and K_c of container-grown plants gravimetrically is least costly and most accurate. The objectives of this study were to determine and compare the water use and crop coefficients of five landscape plants grown in drainage lysimeters and in conventional above-ground containers simultaneously in the same field plot. The comparison of these data will determine if the water use of the same plant species grown in the two culture systems is exchangeable.

Materials and Methods

Plant material and culture. The following species were purchased in 2.6 liter containers (# 1) from a local nursery: *Abelia grandiflora* 'Edward Goucher', *Buddleia davidii* 'Burgundy', *Ilex vomitoria* 'Pride of Houston', *Euonymus japonica*, and *Nerium oleander* 'Hardy Pink'. Ten plants of each species were transplanted in mid-June into 10 liter containers (# 3) filled with a substrate containing composted mulch and Sunshine Mix no. 4 (SunGro Hort., Bellevue, WA) at a ratio of 1 to 1 (by vol). The plants were placed on ground and arranged in a completely randomized design in the field and were spaced at approximately 10 cm (4 in) to simulate commercial nursery practices. Seven plants from each species were transplanted to the 56 liter (15 gal) drainage lysimeters (detailed description below) in mid-June to simulate landscape conditions. The lysimeters were cylinder-shaped with a diameter of 40 cm (16 in) at a height of 52 cm (20.5 in) with a top portion shrinking in diameter from 40 cm to 25 cm (16 to 10 in). Lysimeters were filled with sandy loamy soil with a 5 cm (2 in) layer of 1.9 cm (3/4 in) gravel at the bottom. Each lysimeter had a single 3.8 cm (1.5 in) drainage hole at the bottom. Once again, the five species were arranged in a randomized design within the 35 lysimeters. The lysimeters were spaced at 0.79 m × 1.19 m (2.6 ft × 3.9 ft), which yielded an area of 1.75 m^2/plant (18.9 ft^2/plant). A controlled-release fertilizer (Osmocote; 14N–9P–12K; Scotts-Sierra Hort. Products, Marysville, OH) was applied at a rate of 2.1 g/liter (0.26 oz/gal) to both containers and lysimeters. All plants were well watered every 3 to 6 days depending on species and climatic conditions. Irrigation timing was determined based on container weight or soil moisture content in the lysimeters (≥ 20% volumetric content).

Measurement of climatic conditions and calculation of ET_0. A weather station was installed on site. Solar radiation was measured using a pyranometer (Model LI200, LI-COR Inc., Lincoln, NE). Air temperature and relative humidity were measured by a Vaisala temperature and humidity probe (Model HMP45C, Campbell Scientific Inc., Logan, UT), and wind speed was measured with a RM young wind sentry anemometer (Model 03101-L, Campbell Scientific Inc., Logan, UT). All the sensors were set at 2 m above the soil surface and were measured every 10 sec using a CR23 datalogger (Campbell Scientific Inc., Logan, UT). The hourly and daily averages of all climatic variables and the daily minimum and maximum temperature and relative humidity were recorded. The ET_0 was determined according to Penman-Monteith method (1). An Excel spreadsheet was made for this calculation.

Estimation of water use and crop coefficients. Water use of container-grown plants was determined by irrigating each plant to container capacity, allowing each to drain completely and then weighing them individually. The plants were then reweighed after 24 hr. The difference between the beginning and ending weights over the 24 hr period was the water used in cubic centimeters or milliliters. The estimate for evapotranspiration (ET) was calculated by the following equation: ET (cm) = volume of water use (cm^3) / container surface area (cm^2). Similarly, crop coefficient (K_c) was calculated as follows: $K_c = ET / ET_0$.

Water use (ET) of the plants in the lysimeters was estimated by monitoring the soil moisture depletion using ECH_2O soil moisture probes (Decagon Devices, Inc., Pullman, WA). In 20 of the 35 lysimeters (four per species), two 20 cm (8 in) ECH_2O soil moisture probes were buried inside each lysimeter to monitor soil moisture depletion. The height of the lysimeters filled with sandy-loamy soil was approximately 40 cm (16 in). The soil moisture probes were wired to a multiplexer (AM416, Campbell Scientific Inc., Logan, UT) and connected to the same CR 23X datalogger as mentioned above. The hourly and daily averages soil moisture contents were recorded. The hourly average recorded at 6 AM of each day was used to compute the water use thus minimizing the temperature effect on the soil moisture content readings.

The containers and the lysimeters had the same diameter at the top rim, 25 cm (10 in). Therefore, the same container surface area, 490 cm^2 (76 in^2) was used to calculate the crop coefficients (K_c). Although rainfall was recorded, it was difficult to quantify the amount of rain entering the lysimeters because of the different geometry of the canopies intercepting rain. Soil moisture content data were excluded on days when irrigation or rainfall occurred when determining the moisture depletion in the lysimeters.

Plant growth measurements. Leaf area per plant in early August and October was estimated by counting the number of leaves and shoots categorized in small, medium and large sizes. For each size, the leaf area of five similar leaves from extra plants was measured using a leaf area meter (LI-3100, LI-COR, Lincoln, NE). The extra experimental plants were maintained in 3 gal containers (# 3) in the same field. Plant height and two perpendicular canopy widths measured in October was used to calculate growth index: growth index = (height + (canopy width 1 + canopy width 2) / 2) / 2.

Statistical analysis. The effects of species, culture system and the interaction between species and culture system on water use, crop coefficient and plant growth was determined using PROC GLM (SAS Institute Inc., Cary, NC). When significant differences were found, means were separated among species by Student-Newman-Keuls multiple comparison at

Table 1. Growth index and leaf area of *Abelia grandiflora* 'Edward Goucher', *Buddleia davidii* 'Burgundy', *Ilex vomitoria* 'Pride of Houston', *Euonymus japonica*, and *Nerium oleander* 'Hardy Pink' grown in containers and drainage lysimeters.

Species	*A. grandiflora*	*E. japonica*	*B. davidii*	*I. vomitoria*	*N. oleander*
Culture system			**Growth index (cm)[z]**		
Lysimeter	42.5d[y]	38.1d	98.6a	59.1c	88.5b
Container	37.1c	38.8c	54.9b	51.7b	62.6a
t-test	NS[x]	NS	***	NS	***
			Leaf area (cm²) August		
Lysimeter	297c	1327b	773c	568c	2050a
Container	249c	1271b	233c	454c	1712a
t-test	NS	NS	***	*	NS
			Leaf area (cm²) October		
Lysimeter	454d	1586c	3059b	706cd	7655a
Container	570bc	2519a	977b	460c	2205a
t-test	NS	**	***	*	***

[z]Growth index = ((canopy width 1 + canopy width 2) / 2 + height) / 2.

[y]Means within each row followed by the same letters are not significantly different tested by Student-Newman-Keuls multiple comparison at $P = 0.05$.

[x]NS, *, **, *** nonsignificant, significant at $P = 0.05, 0.01, 0.001$, respectively, between the two culture systems.

$P = 0.05$ and the differences between the two culture systems were analyzed by *t*-test.

Results and Discussion

The growth index determined in October for *B. davidii* and *N. oleander* plants was much greater in the lysimeters, where growing conditions were similar to those in a landscape, than for the container-grown plants (Table 1). The growth index of the remaining species was similar in both culture systems. Among the species, the growth index of *B. davidii* was greater than *N. oleander*, *I. vomitoria*, *A. grandiflora* and *E. japonica* in descending order in lysimeter (Table 1). In the container system, *N. oleander* had the greatest growth index, followed by *B. davidii*, *I. vomitoria*, *E. japonica* and *A. grandiflora*. In August the leaf area of the lysimeter-grown *B. davidii* and *I. vomitoria* plants were significantly larger than those of the same species maintained in the containers. *Abelia grandiflora* and *E. japonica* had greater leaf area in the containers as compared to lysimeters. This is possibly due to the differences in growing media or to the individual species response to the micro-environment in the two culture systems. There was no significant change in the growth of *I. vomitoria* between the two systems. In contrast, the leaf area of *B. davidii* in both systems and the *N. oleander* in the lysimeters increased approximately 300% in two months. There were significant interactions between culture systems and species on growth index and leaf area in October (Table 3).

Due to the differences in plant size and leaf area, water use of plants was expressed in daily water use per plant and per unit leaf area (determined in August and October; Table 2, Fig. 1). Water use per plant and crop coefficient differed by species and culture system, but water use per unit leaf area within species was not affected by the culture system (Table

Table 2. Average water use and crop coefficients of *Abelia grandiflora* 'Edward Goucher', *Buddleia davidii* 'Burgundy', *Ilex vomitoria* 'Pride of Houston', *Euonymus japonica*, and *Nerium oleander* 'Hardy Pink' grown in containers and drainage lysimeters over the four months.

Species	*A. grandiflora*	*E. japonica*	*B. davidii*	*I. vomitoria*	*N. oleander*
Culture system			**Water use per plant (L/d)**		
Lysimeter	0.23b[z]	0.30b	1.13a	0.46b	1.16a
Container	0.31b	0.39ab	0.39ab	0.40ab	0.54a
t-test	NS[y]	NS	***	NS	***
			Water use per unit leaf area (mL/cm²/d)		
Lysimeter	0.60a	0.21b	0.59a	0.72a	0.24b
Container	0.76ab	0.20c	0.64b	0.87a	0.28c
t-test	NS	NS	NS	NS	NS
			Crop coefficient (K_c)		
Lysimeter	0.84b	1.20b	4.37a	1.78b	4.30a
Container	0.93b	1.29ab	1.29ab	1.30ab	1.74a
t-test	NS	NS	***	NS	***

[z]Means within each row followed by the same letters are not significantly different tested by Student-Newman-Keuls multiple comparison at $P = 0.05$.

[y]NS, *, **, *** nonsignificant, significant at $P = 0.05, 0.01, 0.001$, respectively, between the two culture systems.

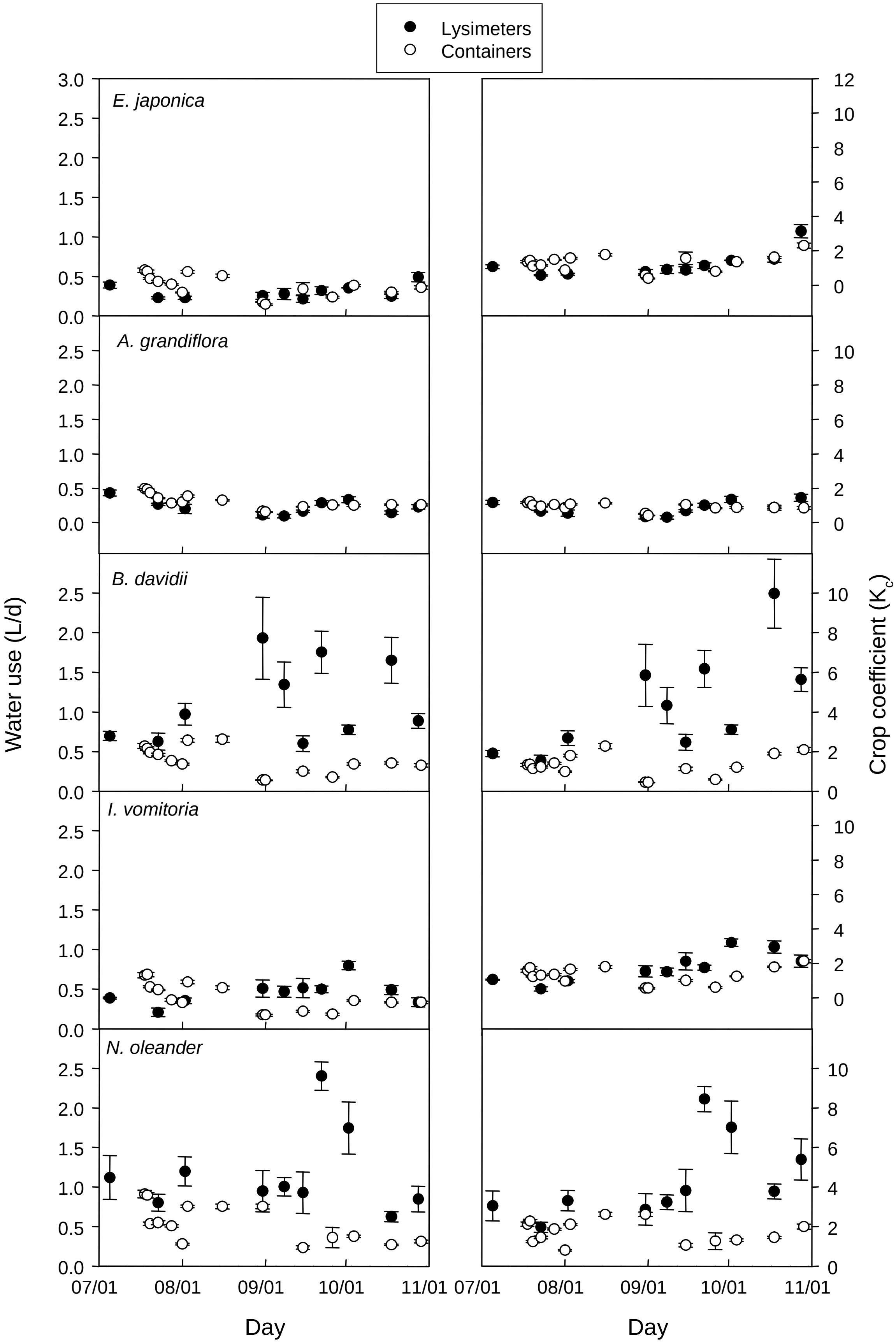

Fig. 1. **Water use per plant and crop coefficient of *Abelia grandiflora* 'Edward Goucher', *Buddleia davidii* 'Burgundy', *Ilex vomitoria* 'Pride of Houston', *Euonymus japonica*, and *Nerium oleander* 'Hardy Pink' grown in containers and drainage lysimeters from July to October. Vertical bars indicate standard errors.**

Table 3. **Significance of culture system (culture) and species on growth index and leaf area, water use per plant (L/d) and per unit leaf area (mL/cm²/d) and crop coefficient (K_c) of *Abelia grandiflora* 'Edward Goucher', *Buddleia davidii* 'Burgundy', *Ilex vomitoria* 'Pride of Houston', *Euonymus japonica*, and *Nerium oleander* 'Hardy Pink'.**

	Growth index	Leaf area (cm²)		Water use		
	(cm)	Aug	Oct	(L/d)	(mL/cm²/d)	K_c
Species	***[z]	***	***	***	***	***
Culture	***	*	***	***	NS	***
Culture × Species	***	NS	***	***	NS	***

[z]NS, *, **, *** nonsignificant, significant at $P = 0.05, 0.01, 0.001$, respectively.

2). In both culture systems, water use per plant was highest in *B. davidii* and *N. oleander*, which had the highest growth index; *A. grandiflora* and *E. japonica* had the lowest water use. When expressing water use per unit leaf area, there were no significant differences among *A. grandiflora*, *B. davidii*, and *I. vomitoria*. Water use per unit leaf area of *E. japonica* was similar to that of *N. oleander*. Culture system and species had significant effect on water use per plant and K_c (Table 3).

The water use per plant in *E. japonica* was generally higher in container-grown plants than those in lysimeters from early July to August (Fig. 1). Plants in the lysimeters were widely spaced so that there was no shading from adjacent plants and it is possible that heat load (heat stress) was higher in lysimeter-grown plants. There were 10 days in July with maximum temperatures over 40C (104F) and 25 days with solar radiation over 30 MJ/m²/d. Similarly, water use of *A. grandiflora* was higher in the containers than lysimeters for the same period. The water use of *B. davidii* and *N. oleander* was much higher from mid-August to September because of their rapid growth.

The average K_c over the four months of *A. grandiflora*, *E. japonica*, and *I. vomitoria* was the same for the two culture systems and among the species (Table 2), although K_c of *I. vomitoria* was higher in the lysimeters because of larger leaf area (Table 1). The K_c of *B. davidii* in the lysimeters was 3.3 times larger than in container-grown plants due to the leaf area in the lysimeters exceeding 3.1 times that of the container-grown plants. Similarly, K_c of *N. oleander* in the lysimeters was much higher than that of container-grown plants. Therefore, K_c of an individual plant varies not only by plant species, but also by leaf area and/or growth rate. Without quantifying plant size, it is difficult to compare the water use per plant and crop coefficients for container-grown ornamental plants, even though same container size is used. For rapidly growing plant species such as *B. davidii* and *N. oleander*, water use per plant and crop coefficient increase rapidly with time.

In addition to species, water use and K_c fluctuated with sampling dates (Fig.1). These differences were caused by climatic conditions and growing stages of the plants. Water use and K_c of 12 container-grown woody ornamentals differed by species, location and month of the year and fluctuated with individual sampling dates (16). K_c of container-grown plants ranged from 1 to 5 (4, 7, 16). These K_c values are much higher than in agronomic crops, which rarely exceed 1.3 (6). This is generally considered to be due to the container surface area, rather than projected canopy area or occupied ground area, being used to calculate K_c.

Montague et al. (14) indicated that water use and K_c of five recently transplanted landscape trees were influenced by factors other than ET_0, which may indicate that those trees were stressed. Water use and K_c of the same sweetgum tree (*Liguidambar styraciflua* L. 'Moraine') differed in three contrasting regions (10), possibly due to the differences in stomatal behavior. It is well-known that stomatal conductance changes with not only atmospheric humidity (vapor pressure deficit) but also soil moisture content. Therefore, irrigation regimens may also affect water use and K_c. When comparing results of water use and K_c, regional climate and irrigation management need to be considered.

Since a typical landscape usually consists of multiple plant species, a landscape coefficient, instead of individual crop coefficient, may be more suitable (5, 9). For example, landscape coefficients can be estimated from individual crop coefficients by considering planting density and microclimate (5): Landscape coefficient = species factor × density factor × microclimate factor. In this equation, species factor, which is the same as crop coefficient, is the key information to be determined. The estimation of other factors is relatively easier. Landscape coefficients may also be determined by real-time measurement. Havlak (9) installed soil moisture probes at 64 locations at three depths to estimate the combined water use of a landscape with multiple plant species and determined the monthly landscape coefficient to be 0.51 to 0.67 for a typical irrigated landscape in southern Texas. It would be desirable to compare this information obtained at a typical landscape site with that determined by other methods.

In summary, water use and crop coefficient differed by species, growth, and months or days for both culture systems. Water use per unit leaf area of the same species was similar in both culture systems. Crop coefficient of the same species was also similar for the two culture systems when growth index was similar. Therefore, water use of landscape plants can be accurately estimated from container-grown plants, provided that growth index and leaf area can be quantified. When applying this information to landscape situation, planting densities as well as growth rate need to be considered.

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