WATER USE OF LANDSCAPE PLANTS GROWN IN AN ARID ENVIRONMENT

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Abstract. An outdoor experiment was conducted in Las Vegas, NV, to quantify the actual evapotranspiration (ETa) of various landscape plants grown in an arid environment. *Washingtonia robusta, Pinus eldarica* and *Cercidium floridum* were planted as #5 and #15 container size trees in 190 L lysimeters and subjected to leaching fractions (LF= volume of solution drained/volume of irrigation water applied) of 0.25, 0 and -0.25 (theoretical). Additional shrubs, groundcover and turfgrasses were also grown in lysimeters but irrigated only at the 0 LF for comparative purposes. Results indicated that ETa of the trees was significantly influenced by planting size and/or LF ($p< 0.05$). Multiple regression equations accounted for 81 to 85% of the variability in measured ETa of the palm, pine and palo verde trees when shoot characteristics and monthly potential evapotranspiration (ETo) were included in the models. ETa of the shrubs, groundcovers and turfgrasses showed significant differences by species ($p=0.05$). Results indicated that consideration must be given to growth and water use relationships and changing ETo if accurate irrigation volumes are to be scheduled for each species.

Key Words: Evapotranspiration, leaching fractions, growth characteristics, irrigation, landscape, tree, shrub, groundcover, grass

With no new and inexpensive sources of water available in the western United States, continued population growth in this region is placing a strain on available water resources. Water managers are looking at all sectors of society to curb water consumption. Outdoor water use represents a sizable portion of the water used in the urban sector (2). Water use on urban landscapes, in particular, is both highly visible and commands a low priority by many when weighed against other uses. It is therefore one of the first areas to be closely examined by water districts and government agencies, to determine the extent to which water is being used efficiently. Limited information exists in the literature on water use by landscape plants (woody ornamental plants 4,8,11,12,14,15, 16,17,18; subtropical landscape plants 7,9; turfgrass 3,6,10), especially in an arid environment (ornamental trees 4; turfgrass 3,10). Such information is needed by the urban sector to aid in the development of lower-water-using landscapes and by the nursery and landscape industry to demonstrate good stewardship in the use of water, to reduce irrigation costs and to alter production to reflect the demand for lower-water-using plants.

The following study was conducted to determine the water use of various landscape plants grown in an arid environment and, in the case of three of the species investigated, to determine water use in response to varying irrigation regimes.

Materials and Methods

A plant water use study was conducted outdoors in Las Vegas, NV for a six-month period. The selection of species for this study was based on feedback from the local nursery and landscape industry. Mexican fan palm (*Washingtonia robusta*), mondel pine (*Pinus eldarica*) and blue palo verde (*Cercidium floridum*) were planted as #5 and #15 container nursery stock (American standard for nursery stock), in non-draining 190 L (50 gal-G) rigid plastic containers (lysimeters). Each species was irrigated to maintain three different leaching fractions (LF = volume of solution drained/volume of irrigation water applied (-0.25, 0, +0.25) and replicated three times. In addition to this experimental design, oleander (*Nerium oleander*), Texas ranger *(Leucophyllum frutescens)*, waxleaf privet *(Ligustrum japonicum)*,

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gazania(*Gazania longiscapa*), myoporum (*Myporum parvifolium 'prostratum'*), rosemary (*Rosmarinus officinalis 'prostratus'*), bermuda grass (*Cynodon dactylon*), bermuda grass/ ryegrass (*Cynodon dactylon/Lolium perenne*), buffalograss (*Buchloe dactyloides*), and bentgrass (*Agrostis palustris*) were also grown in lysimeters but irrigated to maintain only the 0 LF (replicated three times). The oleander, Texas ranger and waxleaf privet were all planted as #5 container nursery stock. The rosemary was planted as #1 container nursery stock (4 per lysimeter). Gazania, myoporum and all grasses (all sod except ryegrass overseed) were planted to achieve 100% soil surface coverage.

Lysimeters [0.54 m (21.3 in) diameter, 0.2287 m^2 (2.46 sq. ft) lysimeter surface area] were filled with a soil mix composed of 75% graded silica sand (23% coarse, 53% medium and 9% fine) and 25% Dakota Sedge Peat (by volume). The lysimeters were lowered into open ended concrete pipes set into the soil and having a sand base flooring. The lysimeters were situated such that the soil level inside and outside of the lysimeters were the same. An air gap existed between the lysimeter and concrete pipe [approximately 15 cm (5.9 in)]. This gap was filled at the surface with a 31 cm (12 in) diameter roll of burlap-covered R19 insulation (wedged) to minimize the impact of ambient air temperatures on root temperatures. The 90 lysimeters were situated in 5 rows of 18 lysimeters. Rows were offset with centers of the lysimeters spaced 4.9 m apart (16 ft) to prevent any possible shading. All trees were fertilized once at the beginning of the experiment with a 15-6.5-12.5 (N-P-K) granular fertilizer at a rate of 18.6 grams (2.5 pounds N per 1000 sq ft) per lysimeter. All turfgrass was cut weekly to a height of 2.5 cm (1 inch) for both bermudagrass and bermudagrass/ ryegrass, 5 cm (2 inches) for buffalograss and 1 cm (3/8 of an inch) for bentgrass. All turfgrass was fertilized monthly with a 34-0-0 (N-P-K) granular fertilizer at a rate of 3.29 grams per lysimeter (1 pound N per 1000 sq ft). All trees, shrubs, groundcover and grass were also foliar sprayed (to runoff) once, with a micro-nutrient fertilizer (15-13-12.5, N-P-K, 0.15% chelated iron and manganese) at a concentration of 0.9 grams per liter (0.75 pounds per 100 G). The area between lysimeters was planted to either tall fescue (*Festuca arundinacea*, Schreb.) or common bermudagrass (*Cynodon dactylon*) to minimize the effects of bare soil on the energy balance of isolated trees and to simulate an urban landscape setting. The turfgrass was irrigated via subsurface drip irrigation to eliminate the possibility of irrigation water entering the lysimeters.

Trees, shrubs, groundcover and turfgrass were all planted in lysimeters in April, 1992. After a three month establishment period, irrigation treatments were imposed for a six month period, by placing the trees under the three different leaching fractions (-0.25, 0 and +0.25). These leaching fractions were maintained by irrigating twice weekly based on the equation I = ETa / (1-LF), where I is the irrigation volume to apply, ETa is the actual evapotranspiration and LF is the leaching fraction. Thus a deficit soil water status was attained by placing a theoretical negative LF (-0.25) into the equation resulting in each week's total irrigation for the -0.25 LF treatment to be less than the previous week's ETa. ETa was measured by using the hydrologic balance approach of ETa = (Irrigation + Precipitation) - Drainage - Change in Storage, where changes in soil water in storage were estimated as the difference in lysimeter weighings taken every seven days with a load cell (Port-aweigh 4260, Measurements Systems Int., Seattle WA., 2270 kg capacity, 0.1% accuracy). For weighings, nylon slings were wrapped around a lysimeter and connected to metal hooks that hung from a rectangular metal frame attached to the load cell. The load cell was attached to an electrical hoist that was mounted on a large movable frame positioned over each lysimeter. Drainage from each individual lysimeter was collected four days per week by placing a vacuum of 17kPa for one hour on two large ceramic extraction cups buried in 10 cm of diatomaceous earth at the bottom of each lysimeter.

Trunk diameters (15 cm (6 in) above the soil line) and tree heights were measured at planting and on a monthly basis during the six month experimental period. Canopy volumes were estimated as an upper half spheroid (palm, palo verde) or an inverted cone (pine). Basal canopy areas were estimated by measuring the basal canopy circumference and basal canopy diameter in two directions for each tree and shrub.

Meteorological conditions were monitored with an automated weather station (model 012 Campbell Scientific, Logan, UT) which was situated in the center of the experimental area. Hourly measurements of solar radiation, maximum and minimum temperature, relative humidity, wind and rainfall were downloaded to a computer. Potential evapotranspiration (ETo) was estimated with the Penman combination equation (3).

Palm, pine and palo verde trees were replicated three times in a randomized block design (species x planting container size x leaching fraction) and analyzed using analysis of variance (ANOVA). Tree data, along with shrub, groundcover and grass data, were also analyzed with descriptive statistics and/or linear and multiple linear regression analysis. Multiple regressions were performed in a backward stepwise manner, with deletion of terms occurring when p values for the T-test exceeded 0.05. Average treatment values were compared based on an LSD generated from a mean square of the error term from the corresponding ANOVA.

Results and Discussion

Leaching fractions (LF) had no significant influence on canopy volumes or basal canopy areas of palm, pine or palo verde trees at the end of the six month experimental period (Table 1). Greatest influence of LF on growth characteristics was measured on trunk diameters and tree heights. However, changes in trunk diameter and tree height between the first and last day of the experiment were significantly different only for trunk diameters of the #5 container size palm trees. These decreasing trunk diameters reflected the influence of the negative LF on the water storage of small palms and would be in agreement with the findings of Holbrook and Sinclair (9) that stem water storage can play a critical role in the water balance of palms under water deficit conditions (Table 2). Actual evapotranspiration (ETa) showed significant separation both by planting size and LF (Table 2). Analysis of variance indicated: 1) a significant interaction of size and LF on ETa occurred for palm trees ($p = 0.01$), 2) pine tree ETa was significantly different by size ($p = 0.001$) and by LF ($p = 0.05$) but the interaction was not and 3) only size was significant ($p = 0.001$) for ETa of palo verde trees. Within the tree category, the #15 container size palm trees irrigated at a +0.25 LF were the highest water users (769 L, 203 G) while the #5 container size pine trees irrigated at a 0 LF were the lowest water users (173 L, 46 G); associated with the highest and lowest basal canopy areas, respectively. Within the shrub category, oleander was the highest water user (346 L, 92 G), with waxleaf privet being the lowest water user (252 L, 67 G). However, oleanders were also significantly larger in trunk diameter and basal canopy area than the other two shrubs (Table 3). Within the groundcover category both myoporum and rosemary were similar and high (258 L, 68 G), compared to gazania which was significantly lower (208 L,55 G). Within the grass category, bermudagrass and bermudagrass/ryegrass were significantly higher (195 L, 51 G) than both buffalograss (166 L, 44 G) and bentgrass (153 L, 41 G).

The ETa response followed the general pattern of the measured potential evapotranspiration (ETo), where ETo was converted to liters based on lysimeter surface area (Fig. 1). Greatest separation among LF treatments occurred during the summer/fall months of August, September and October, with little differences occurring during the winter months of November, December and January. ETo for the six month period totaled 90.78 cm (35.7 in) or 42% of the total for the extended one year period. Although not a one-to-one relationship, ETa (L) was highly correlated to ETo (cm) for all species in this experiment (Table 4). ETa was calculated in L and ETo in cm so the equations would have the greatest utility to irrigators, as ETo is typically reported in cm or inches and irrigations are applied to trees and shrubs on a volume basis. It should be noted that because the change in ETa to ETo was based on different units, the slopes reported in this study do not represent crop coefficients.

Multiple regression equations were developed for the three tree species to account for the greatest amount of variability in the measured monthly

Table 1. Average size characteristics of palm, pine and palo verde trees measured at the end of the 6 month experimental period.

Planting[z] size	LF	Height (m)	Trunk diameter (mm)	Canopy volume (m^3)	Basal canopy area (m^2)	Fronds (#)
Palm						
18.9 L	-0.25	0.76	97.1	0.69	0.90	8.7
(#5)	0	0.90	117.5	1.02	0.91	10.0
	+0.25	0.91	122.5	0.80	0.77	8.0
$LSD_{0.05}$		0.14	11.2	NS	NS	NS
56.8 L	-0.25	1.04	158.3	0.58	0.62	9.3
(#15)	0	0.93	157.9	0.75	0.81	10.7
	+0.25	1.08	180.6	1.08	1.05	12.0
$LSD_{0.05}$		NS	NS	NS	NS	1.7
Pine						
18.9 L	-0.25	0.86	26.9	0.07	0.22	---
(#5)	0	0.78	25.3	0.05	0.18	—
	+0.25	0.79	26.6	0.07	0.26	—
$LSD_{0.05}$		NS	NS	NS	0.08	
56.8 L	-0.25	2.03	45.5	0.37	0.59	—
(#15)	0	1.86	53.6	0.42	0.74	—
	+0.25	2.01	56.8	0.38	0.64	—
$LSD_{0.05}$		NS	7.4	NS	NS	
Palo Verde						
18.9 L	-0.25	1.35	20.7	0.76	0.46	—
(#5)	0	1.71	24.8	1.15	0.65	—
	+0.25	1.59	20.5	1.06	0.70	—
$LSD_{0.05}$		0.19	NS	NS	NS	
56.8 L	-0.25	2.06	23.0	1.40	0.70	—
(#15)	0	1.53	23.0	0.80	0.49	—
	+0.25	1.80	22.9	1.05	0.60	—
$LSD_{0.05}$		0.28	NS	NS	NS	

[z] 18.9 L = 5 gallon = #5 56.8 L = 15 gallon = #15

ETa (L). Growth characteristics (height, trunk diameter, basal canopy area, and # fronds for palms), LF's, and monthly ETo (cm) were included in the development of the models, with terms eliminated if not significant at the p = 0.05 level. We determined that 81% of the variability in the ETa of palm trees was accounted for when ETo, canopy volume and planting size were included in the model (ETa = -127.35 + 6.31(ETo) + 111.33 (canopy volume) + 0.62 (planting size), p = 0.001). For pines 85% of the variability in the ETa was accounted for when ETo and trunk diameter were included in the model (ETa = -29.39 + 2.62(ETo) + 0.92 (trunk diameter), p = 0.001). Eighty-four percent of the variability in ETa of palo verde trees was accounted for when just ETo was included in

Table 2. Total (6 months) evapotranspiration (ETa) of palm, pine and palo verde trees separated by planting size and LF. Also, 6 month ETa totals for various shrubs, ground cover and grasses.

Planting size[z]	LF	ETa (L) Palm	Pine	Palo verde
18.9 L	-0.25	288	213	228
(#5)	0.00	514	173	290
	+0.25	470	233	303
$LSD_{0.05}$		93	42	NS
56.8 L	-0.25	465	285	372
(#15)	0.00	552	346	357
	+0.25	769	389	314
$LSD_{0.05}$		169	96	NS
Shrubs				
Oleander			346	
Texas Ranger			297	
Waxleaf Privet			252	
$LSD_{0.05}$			79	
Ground cover				
Myoporum			258	
Rosemary			258	
Gazania			208	
$LSD_{0.05}$			38	
Grass				
Bermudagrass/Ryegrass			195	
Bermudagrass			195	
Buffalograss			166	
Bentgrass			153	
$LSD_{0.05}$			23	

[z]18 L = 5 gallon = #5 57 L = 15 gallon = #15

Table 3. Average size characteristics of oleander, Texas ranger and waxleaf privet.

	Height (m)	Trunk[z] diameter (mm)	Volume (m^3)	Basal canopy area (m^2)
Oleander	0.98	44.4	0.63	0.51
Texas ranger	0.64	17.9	0.21	0.25
Waxleaf privet	0.76	28.4	0.28	0.31
$LSD_{0.05}$	0.26	11.9	0.18	0.14

[z] Trunk diameter measured at 5 cm above soil surface as opposed to 15 cm above soil surface for trees.

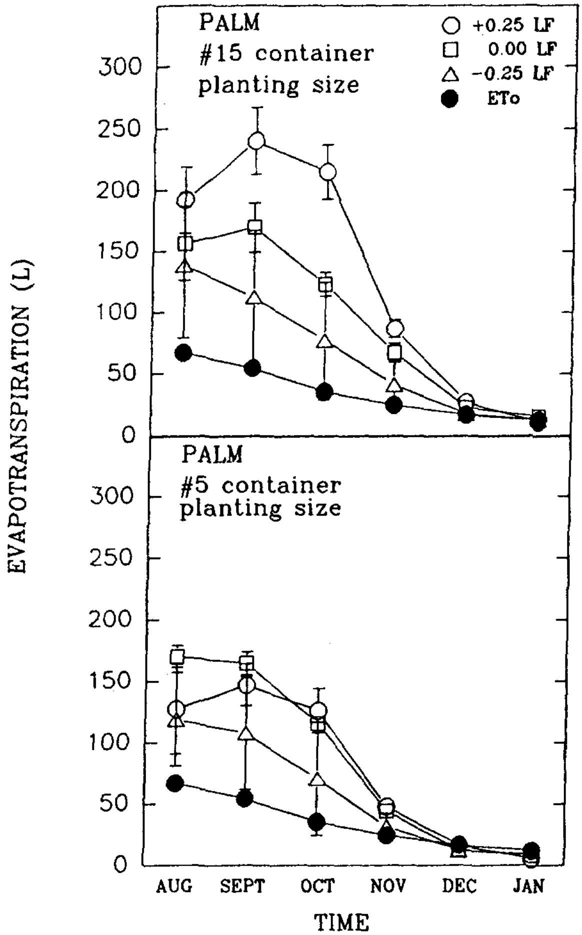

Fig. 1. Evapotranspiration (L) of palm trees as a function of planting size, leaching fraction (LF) and time (mo). Potential evapotranspiration (ETo) converted to liters per month based on lysimeter surface area. Error bars indicate standard error (+/-) associated with average values based on three replications.

the model (ETa = -27.33 + 5.10(ETo), p = 0.001).

Although this research was conducted for only a six month period (area was lost to road widening), the experiment revealed that even during such a short period of time, measured ETa was influenced by species, by size and by irrigation management (LF's). In longer term studies , varied irrigation rates have been shown to have a more dramatic impact on growth parameters (4,12,13) and subsequent plant water use (4). Results suggest that although plant lists, devel-

Table 4. Regression equations and correlation coefficients (r) for the relationship between monthly evapotranspiration (ETa,L) and monthly potential evapotranspiration (ETo,cm).

	ETa (L)	r*
Palm	ETa = -5.97 + 7.68(ETo)^{Z}	0.90
Palo Verde	ETa = -33.32 + 5.90(ETo)^{Z}	0.99
Pine	ETa = 15.88 + 3.02(ETo)^{Z}	0.91
Myoporum	ETa = -11.46 + 3.61 ETo)	0.99
Rosemary	ETa = 2.65 + 2.68(ETo)	0.97
Gazania	ETa = 2.01 + 2.20(ETo)	0.99
Oleander	ETa = -14.12 + 4.75(ETo)	0.96
Texas Ranger	ETa = -20.12 + 4.20(ETo)	0.99
Privet	ETa= 4.19 + 2.51(ETo)	0.99
Bermuda/Rye	ETa = - 7.55 + 2.19(ETo)	0.99
Bermuda	ETa = -15.43 + 3.16(ETo)	0.95
Buffalo	ETa = -16.73 + 3.25(ETo)	0.98
Bentgrass	ETa = -15.45 + 2.82(ETo)	0.97

^{Z} includes data only for the 0.00 and +0.25 LF treatments of the 57 L planting size.
* p = 0.001

Table 5. Total (6 months) actual evapotranspiration per basal canopy area (trees, shrubs) or lysimeter area (ground cover, grasses). Numbers in parenthesis represent a ratio of tree, shrub or groundcover evapotranspiration to high fertility bermudagrass evapotranspiration.

		Evapotranspiration (L/m^2)^Z		
Planting^Z size (L)	LF	Palm	Pine	Palo verde
	-0.25	324 (0.39)	989 (1.17)	555 (0.66)
18.9	0.00	604 (0.71)	948 (1.12)	502 (0.59)
(#5)	+0.25	607 (0.72)	678 (0.80)	488 (0.58)
	-0.25	756 (0.89)	539 (0.64)	833 (0.98)
56.8	0.00	736 (0.87)	469 (0.55)	735 (0.87)
(#15)	+0.25	819 (0.97)	743 (0.88)	521 (0.62)
$LSD_{0.05}$		253	318	NS
Shrubs				
Oleander			692 (0.82)	
Texas Ranger			974 (1.15)	
Waxleaf Privet			829 (0.98)	
$LSD_{0.05}$			NS	
Ground cover				
Myoporum			1123 (1.33)	
Rosemary			1123 (1.33)	
Gazania			903 (1.07)	
$LSD_{0.05}$			164	
Grass				
Bermudagrass/Ryegrass			846 (1.00)	
Bermudagrass			846 (1.00)	
Buffalograss			666 (0.79)	
Bentgrass			734 (0.87)	
$LSD_{0.05}$			113	

^{Z} 18 L = 5 gallon = #5 57 L = 15 gallon = #15

oped as guidelines for landscapes where water is a limited resource, can be helpful, they should not be relied upon as the main water conservation strategy. Such lists may provide a false sense of security with regards to achieving reduced water use on urban landscapes. Any plant can be over watered and many plants actually increase water usage with increased water availability (4). It is thus through water management that significant water savings can and will be realized. Because water use increases with plant size, comparing water use of one species with another requires that it be done on an equivalent area basis and that the size of the tree, shrub, or groundcover be characterized in a way that reflects the transpiring surface. In this study, the trees clearly used more water than the shrubs, which in turn used more water than the groundcovers, which used more water than the turfgrass. However, basal canopy areas of the trees were significantly larger than the area planted to turfgrass (lysimeter surface area). When the ETa data were normalized by dividing the number of liters of water lost through evapotranspiration by the basal canopy area (trees, shrubs) or lysimeter area (groundcover, grasses), ETa on a L/m^2 basis (Table 5) indicated that most trees and shrubs used less water than the high fertility bermudagrass. In a previous study (5), higher tree to grass water use ratios were reported for oak, mesquite and desert willow when compared to low fertility bermudagrass, indicating that management factors such as fertility can play a significant role in altering water use rates and water use comparisons. ETa on a L/m^2/day basis for the three tree species ranged from 1.8 to 5.4. Similar values (0.96 - 3.10) were reported for Asian pears during late summer and early fall in New Zealand (1). The present data indicate that significant variation exists in the water use of trees, shrubs, groundcover and turfgrass such that consideration must be given to growth and water use relationships and changing ETo if accurate irrigation volumes are to be scheduled for each species. Compounding this ETa-ETo-Irrigation relationship in urban landscapes would be the influence of energy exchanges between nearby buildings and walls on landscape plant material (8) and between groundcover (soil, mulch, grass) and plant water use (18). Finally, any possible tradeoffs that could occur between planting area and species planted must be based on quantified water use rates in which the size of the plant and the irrigation and cultural management imposed are characterized.

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Résumé. Une expérience sur le terrain a été menée à Las Vegas au Nevada afin de quantifier le taux instantané d'évapotranspiration de diverses plantes paysagères en milieu aride. Des palmiers du Mexique (Washingtonia robusta), des pins eldariques (Pinus eldarica) et des paloverdis bleus (Cercidium floridum) ont ét plantés dans des lysimètres 190 L et soumis à des «fractions de lessivage». Les résultats ont indiqué que l'évapotranspiration est significativement influencée par la dimension de plantation et/ou par les «fractions de lessivage» (p <0,05). Les équations de régressions multiples permettaient d'expliquer 81 à 85% de la variabilité dans les mesures d'évapotranspiration instantanée des palmiers, des pins et des paloverdis lorsque les caractéristiques de croissance et l'évapotranspiration potentielle mensuelle étaient incluses dans les modèles.

Zusammenfassung. In Las Vegas, Nevada, wurde ein Feldversuch durchgeführt, um die tatsächliche Evapotranspiration (ETa) von verschiedenen Pflanzen an einem trockenen Standort mengenmäßig zu erfassen.Eine mexidanische Fächerpalme (*Washingtonia robusta*), eine Kiefernart (*Pinus eldarica*) und ein blaublühender Palo verde (*Cercidium floridum*) wurden in 190 L Lysimeter gepflanzt und auslaugenden Bodenfraktionen ausgesetzt. Die Ergebnisse der Tests ergaben, die Evapotranspiration der Bäume wesentlich durch die Pflanzgröße und der Durchlässigkeit der Fraktionen (p < 0.05) beeinflußt wird. Multiple Regressionsgleichungen ergaben 81 - 85% der Variabilität der gemessenen ETa von der Palme, der Kiefer und des Palo-verde-baumes, wenn die Wachstumseigenschaften und die monatliche potentielle Evapotranspiration in das Modell mit einbezogen wurden.