Evaluation of a Method for Classifying Landscape Plants by Relative Water Use

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There is increasing demand for landscape plantings that have a low water requirement. Appropriate plant selection, an essential component of this landscaping trend, depends on identification of the water needs of different species so that the availability of water at a given site can be matched with water requirements of the species. However, little information about water use of landscape species is found in the literature, and in most cases it is given in reference lists based on anecdotal observations of plant performance in mixed plantings. Estimates of the water use of agricultural crops are usually based on empirical determination of a crop coefficient, which relates reference evapotranspiration to actual evapotranspiration of the crop under study. Unfortunately, the set of conditions required for this procedure—especially a uniform plant canopy and sufficient irrigation water and fertilizer to achieve full growth potential—are not usually present in landscape settings. The presence of isolated specimens, or of mixed plantings with varied water requirements and different conditions of hardening, and the influence of adjacent structures and surfaces, are all confounding factors that hinder the application of the crop coefficient method for predicting or determining landscape water use.

Clearly, the determination of water use by the numerous species commonly used in our landscapes is a difficult task. Direct determination is difficult to achieve, and indirect methods are slow and confounded by both plant geometry and interactions with other plants. In addition, their extrapolation or broad application to different situations will always be limited by the many microclimate factors influencing water use in landscape settings.

The other type of determination commonly made in the selection of low water use plants involves the identification of plants with low water use and favorable responses in terms of growth and appearance when grown under limited irrigation. In fact, this approach may lead to the selection of plants that are lavish in their water consumption when water is not a limiting factor. Rapid depletion of water reserves to the detriment of surrounding species with a more conservative use of water may, in fact, increase the irrigation needs of the landscapes in which they are incorporated.

A new, direct method of classification of woody ornamental species according to their water use was tested in this study. It was undertaken to test the hypothesis that relative water use of different species growing in standard one-gallon containers in commercial nurseries may be representative of the relative water use of those species growing in soil in the landscape.

Material and Methods

Plant material. Four species of woody landscape shrubs in one-gallon containers were purchased from a commercial nursery during the spring of 1998. Based on published reports of water use of woody plants in commercial nurseries (Burger et al., 1987) and previous studies on minimum irrigation of landscape species (Sachs et al.,1994), we expected two of the species selected, *Spiraea* x *vanhouttei* (Briot.) Zabel and *Viburnum tinus* L., to have high water consumption. The other two, *Arctostaphylos densiflora* M.S. Baker ‘Howard McMinn’ and *Leucophyllum frutescens* (Berl.) I.M. Johnst., were expected to have low water consumption.

Testing of plants in containers. Thirty-two plants of each species were arranged into two sixteen-plant blocks. In each 4 x 4 block, the outer rows were used as a buffer and the treatments were applied to the four inner plants. Containers were set 30 cm apart (12 inches) in a square pattern, giving a plant density of 11 plants per square meter. All of the plants were watered to container capacity daily during the weeks previous to the start of the experiment. Beginning on August 3, the stress treatment was imposed on one of the two blocks of plants in each species. Plants in the control group

Table 1. Percentage of ET_0 applied to stressed plants.

Irrigation date	Water applied (% ET_0)
July 28	15
Aug 5	20
Aug 13	50
Aug 24	50
Sept 3	30
Sept 17	20

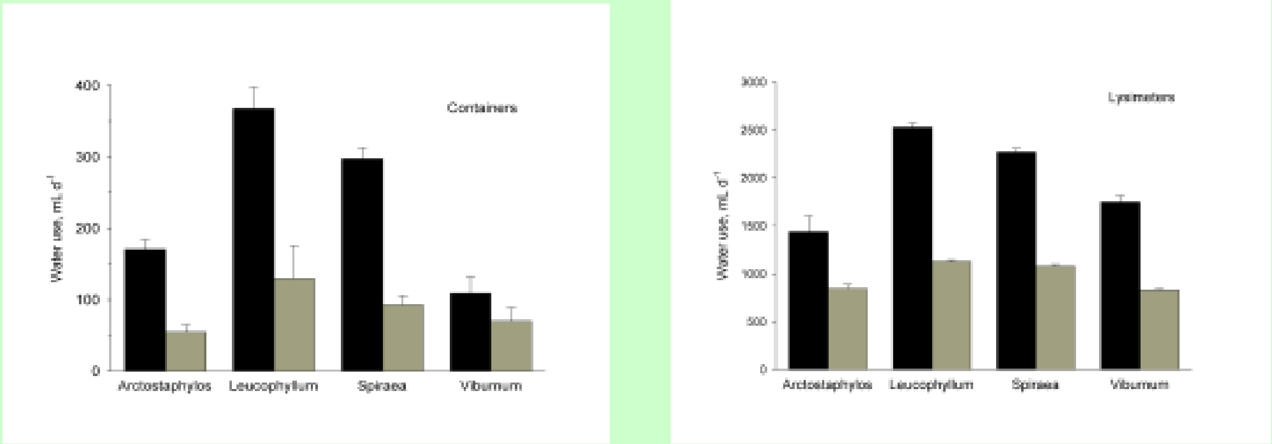

Figure 1. Average daily water use of shrubs growing in one-gallon containers or 55-gallon lysimeters, and receiving well-irrigated (dark bars) or water stress (light bars) treatments. Error bars indicate standard error of the mean.

were irrigated daily to container capacity. For plants in the stress treatment, irrigation was withheld until almost all of the available water was removed from the container. Plants were then irrigated to container capacity and subjected to a new cycle of stress. The cycles of stress were repeated during the summer to allow for the acclimation of the plants. For the first two cycles, the interval between irrigations was two days. The interval increased to three or four days during the next five cycles as the rate of water use in stressed plants declined. The two last cycles of stress were six and seven days long. Daily water use was measured gravimetrically. Measurements were taken for three periods of eleven days each. The first period of measurement extended from July 27 to August 6 and encompassed both the week before imposition of the first water stress and the first four days after stress was imposed. After three more cycles of stress, a second period of measurements started on August 24. The last period of measurement started September 14.

Several characteristics of the plant response to water stress were measured periodically on the plants under both treatments. Plant growth was assessed through non-destructive measurements of plant height, stem diameter and length, and number of leaves or defoliation of selected shoots. Pressure-volume curves of each species under study were done using a pressure chamber (Soil Moisture equipment, Santa Barbara, CA) and using the Richards method (Nilsen, 1996), also known as the bench drying technique. Osmotic potential at full turgor (ψ_π^{100}), water potential at the turgor loss point (ψ_π^{0}), relative water content at turgor loss point (RWC_o), and modulus of elasticity at full turgor (ε_{max}), were determined from the curves. Predawn leaf water potential was determined with a pressure chamber on September 18. The terminal portion of randomly selected branches was used. Stomatal conductance was measured on young, fully expanded leaves with a LICOR 1600 steady-state porometer on the morning of October 7, one day after irrigation of stressed plants.

Carbon isotope discrimination was determined on sun-exposed leaves of the terminal portion of randomly selected branches, which were collected from randomly selected plants in each treatment group. The foliage was oven-dried (80^{o}C, 48h) and ground in a Willey mill to pass a 40 mm mesh. Carbon isotope ratios were measured with a mass spectrometer and expressed as δ^{13}C relative to PDB standard. δ^{13}C values were transformed to discrimination D values assuming a δ^{13}C for air of -8 $^{0}/_{00}$.

Aboveground biomass was determined at the end of the experiment. Plants were cut at the ground level and separated into stems, leaves and flowers. Leaf area per plant was determined with a LICOR area meter. Leaves, stems and flowers were oven-dried and then weighed.

Testing of plants in lysimeters. Forty-eight drainage lysimeters (60-cm diameter and 80-cm height), each with a single 2.5-cm drainage hole in the bottom, were set on a concrete pad. They were set at a spacing

Table 2. Crop coefficients for well-irrigated container-grown plants calculated by Burger et al. (1987) and for Sept. 14-24, 1998.

Species	Burger et al.	Summer 1998
Arctostaphylos	1.7	2.13
Leucophyllum		4.60
Spiraea	3.4	3.72
Viburnum		1.36

of 100 cm x 75 cm. The pad had been plumbed so that drainage water from each lysimeter could be captured and measured. In spring 1997, twelve plants of each of the species described above were transplanted from one-gallon containers into the lysimeters. The plants were arranged in a completely randomized design, with four species, two irrigation treatments, and six replicates.

Ironically, the water stress experiment was not started until July 1998 because of an unusually long rainy season. The irrigation treatments had been planned to provide 100% or 15% of ET_0 (reference evapotranspiration), based on data obtained from the CIMIS station on the UC Davis campus. The experiment began after plants in all treatments were irrigated to container capacity. Plants in the 0.15 ET_0 treatment began to defoliate as the soil dried after the first irrigation (presumably because the extended rainy season left them unprepared for water stress), so the water stress treatment was modified. Actual irrigation volumes relative to ET_0 are presented in Table 1.

Water use was determined from the difference in volume of water applied and water collected from drainage, assuming that soil moisture content at container capacity was the same after each irrigation. Water use of stressed plants was determined once for the entire duration of the study because no drainage occurred after intervening irrigation events. At the end of the experiment, all plants were irrigated with a measured volume of water to bring the soil back to its initial moisture content in both control and stress treatments.

Measurements of plant growth and water status were conducted as described for the plants growing in one-gallon containers. In addition, midday stem water potentials were determined on three plants per treatment. Small branches in the base of the plant were selected and bagged to prevent transpiration. After at least one hour, branches were cut at their base and their water potential rapidly measured in a pressure chamber.

Results and Discussion

Water consumption among the four species followed similar patterns in both the gallon containers and the lysimeters (Fig. 1). The relative consumption of water by well-watered plants was highest in *Leucophyllum*, followed by *Spiraea*, and then by *Viburnum* and *Arctostaphylos*, which had similar water consumption values. In the gallon containers, average daily water use of well-watered plants ranged from 110 mL (*Viburnum*) to 370 mL (*Leucophyllum*). In lysimeters, average daily water use of well-watered plants ranged from 1440 mL (*Arctostaphylos*) to 2530 mL (*Leucophyllum*).

Crop coefficients calculated for the well-irrigated plants also reflect the relative order of water use (Table 2). Under the classification established by Burger *et al*. (1987) for container plants, *Arctostaphylos* and *Viburnum* fall within the low water use category, while *Spiraea* and *Leucophyllum* may be considered as moderate and heavy water users respectively. The values obtained for *Arctostaphylos* and *Spiraea* are consistent with those calculated by Burger *et al*. As in that study, the values of K_c for container grown species were higher than those reported for agronomic crops or orchard trees. They also were higher K_c values for the same species grown in lysimeters.

Reducing irrigation to a low fraction of ET_0 re-

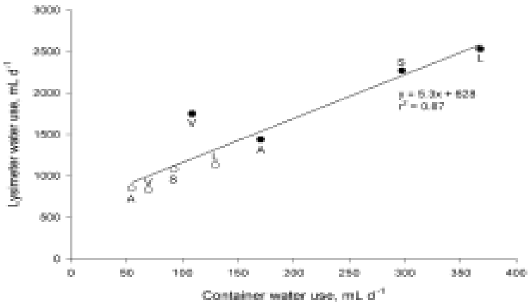

Figure 2. Linear relationship between water use of plants in lysimeters and in containers. Closed circles represent well-irrigated plants; open circles represent water-stressed plants. Letters next to symbols indicate first letter of plant genus.

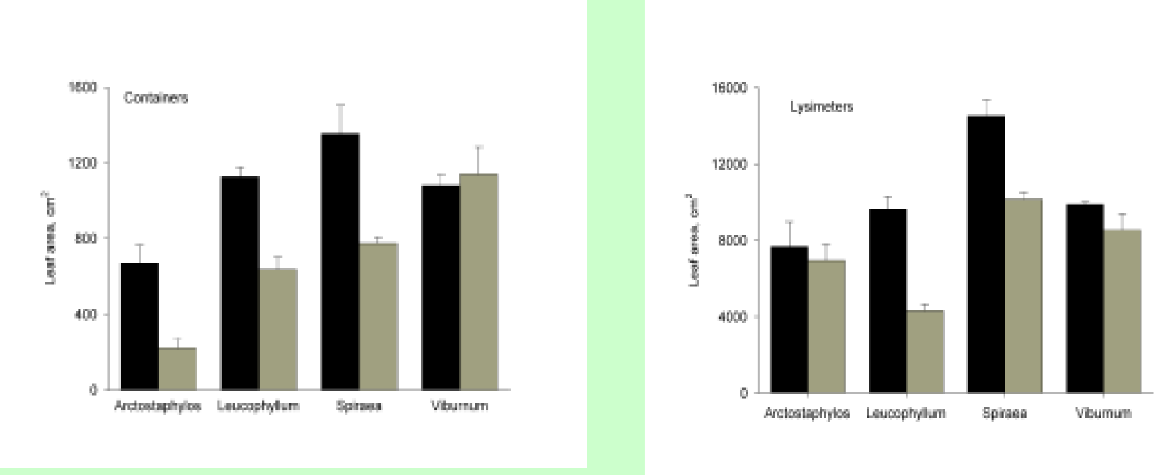

Figure 3. Leaf area of shrubs growing in one-gallon containers or 55-gallon lysimeters, and receiving well-irrigated (dark bars) or water stress (light bars) treatments. Error bars indicate standard error of the mean.

sulted in a substantial decrease in plant water use in either containers or lysimeters (Fig. 1), but the relative order of water consumption did not change significantly. In containers, water use of stressed plants was approximately 65–70% lower than that of well-watered plants (except for *Viburnum*, which was only 35% lower). In lysimeters, water use of stressed plants was about 55% lower than that of well-watered plants.

The relative water use of the four species in the lysimeter experiment was consistent with that in the container experiment. The good fit of the regression of average daily water use by lysimeter plants on average daily water use by container plants (R^2=0.87) illustrates the consistency of the relative water use in both experiments (Fig. 2). This is particularly interesting because it indicates that measurement of water use of well-irrigated plants at the end of nursery production might be useful for predicting the eventual relative water use of various species after establishment in the landscape, regardless of whether those plants receive copious or limited amounts of irrigation water.

Confidence in this conclusion must be tempered by the observation that only four species were tested. However, it is worth noting that these species differ in form and that they responded to water stress in quite different ways. Therefore they may represent broad groups of landscape plants. Evidence of this comes from measurements taken of plant responses to water stress. In containers, water-stressed plants of all species except the *Viburnum* had a substantially reduced leaf area (Fig. 3). In contrast, only water-stressed *Leucophyllum* and *Spiraea* had a significantly smaller leaf area in lysimeters. Early senescence and leaf shedding were observed for *Leucophyllum* and *Spiraea*. *Spiraea* reduced further its effective leaf area by wilting and rolling of the remaining leaves. *Leucophyllum* plants, although showing responses similar to those of the other species, were able to withstand higher levels of dehydration as shown by the lower values of RWC_0 (Tables 3 and 4), apparently due to a relatively high tissue elasticity, and the low predawn and midday water potentials (Fig. 4). Among the species studied, *Leucophyllum* seems to be the most drought-tolerant.

Differences in water stress responses were also apparent in leaf water potential values (Fig. 4) and stomatal conductance values (Fig. 5). In containers, all species except *Viburnum* had a much more negative water potential when water-stressed. In lysimeters, water-stressed plants of *Leucophyllum* and *Spiraea* had much more negative water potentials, with that of *Leucophyllum* particularly low, and the water potential of stressed *Viburnum* was also significantly more negative than that of well-irrigated plants. Container-grown *Arctostaphylos* and *Spiraea* responded to water stress by reducing stomatal conductance, but all four species reduced stomatal conductance substantially when grown in lysimeters under water stress conditions.

The mechanisms involved in the adaptations to water stress of the four species are compatible with the avoidance strategy defined by Ludlow (1989). Species

Table 3. Values of parameters describing the tissue water relations obtained from pressure-volume curves at the end of the container experiment (ψ_π^{100}: osmotic potential at full turgor; ψ_π^{0}: osmotic potential at turgor loss point; ε: bulk modulus of elasticity; RWC_0: relative water content at turgor loss point).

	Irrigation[1]	ψ_π^{100} (MPa)	ψ_π^{0} (MPa)	ε (MPa)	RWC_0 (%)
Arctostaphylos	W	-1.56 ± 0.36	-1.99 ± 0.38	16.4 ± 4.56	91 ± 1.71
	S	-1.85 ± 0.63	-2.37 ± 0.73	16.5 ± 6.05	91 ± 2.45
Leucophyllum	W	-0.98 ± 0.23	-1.47 ± 0.22	3.9 ± 1.79	86 ± 3.86
	S	-1.26 ± 0.54	-1.93 ± 0.66	4.6 ± 1.77	76 ± 4.24
Spiraea	W	-1.44 ± 0.40	-2.01 ± 0.49	7.5 ± 1.29	91 ± 2.16
	S	-1.59 ± 0.21	-2.25 ± 0.24	11.5 ± 5.54	91 ± 2.16
Viburnum	W	-1.45 ± 0.32	-2.07 ± 0.43	12.0 ± 4.85	89 ± 2.99
	S	-1.33 ± 0.23	-1.80 ± 0.32	10.2 ± 2.01	90 ± 2.06

[1] W, well-irrigated plants; S, water stressed plants

showing this strategy are characterized by the maintenance of high water potentials as stress develops. These plants minimize their water loss or maximize their water uptake by different mechanisms. Reduced stomatal conductance, leaf area or changes in leaf angle contribute to a lower transpiration. Low osmotic adjustment is usually associated with the avoidance strategy. Higher root density and hydraulic conductivity increase the water extraction from the soil.

The most likely causes of differences in the way a given species in a small container responds to water stress, when compared to its response to stress in a lysimeter (or in the landscape), are the differences in the magnitude of the water stress and in the rate at which water stress intensifies. Container media can undergo a rapid transition from plentiful water to no available water, whereas that transition tends to be slower in field conditions. Another factor that may have influenced plant responses to water stress is the difference in plant age: Those in lysimeters were a year older than those in the one-gallon containers. The important point that arises from these results is that, despite different responses to water stress attributable to plant species or age, or to growing conditions, the landscape water use of the species evaluated in this study could be ranked accurately, based on water use in one-gallon containers.

Conclusions

Differences in water use among landscape species growing in lysimeters, representative of landscape conditions, were consistent with differences in water use among the same species when growing in one-gallon containers at the end of the production cycle. In spite of the different specific mechanisms of response to water stress, the relative water use of the plants remained similar in both experiments. Since the species used were very different in their growth habits, native environment, and plant characteristics, the generalization of this method is expected to yield good results when applied to other species. The relative values of water use of one-gallon container plants may be used to predict the relative water use of the same species in the landscape. The use of well-watered plants to establish the classification seems to be better than the use of stressed plants since differences in water use among species under limited irrigation are less marked.

The species may be placed under broad categories that might well be determined by those defined by Burger *et al*. (1987) for container-grown plants, based on the calculated crop coefficients after production in the nursery. Under such a classification, *Leucophyllum* would be a heavy water user, *Spiraea* a moderate water user, and *Arctostaphylos* and *Viburnum* would be low water users. These placements differ somewhat from those presently used by WUCOLS, Water Use Classifi-

Table 4. Values of parameters describing the tissue water relations obtained from pressure-volume curves at the end of the lysimeter experiment. Symbols and abbreviations are given in Table 3.

	Irrigation	ψ_π^{100} (MPa)	ψ_π^{0} (MPa)	ε (MPa)	RWC_0 (%)
Arctostaphylos	t_0	-1.63 ± 0.51	-2.14 ± 0.65	13.9 ± 5.37	90.6 ± 5.68
	W	-2.34 ± 0.82	-2.74 ± 0.72	29.0 ± 7.39	93.0 ± 1.15
	S	-1.98 ± 0.85	-2.40 ± 0.94	22.3 ± 1.50	92.0 ± 3.87
Leucophyllum	t_0	-1.45 ± 0.45	-2.22 ± 0.37	3.6 ± 2.84	75.6 ± 4.97
	W	-1.49 ± 0.36	-2.02 ± 0.31	8.4 ± 3.26	85.0 ± 0.58
	S	-0.80 ± 0.27	-1.67 ± 0.32	1.0 ± 1.02	72.0 ± 2.99
Spiraea	t_0	-1.44 ± 0.15	-2.18 ± 0.19	5.9 ± 3.34	76.6 ± 5.46
	W	-1.55 ± 0.61	-2.29 ± 0.39	16.0 ± 3.92	89.0 ± 3.70
	S	-1.87 ± 0.35	-2.58 ± 0.40	18.0 ± 2.50	90.0 ± 1.50
Viburnum	t_0	-1.79 ± 0.15	-2.33 ± 0.16	10.9 ± 1.95	81.6 ± 1.50
	W	-1.46 ± 0.07	-1.82 ± 0.0.6	11.4 ± 3.46	89.0 ± 1.83
	S	-1.16 ± 0.07	-1.45 ± 0.13	10.4 ± 3.92	92.0 ± 2.36

cation of Landscape Species (Costello and Jones, 1999). WUCOLS, which bases its rankings primarily on anecdotal information, lists *Leucophyllum* and *Arctostaphylos* as low water users, and *Spiraea* and *Viburnum* as moderate water users. The discrepancies between the WUCOLS ranking and the values determined in this study may well be due to undetectable species interactions in landscapes. For example, *Leucophyllum* may appear to be a low water user in the landscape because it competes successfully with other plants, obtaining more than its "share" of water.

The knowledge about how aesthetic and functional characteristics are influenced by water stress may help in the landscape design process. In this study, growth of all species was affected by reduced irrigation. Visual appearance of plants was more seriously affected in *Spiraea* and *Viburnum* than in either *Arctostaphylos* or *Leucophyllum*. Density of foliage in *Spiraea* decreased as stress progressed, and the leaves remaining on the plants showed scorching or desiccation of the margins, in-rolling, and wilting. Nevertheless, *Spiraea* plants are able to withstand severe water stress by maintaining only their perennial structures, roots and stems, and to resprout when favorable conditions occur. This fact makes the plant suitable for some purposes in which survival of the plant is more important than the maintenance of aesthetic characteristics. *Viburnum* leaves did not senesce but those more exposed to light suffered sunburn. A long period of drought might render plants of this species unable to recover after rain or irrigation. Even well-irrigated *Viburnum* plants stopped growth during the more extreme summer conditions in this study. Reduction of growth was the only adverse effect of reduced irrigation observed in *Arctostaphylos*. Plants retained most of their foliage and maintained turgor of leaves and branches. The moderate defoliation and reduction of growth in *Leucophyllum* did not prevent the plant from blooming and restarting rapid growth after each irrigation.

Literature Cited

Burger, D.W., J.S. Hartin, D.R. Rodel, T.A. Lukaszewski, S.A. Tjosvold, and S.A. Wagner. 1987. Water use in California's ornamental nurseries. Calif. Agric. 41: 7-8.

Costello, L.R., and K.S. Jones. 1999. WUCOLS: A guide to irrigation water needs of landscape plants in California. http://wwwdpla.water.ca.gov/urban/conservation/landscape/wucols/

Ludlow, M.M. 1989. Strategies of response to water stress. pp. 269-281. In: Kreeb, K.H., H. Richter and T.M. Hinckley. Structural and functional responses to environmental stresses. SPB Academic Publishing, The Hague, The Netherlands.

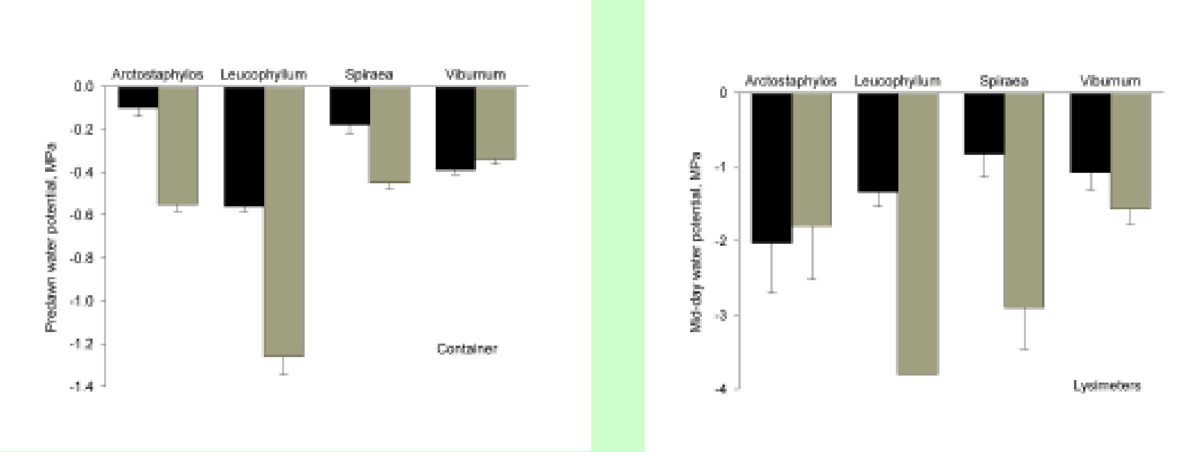

Figure 4. Pre-dawn water potential of shrubs growing in one-gallon containers and mid-day water potential of shrubs growing in 55-gallon lysimeters, and receiving well-irrigated (dark bars) or water stress (light bars) treatments. Error bars indicate standard deviations.

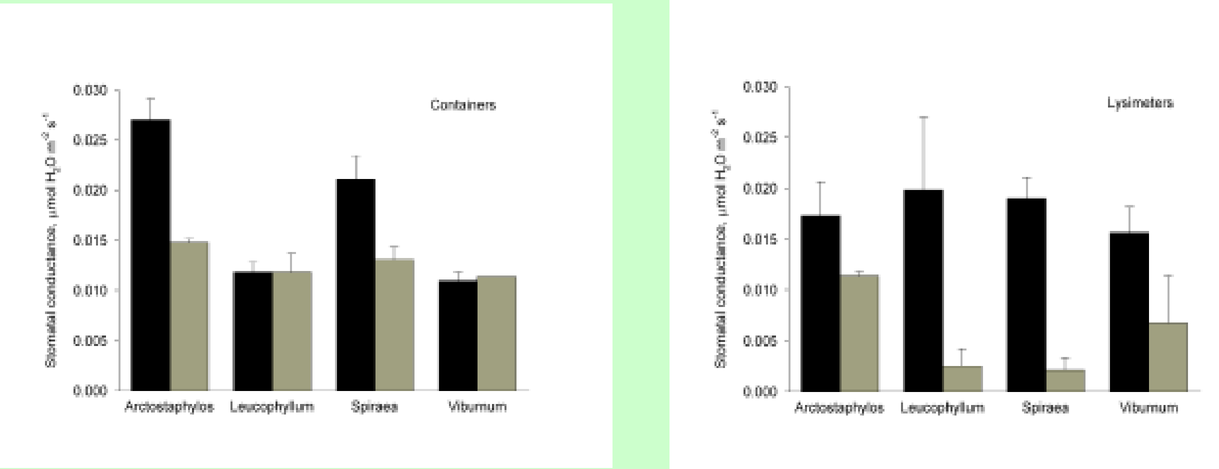

Figure 5. Stomatal conductance values for leaves of shrubs growing in one-gallon containers and 55-gallon lysimeters, and receiving well-irrigated (dark bars) or water stress (light bars) treatments. Error bars indicate standard deviations.

Nilsen, E.T. 1996. The physiology of plants under stress: abiotic factors. Nilsen, E.T. and D.M. Orcutt (eds.). New York, NY.

Sachs, R.M., R.Y. Evans, and D.A. Shaw. 1994. Reduced water consumption by acclimatized landscapes. Report to the Slosson Foundation.

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