Water Use and Crop Coefficients of Woody Ornamentals in Containers

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ABSTRACT. Twelve species of woody ornamentals were grown in containers in Riverside and Davis, Calif., to determine plant water use and compare crop coefficients (K_c) calculated with reference evapotranspiration (ET) from local weather stations (ET_{cim}) or atmometers (ET_{atm}). Water use, $K_{c\text{atm}}$, and $K_{c\text{cim}}$ differed by species, location, and month of the year. *Raphiolepis indica* (L.) Lindl., *Pittosporum tobira* (Thunb.) Ait., *Juniperus sabina* L., and *Photinia × fraseri* Dress. were the highest water users in Riverside and *Arctostaphylos densiflora* M.S. Bak., *Juniperus*, *Cercis occidentalis* Torr., and *Pittosporum* used the highest amount of water in Davis, when averaged over the 20-month study period. *Rhamnus californica* Eschsch., *Prunus ilicifolia* (Nutt.) Walp., and *Cercocarpus minutiflorus* Abrams. were among the lowest water users in both locations. Although plant water use fluctuated considerably between individual sampling dates, the relative ranking of species water use in each location changed very little over the study period. During periods of high winds, ET_{cim} may not provide an accurate reference for container crops. K_c values fluctuated seasonally from as much as 1 to 4.7 for high water users, while values were stable for low water users and also for *Buxus microphylla japonica* Rehd. & E.H. Wils., an intermediate water user. During periods of low ET, especially in fall and winter, K_c values were artificially high and failed to correspond to the plants' low water use. K_c values for low water users seem to be useful to estimate water requirements over an extended period of time, whereas general K_c values seem to have limited value for plants with high water demand and need to be modified for different growth stages and growing locations.

Water use requirements of ornamental nursery crops are of greater interest as nurseries attempt to conserve water and reduce runoff. Increasing water prices, possible allocation or availability limits, and pollution of groundwater and surface water through runoff are rationales to estimate the amount of water plants need as closely as possible. Once daily water use requirements are known, irrigation efficiency can be increased by grouping plants with similar irrigation demands.

Water use of plants is a function of evaporation and transpiration and, therefore, fluctuates considerably daily. In addition to climatic factors, evapotranspiration of a specific crop will be influenced by plant morphology and physiology of the individual plant, as well as the characteristics of the crop canopy (Doorenbos and Pruitt, 1975). Evapotranspiration is calculated or estimated from meteorological data. To relate the effect of different climatic conditions on growth characteristics of a crop, reference crop evaporation (ET) has been defined as the rate of evapotranspiration from an extensive surface of 8 to 15-cm-tall green grass cover of uniform height, actively growing, completely shading the ground, and not short of water (Doorenbos and Pruitt, 1975). Crop coefficients (K_c) were then developed to compare water use of a specific crop to that of a reference crop (Doorenbos and Pruitt, 1975). Dimensionless K_c values are calculated as follows:

$$K_c = ET_{\text{crop}}/ET \quad [1]$$

ET_{crop} is measured over the course of a day, week, or month. ET can be obtained by collecting meteorological data and calculating daily, weekly, or monthly ET with the Penman (1948), radiation (Makkink, 1957), or Blaney-Criddle equation (1950), or using

direct methods such as pan evaporation (Doorenbos and Pruitt, 1975). In California, the California Irrigation Management Information System (CIMIS) weather stations collect data in different locations throughout the state and calculate ET with the modified Penman equation. While this data is of great interest for a general geographic area, it may not account for local microclimates.

Atmometers are alternative devices that estimate evapotranspiration by exposing porous ceramic or paper evaporating surfaces to the atmosphere (Doorenbos, 1976; Rosenberg et al., 1983). Atmometers need to be calibrated to actual ET data, as they are sensitive to placement and exposure. According to the manufacturer, cumulative ET measured with an atmometer, as the one used in this study, is very similar to ET as calculated from the Penman-Monteith, turf-based equation (C. Asbell, personal communication).

For container crops, K_c has been calculated to account for the surface area of the container where water enters the soil volume (Burger et al., 1987).

$$ET_{\text{crop}} = \text{crop water use/container surface area} \quad [2]$$

where ET_{crop} is in centimeters, crop water use is in cubic centimeters, and container surface is in square centimeters. K_c for container crops is then calculated according to Eq. [1].

Crop coefficients were first developed for agronomic or orchard crops with a uniform canopy such as alfalfa (*Medicago sativa* L.) pastures, citrus (*Citrus* sp.), apples (*Malus domestica* Borkh.), and peaches (*Prunus persica* L. Batsch.) (Doorenbos and Pruitt, 1975). Coefficients for individual crops change with the rate of crop development, the length of the growing season, and cultural practices (Doorenbos and Pruitt, 1975; Regan, 1994). Crop coefficients for containerized woody ornamental plants ranging from <1 to >5 have been reported (Burger et al., 1987; Regan, 1994). Many of these K_c values are considerably higher than those reported for field crops, which rarely exceed 1.3 (Doorenbos and Pruitt, 1975). Plants growing in containers seem to have more similarities to isolated stands of vegetation than to a uniform crop

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canopy. Isolated or nonuniform vegetation has a greater K_c value than large, continuous areas of plant cover because single plants capture more net radiation and have a higher resistance to heat flux (Allen, 1993). Isolated plants are subject to advection and higher Et_{crop} and, therefore, higher K_c can be expected for these plants or at the edge of small plots (Doorenbos and Pruitt, 1975).

Changes in the K_c of field crops are often proportional to canopy coverage, for example, in tomato (*Lycopersicon esculentum* Mill.) The K_c value is 0.2 during the establishment phase and increases to 1.1 for the fully developed canopy (Snyder et al., 1987). Higher K_c values for container crops are due to the difference between the container surface area and the variable surface area of the plant canopy (Burger et al., 1987). In container crops it is not unusual for the canopy to considerably exceed the container surface area. For a large plant in a small container, high crop water use will result in a higher K_c . If that same plant were transplanted to a larger container with increased surface area and water use and ET remained the same, Et_{crop} would be lower and subsequently K_c would be lower.

The objectives of this study were to 1) determine the water use of 12 containerized woody ornamental plant species growing in two locations in California from the liner stage up to 2 years and 2) compare K_c values as determined with ET data from CIMIS or atmometers.

Materials and Methods

The following plant species were used in this study: *Arctostaphylos densiflora* M.S. Bak. 'Howard McMinn', *Buxus microphylla japonica* Rehd. & E.H. Wils. 'Green Beauty', *Ceanothus* sp. L. 'Concha', *Cercocarpus minutiflorus* Abrams., *Cercis occidentalis* Torr., *Heteromeles arbutifolia* (Ait.) M.J. Roem., *Juniperus sabina* L. 'Buffalo', *Photinia xfraseri* Dress., *Pittosporum tobira* (Thunb.) Ait., 'Wheelers Dwarf', *Prunus ilicifolia* (Nutt.) Walp., *Raphiolepis indica* (L.) Lindl. 'Springtime', and *Rhamnus californica* Eschsch. 'Eve Case'. Liners were transplanted in August 1992 into 3.0-L black polyethylene containers with Univ. of California no. 3 mix (Baker, 1985) and established outdoors. In Davis, plants were irrigated to saturation with overhead sprinklers once a week from November to March and every other day from March to November. In Riverside, overhead irrigation was applied to saturation once a day from July to October, and two to three times a week for the rest of the year. In Riverside, controlled-release fertilizer (20N-7P-10K, Nutricote, Brampton, Ontario) was added as topdress at transplanting and was replenished at $\approx$ 4-month intervals at 5 g/pot for *Photinia*, *Pittosporum*, *Buxus*, *Raphiolepis*, and *Juniperus*, and at 2.5 g/pot for the remaining seven species. In Davis, the same fertilizer as described above was applied at 15 g per pot at transplanting, and follow-up applications were made in spring of the following years. Plants were moved to 15.6-L containers in Spring 1994, 19 months after transplanting. Containers were spaced can tight immediately after transplanting. A closed canopy, similar to nursery production conditions, was maintained, as containers were gradually spaced further apart to allow for horizontal canopy expansion. Plants were not pruned in either location during the entire study.

Thirty-two plants of each species were arranged in two blocks of four by four. Water use and plant growth of the central four plants per block was monitored. Using only center plants minimized edge effects of border plants, where one side of the container and plant is exposed to higher solar radiation, generally resulting in slower plant growth. The study was conducted at the Univ. of California at Riverside (33°57'N, 117°20'W) and at Davis (38°32'N, 121°46'W).

From March 1993 until November 1994, water use was measured seven and eleven times in Davis and Riverside, respectively, using the following procedure. In the morning, pots were irrigated to saturation, allowed to drain for 1 to 2 h and then weighed to a resolution of 1 g. Pots were weighed again 24 h later and the whole procedure was repeated. This provided data of plant water use for two consecutive 24-h periods during each sample month.

ET during this time was estimated from nearby CIMIS weather stations (ET_{cim}) and from one atmometer (ET_{atm}) (C&M Meteorological Supply, Colorado Springs, Colo.) installed at canopy height adjacent to each study site. The atmometer (ET_{gage}) used in this study consists of a ceramic plate covered with a green fabric cover. The bottom of the plate is connected through a rubber stopper with a glass supply tube and a check valve at the lower end of the glass tube. The atmometer plate with the attached glass tube is placed to seal the top of a distilled water reservoir. A water level on the side of the container indicates the amount of water, in millimeters or inches, that is lost through evaporation. The device can be mounted on a pole next to a crop to determine reference evapotranspiration. Two crop coefficients were calculated: K_{ccim} , which used the local ET_{cim} , and K_{catm} , which used the local ET_{atm} in place of ET in Eq. [1]. Plant height and canopy width were frequently measured and canopy size was calculated as the average of height and two widths.

Water use, K_{ccim} , and K_{catm} were analyzed with a general linear procedure (SAS Institute, Cary, N.C.) including species, locations, and month of the year. Water use at the Riverside location was also calculated as a function of plant height and month of the year. To account for the differences in plant growth throughout the year, the variable month for each year was converted to angles as a fraction of 360° and the cosine and sine of the angles were used in the regression along with their interactions with plant height. This conversion of month per year to a Fourier curve accounts for fluctuations that occur at regular intervals (Little and Hills, 1978) and are typical for the seasonal fluctuations encountered in an annual growth cycle.

Results and Discussion

Water use, K_{catm} , and K_{ccim} were affected by significant interactions between species, location, and month (Table 1, Fig. 1). Water use was primarily influenced by month, while the most important factor for K_{catm} and K_{ccim} was location. *Raphiolepis* and *Pittosporum*, followed by *Juniperus* and *Photinia*, respectively were the highest water users in Riverside when averaged over the 20-month study period (Table 2). *Arctostaphylos* was the highest water user in Davis, followed by *Juniperus*, *Cercis*, and *Pittosporum* (Table 2). *Rhamnus*, *Prunus*, and *Cercocarpus* were among the lowest water users in both locations. The largest difference in species water use between the two locations was found for *Arctostaphylos* and *Cercis*, both high water users in Davis but moderate or low water users in Riverside. The other species ranked similarly in both locations. Although plant water use fluctuated considerably between individual sampling dates, the relative ranking of species' water use in each location changed very little over the study period.

June and August 1994 were the two sampling times with the highest water use in Riverside and Davis (Table 3). Major climatic differences between the two locations occurred from the middle of June 1993 until the end of August 1993 and June 1994 until the end of July 1994 when ET_{cim} in Davis was considerably higher, mainly due to higher solar radiation and greater wind speed (Fig. 2). ET_{cim} was higher in Riverside than Davis from the middle of November 1993 until the middle of February 1994 with higher solar radiation. Wind speed at Davis was always higher than at Riverside, with a

few exceptions during the winter months.

Predicting water use of plants growing in Riverside in response to ET_{cim} , month of the year, and plant height yielded regressions accounting for 76% to 94% of the variation (Table 4).

ET_{cim} was generally the most important factor in predicting water use and was added to the model as the first variable following the intercept in the stepwise regression using forward selection. Exceptions were *Ceanothus*, where the interaction between ET_{cim} and sine (month of the year) was most significant, and *Pittosporum*, where the height squared contributed most to water use. Calculations to predict water use only with plant height, time, and their interactions yielded regressions with poorer R^2 . An attempt to predict K_c with the same variables was even less meaningful.

ET_{cim} is the main factor determining water use. The significant interaction between ET_{cim} and month of the year indicates that the relationship between water use and reference ET varies seasonally (Table 4). This proportional change of water use in relation to ET was also indicated by the different ranking of months for water use and associated K_c values (Table 3).

Crop coefficients K_{catm} and K_{ccim} of individual species, when averaged over the 20-month sampling period ranked similar to water use (Table 2). The K_{catm} and K_{ccim} values of individual species varied considerably between months and years in both locations (Fig. 1). Generally, greater variability was found in 1993 than 1994. Large seasonal fluctuations in K_c values were found for the high water users (Fig. 1), and values were relatively stable in both locations over the 20 months for low water users such as *Cercocarpus* and *Prunus*, but also for *Buxus*, an intermediate water user.

Raphiolepis and *Pittosporum* had the largest range of K_c values in Riverside, ranging from <1 to 4.7 (Fig. 1), a range similar to previous studies (Burger et al., 1987; Regan, 1994). Extremely high K_c values were determined in November and December. While this can be observed to a lesser degree in some of the other species, it seems excessive in *Pittosporum* and *Raphiolepis*. The high water users in Davis—*Arctostaphylos*, *Juniperus*, *Cercis*, *Pittosporum*, and *Photinia*—also showed the greatest variability in K_c values ranging from 1 to 4 (Fig. 1).

During 1993, most species had a low K_c in March and April, a high K_c in June and September, and a low K_c again in October. This pattern is similar in both locations and is easily observed for high water users, but becomes less obvious for species with lower water use. K_c values differed less in 1994 and were lower than in 1993 when determined during the same month. Exceptions were K_c values in June for *Pittosporum*, *Juniperus*, and *Arctostaphylos* growing in Davis (Fig. 1). The lower variability in 1994 stems most likely from the plants' being shifted to larger containers in Spring 1994, thereby increasing the surface area that is used to calculate ET_{crop} (Eq. [2]), and thereby lowering K_c .

Dividing plant water use by the surface area of the container is an attempt to normalize crop water use to a uniform surface area, similar to field crops. However, this is an artificial value that is often not correlated to the area that is covered by the canopy. Although the canopy of a 1-year-old plant will initially be smaller than the container surface area and after 1 year will exceed this surface area considerably, no allowances are made for this change in canopy in the K_c calculations for container plants. Correlating water use to the area covered by the canopy would be an alternative approach to calculating K_c , independent of container surface area and plant spacing, as K_c values are known to vary with different container spacing (Burger et al., 1987; Regan, 1994).

K_c values for some species varied occasionally between consecutive days. Smaller differences seem to be associated with the summer months when water use was high, but in some cases K_c varied during fall and winter by one to two units for consecutive sampling days. These discrepancies indicate that plant water use of species in this experiment may not respond in the same manner as the reference crop to changes in environmental conditions. Annandale and Stockle (1990) investigated the stability of full-canopy cover crop coefficients and found that environmental factors did not affect ET in the same way they affected the crop of interest.

In Davis, *Photinia* K_{ccim} was 1.8 and 2.7 on 27 and 28 Oct., and K_{catm} was 2.7 and 2.3, respectively. The low K_{ccim} on 27 Oct. was due to the high ET_{cim} of 0.8 cm versus the ET_{atm} of 0.5 cm. Upon examination of the climatic components that enter the ET_{cim} equation, we found that higher wind speed was the major difference between the 2 days, while solar radiation and temperature were similar. Wind speed has a profound effect upon ET_{cim} , but the closed canopy structure of our container plants may have prevented increased water use proportional to the wind speed. Also, plants may have closed their stomates in response to high wind speed during the day to prevent desiccation. Sensitivity analysis of K_c values under different environmental conditions found that at very low wind speeds, K_c increased sharply because the reference crop had lower heat exchange (Annandale and Stockle, 1990). At higher wind speeds, K_c either increased or decreased, depending on stomatal resistance of the crop. Wind speed increases with elevation above ground surface (Rosenberg et al., 1983), and discrepancies between ET_{cim} and ET_{atm} may result from CIMIS stations' measuring wind speed at 2 m above ground, while atmometers in our experiment were placed at canopy height, ≈ 50 cm above ground. Therefore, ET_{cim} may not provide an accurate reference ET for container crops on windy days.

ET_{cim} and ET_{atm} at each study site were compared by calculating a regression with ET_{cim} as the dependent variable for both study locations. For Riverside, $ET_{cim} = 0.974 \times ET_{atm}$ ($R^2 = 0.96$), and for Davis $ET_{cim} = 1.13 \times ET_{atm}$ ($R^2 = 0.95$). The CIMIS station

Table 1. Results of the general linear procedure calculated for water use, K_{catm} and K_{ccim} of 12 species of woody ornamental plants growing in containers at Riverside and Davis, Calif., and sampled for water use (milligrams per day per plant) over a 20-month period.

Source of variation	df	Water use		K_{catm}		K_{ccim}	
		Mean square	F value	Mean square	F value	Mean square	F value
Species (S) ²	11	331,862	13.4***	33.6	29.2***	21.4	22.5***
Location (L)	1	256,932	18.7***	539.0	1096.1***	164.9	545.4***
S $\times$ L	11	146,937	10.7***	8.3	16.9***	5.5	18.4***
Month (M)	9	7,148,360	521.7***	99.1	201.6***	39.4	130.2***
S $\times$ M	99	49,566	3.6***	2.7	5.5***	1.5	5.1***
L $\times$ M	5	569,707	41.6***	0.8	1.6 ^{NS}	11.9	39.5***
S $\times$ M $\times$ L	50	40,436	2.9***	1.6	3.3***	1.2	4.0***

²Test of hypotheses used the block $\times$ species interaction for species.

^{NS},***Nonsignificant or significant at $P < 0.0001$.

Fig. 1. Crop coefficients $K_{c_{atm}}$ and $K_{c_{cim}}$ calculated with local reference evapotranspiration (ET) obtained from an atmometer or CIMIS stations, respectively, for *Raphiolepis*, *Pittosporum*, *Juniper*, and *Photinia*. Plants were grown in containers in Riverside and Davis, Calif. Each data point represents the average K_c of eight plants, the two points per month represent K_c values determined on 2 consecutive days.

Fig. 2. Crop coefficients $K_{c_{atm}}$ and $K_{c_{cim}}$ calculated with local reference evapotranspiration (ET) obtained from an atmometer or CIMIS stations, respectively, for *Arctostaphylos*, *Heteromeles*, *Buxus*, and *Ceanothus*. Plants were grown in containers in Riverside and Davis, Calif. Each data point represents the average K_c of eight plants, the two points per month represent K_c values determined on 2 consecutive days.

Fig. 3. Crop coefficients $K_{c_{atm}}$ and $K_{c_{cim}}$ calculated with local reference evapotranspiration (ET) obtained from an atmometer or CIMIS stations, respectively, for *Rhamnus*, *Cercis*, *Prunus*, and *Cercocarpus*. Plants were grown in containers in Riverside and Davis, Calif. Each data point represents the average K_c of eight plants, the two points per month represent K_c values determined on 2 consecutive days.

Table 2. Twenty-month average water use, K_{catm} , and K_{ccim} of 12 woody ornamental species grown in containers at Davis ($n = 1152$) and Riverside ($n = 1920$), Calif.

Davis				Riverside			
Species	Plant water use ($mg \cdot d^{-1}$)	K_{catm}	K_{ccim}	Species	Plant water use ($mg \cdot d^{-1}$)	K_{catm}	K_{ccim}
<i>Arctostaphylos</i>	405 a ²	2.9 a	2.5 a	<i>Raphiolepis</i>	331 a	2.3 a	2.1 a
<i>Juniperus</i>	363 b	2.8 ab	2.4 a	<i>Pittosporum</i>	320 a	2.3 a	2.1 a
<i>Cercis</i>	350 b	2.6 c	2.2 bc	<i>Juniperus</i>	270 b	1.9 b	1.7 b
<i>Pittosporum</i>	344 b	2.8 ab	2.3 ab	<i>Photinia</i>	264 b	2.0 b	1.8 b
<i>Photinia</i>	301 c	2.6 bc	2.1 c	<i>Arctostaphylos</i>	242 bc	1.6 c	1.5 c
<i>Heteromeles</i>	272 cd	2.4 d	1.9 d	<i>Heteromeles</i>	241 bcd	1.6 c	1.5 c
<i>Raphiolepis</i>	243 de	2.0 e	1.7 e	<i>Buxus</i>	218 cde	1.3 de	1.2 de
<i>Buxus</i>	237 de	1.9 ef	1.6 ef	<i>Ceanothus</i>	206 def	1.6 c	1.5 c
<i>Ceanothus</i>	236 de	2.3 d	1.9 d	<i>Rhamnus</i>	199 efg	1.5 cd	1.4 cd
<i>Cercocarpus</i>	216 e	1.7 f	1.4 f	<i>Cercis</i>	184 efg	1.2 e	1.2 ef
<i>Rhamnus</i>	202 ef	2.1 e	1.7 e	<i>Prunus</i>	173 fg	1.2 e	1.1 ef
<i>Prunus</i>	174 f	1.5 g	1.2 g	<i>Cercocarpus</i>	167 g	1.1 e	1.0 f

²Mean separation within each column by Fisher's protected LSD ($P < 0.05$).

in Riverside was located ≈ 100 m from the nursery study site. The distance between the Davis CIMIS station and the nursery study site was ≈ 2 km. Higher wind speeds at the Davis CIMIS location (Fig. 4) compared to the more protected nursery site at Davis could account for K_{catm} underpredicting K_{ccim} by 13%. Microclimate has a strong influence on water use and can change considerably over a short distance (Oke, 1978). The difference between ET_{atm} and ET_{ccim} over the short distance in Davis suggests that an appropriately placed atmometer provides ET information that is specific to the nursery microclimate and more accurate for use in a K_c calculation.

Differences between ET_{atm} and ET_{ccim} introduced considerable variability to K_{catm} and K_{ccim} on the same day. When water use is low during the winter months, small differences in reference ET resulted in large differences in K_c . Large discrepancies between K_{catm} and K_{ccim} , up to 90%, were found in November 1994. Although the difference in ET_{ccim} and ET_{atm} was only 47% at that time, far greater differences between the two ET values at times when plant water use was high resulted in much smaller differences between K_c values. It seems, therefore, that K_c during the winter or during times when water use is low is less reliable than during the summer, when water

use is usually high, and small discrepancies in reference ET will result in only minor differences between K_{ccim} and K_{catm} . Comparing the ranking of water use and the two K_c values in Table 3 confirms that K_c tends to be artificially high in winter and is not correlated to the low water use during that time.

In this study we demonstrated that K_c varied for each species by growing location and time of year. In contrast, Burger et al. (1987) reported that K_c values of three species of containerized ornamentals remained fairly constant at four different locations in California. Similar K_c values in that study can probably be attributed to uniform plant material and to data that were collected only in summer during high water use. In our study, differences in plant growth developed over the 2-year period, with some species performing better in one location versus the other. Growth rates also likely differed between the two locations for individual species. Stage of crop development and growth rate affected K_c values of containerized woody plants (Regan, 1994).

It is questionable that K_c is a useful concept for container crops in general, because it was developed for specific conditions that are not met by container plants. Annandale and Stockle (1990) state

Table 3. Average monthly water use, K_{catm} , and K_{ccim} of 12 woody ornamental species grown in containers at Davis and Riverside, Calif. ($n = 192$).

Davis				Riverside			
Month	Plant water use ($mg \cdot d^{-1}$)	K_{ccim}	K_{catm}	Month	Plant water use ($mg \cdot d^{-1}$)	K_{ccim}	K_{catm}
				1993			
March	---	---	---	March	112 fg ²	1.49 c	1.49 d
April	98 e	1.36 d	1.77 e	April	41 h	0.54 e	0.61 g
June	282 c	1.88 bc	2.40 c	June	---	---	---
July	---	---	---	July	231 d	1.85 b	2.23 b
September	161 d	1.97 b	2.85 b	September	133 f	2.06 a	2.36 b
October	173 d	1.78 c	2.08 d	October	115 fg	1.12 d	1.07 f
December	---	---	---	December	124 f	2.15 a	2.40 b
				1994			
February	---	---	---	February	96 g	1.40 c	1.69 c
June	535 a	1.99 b	2.18 cd	June	490 b	1.25 d	1.08 f
August	495 b	2.43 a	2.37 c	August	517 a	1.23 d	1.29 e
September	---	---	---	September	455 c	1.86 b	1.34 de
November	---	---	---	November	190 e	1.77 b	3.33 a
December	125 e	2.40 a	3.43 a	December	---	---	---

²Mean separation within each column by Fisher's protected LSD ($P < 0.05$).

Fig. 4. Cumulative weekly evapotranspiration, and average weekly solar radiation and wind speed obtained from CIMIS stations in Davis and Riverside, Calif.

that “universally valid” crop coefficients are nonexistent, even for fully developed canopies, because K_c values are sensitive to variations in solar radiation, air temperature, air vapor density, and wind speed. They also found that instability of K_c values increased with crop height. However, K_c values for *Buxus*, *Rhamnus*, *Prunus*, and *Cercocarpus* remained relatively constant in both locations over the 20 months of the study and seem to be useful to estimate water requirements and schedule irrigation relative to ET. K_c values of *Cercis* and *Heteromeles* in Riverside also remained stable, but

increased from spring to fall in Davis, probably because of differences in growth rates. K_c values of the high water users fluctuated considerably and seem to be more specific to a growth stage or time of year and growing location. Therefore, general K_c values have limited value for plants with high water demand and need to be developed for individual growth stages and microclimates for these plants. K_c values of high water users, as determined in this study, are not useful for irrigation scheduling. However, the stable ranking of relative water use of the 12 species in each location provides useful information for grouping plants with similar water needs. Atmometers placed adjacent to the plants provided a reliable and economical estimate of ET and might be used to determine reference ET in this situation.

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Table 4. Regression equations as a function of evapotranspiration estimated by CIMIS weather station (ET_{cim}), canopy height (Ht), and month of year (t) to predict water use of 12 species growing in Riverside, Calif.

Species	Equation	
<i>Arctostaphylos</i>	$-1293 + 2.3 \text{ Ht} + 3454 \text{ ET}_{cim} - 599 \cos(t) + 2007 \text{ ET}_{cim} \times \cos(t)$	($R^2 = 0.86$)
<i>Buxus</i>	$-643 + 0.06 \text{ Ht}^2 + 1769 \text{ ET}_{cim} + 3.6 \text{ Ht} \times \cos(t)$	($R^2 = 0.94$)
<i>Ceanothus</i>	$117 + 1175 \sin(t) - 3051 \text{ ET}_{cim} \times \sin(t) + 301 \text{ ET}_{cim} \times \cos(t)$	($R^2 = 0.90$)
<i>Cercis</i>	$-841 + 2386 \text{ ET}_{cim} - 234 \cos(t) + \text{ET}_{cim} \times \cos(t)$	($R^2 = 0.94$)
<i>Cercocarpus</i>	$-828 + 2345 \text{ ET}_{cim} - 329 \cos(t) + 1137 \text{ ET}_{cim} \times \cos(t)$	($R^2 = 0.87$)
<i>Heteromeles</i>	$-1275 + 3603 \text{ ET}_{cim} - 615 \cos(t) + \text{ET}_{cim} \times \cos(t)$	($R^2 = 0.76$)
<i>Juniperus</i>	$-713 + 2202 \text{ ET}_{cim} - 131 \text{ ET}_{cim} \times \sin(t) + 331 \text{ ET}_{cim} \times \cos(t)$	($R^2 = 0.87$)
<i>Photinia</i>	$-1263 + 3610 \text{ ET}_{cim} - 555 \cos(t) + 1947 \text{ ET}_{cim} \times \cos(t)$	($R^2 = 0.90$)
<i>Pittosporum</i>	$-1227 + 0.26 \text{ Ht}^2 + 3293 \text{ ET}_{cim} - 658 \cos(t) + 2107 \text{ ET}_{cim} \times \cos(t)$	($R^2 = 0.88$)
<i>Prunus</i>	$-838 + 2388 \text{ ET}_{cim} - 383 \cos(t) + 1308 \text{ ET}_{cim} \times \cos(t)$	($R^2 = 0.84$)
<i>Raphiolepis</i>	$-1575 + 5.3 \text{ Ht} + 4004 \text{ ET}_{cim} - 722 \cos(t) + 2277 \text{ ET}_{cim} \times \cos(t)$	($R^2 = 0.87$)
<i>Rhamnus</i>	$-802 + 0.05 \text{ Ht}^2 + 2184 \text{ ET}_{cim} - 332 \cos(t) + 1127 \text{ ET}_{cim} \times \cos(t)$	($R^2 = 0.87$)