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HIGHWAY LANDSCAPE MAINTENANCE WATER CONSERVATION

Final Report

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16. ABSTRACT

The Crop Water Stress Index (CWSI) uses leaf temperature and air vapor pressure deficit data to calculate a relative amount of water stress. The CWSI has been successfully applied to agronomic plants but has not been applied to landscape plants. The Arizona Department of Transportation funded a research project to determine if the CWSI can be used to efficiently irrigate freeway landscape plants. Nine species of landscape plants were studied on the Superstition Freeway in Mesa, AZ. Leaf temperatures were measured with an infrared thermometer (IRT). Results showed that the CWSI was suited to two of the nine species. Two factors were essential for the successful application of the CWSI. First, plants had to have a sufficiently dense canopy so that only foliage is viewed by the IRT. Second, well watered plants needed to transpire at a maximum rate during midday. The use of the CWSI to irrigate freeway landscape plants appears to be limited based on the low proportion of plants which were suited to the CWSI.

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INTRODUCTION

The United States is currently depleting its groundwater supply by 21 billion gallons per day. Water conservation measures are especially important in the arid southwest where landscape irrigation often accounts for 50 percent of urban water use. The Arizona Groundwater Management Act of 1980 mandates municipal water conservation which includes water to irrigate freeway landscape plants. Since there will soon be over 350 miles of freeway landscape, ADOT funded the research project "Highway Landscape Maintenance Water Conservation" in an attempt to reduce the amount of irrigation water used by municipalities.

One strategy to conserve irrigation water is to irrigate plants with the minimum amount of water which maintains plants in an aesthetically acceptable condition. However, no minimum irrigation recommendations exist for species planted along freeways.

To determine minimum irrigation requirements, the degree of water stress a plant can tolerate needs to be established. Considerable research has focused on the development of methods to measure and quantify water stress of agronomic crops. Tanner (21) discussed the use of plant temperatures in assessing crop water deficits and suggested infrared thermometry as the most likely tool for this purpose. Subsequent studies confirmed the advantages of the non invasive infrared thermometer (IRT) over other, direct contact sensors (22,1). By relating radiant crop temperature data to vapor pressure deficit (VPD) of the air, Idso et al. (4) developed a crop water stress index (CWSI). This index has been correlated with soil water content in the root zone of cotton (8), plant water potential in wheat (5), net photosynthesis in cotton (6) and has been shown to be applicable to 26 plant species (7). In a comparison of eight crop water stress measurement methods, O'Toole et al (17) consider the CWSI a significant advancement in water stress measurement.

Until now, the CWSI has only been applied to agronomic crops. However, there are no reports on the use of the CWSI with landscape plants. Sachs et al (18), prior to the development of the CWSI, suggested that leaf temperatures measured with an IRT could be used to schedule irrigation of landscape plants. Thus, the objective of this research was twofold: 1) to determine if desert landscape plants are suited to the use of the CWSI; 2) to identify threshold CWSI values at which plants require irrigation to be maintained in an aesthetically acceptable condition.

THEORY

As plants photosynthesize, stomates, pores on leaf surfaces, are open to allow carbon dioxide to enter the leaf. During this process transpiration occurs, the loss of water vapor through stomates, which reduces leaf temperature via evaporative cooling. The rate of transpiration is affected by temperature and VPD of the air and by the water status of the plant. A well watered plant transpires at its maximum potential, resulting in maximum temperature reduction of its foliage. A water stressed plant transpires at a low rate causing a minimal temperature reduction or a temperature increase if the stress is severe.

The CWSI is based on the discovery that for a well watered crop there exists an inverse, linear relationship between the foliage minus air temperature differential ($T_f - T_a$) and VPD (Fig. 1). This line, termed the baseline, is crop specific and represents the lower limit (maximum transpiration) of the CWSI. The upper limit of the CWSI can be constructed from data of a non-transpiring crop.

The following is an example of the CWSI concept: a data point (z), representing a $T_f - T_a$ value of a water stressed plant at a certain VPD, will be located above the baseline. The vertical distance between point z and the baseline divided by the total distance between the upper and lower limit at that VPD yields a CWSI value. The index ranges from 0, no stress, to 1.0, which designates maximum stress.

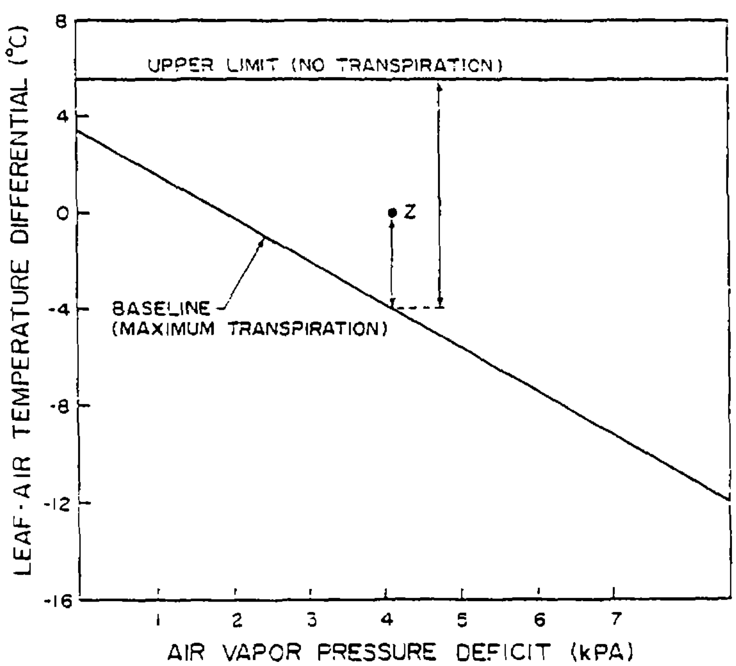

FIG. 1. THE RELATIONSHIP BETWEEN $T_F - T_A$ AND VPD FOR A WELL WATERED CROP AND AN ILLUSTRATION OF THE CWSI DEFINITION.

MATERIALS AND METHODS

There were nine species of landscape plants in the study: *Acacia redolens*, *A. salicina*, *A. saligna*, *Caesalpinia pulcherrima*, *Cassia nemophila*, *Cercidium floridum*, *Eucalyptus microtheca*, *Nerium oleander*, and *Prosopis chilensis*. There were an insufficient number of *A. saligna* plants to test treatment differences, however, as agreed with ADOT officials, a few *A. saligna* plants were informally tested to determine whether this species was suited to the CWSI.

Fifteen mature plants per species were selected on the basis of uniformity in size, form, and state of health. Microhabitat was also taken into consideration so that a minimum amount of variability with regard to location as well as appearance existed among plants of a species.

The study area was located on the north side of the Superstition freeway and extended approximately 800 m east and 550 m west of Mesa Drive, in Mesa, AZ. Soil samples were taken throughout the study area and tested for soil texture, pH, bulk density, salt content, and soil moisture capacity at wilting and field capacity. Results of soil tests (Table 1) show that the variability in soil characteristics between locations was relatively minor.

TABLE 1. SOIL TEST RESULTS FROM SOIL SAMPLES TAKEN THROUGHOUT THE STUDY AREA.

Soil type	clay loam
pH	8.3 (SD = 0.1)
bulk density (g cm^{-3})	1.4 (SD = 0.1)
salt content (dSm^{-1})	1.2 (SD = 0.7)
moisture holding capacity at wilting (%)	16.0 (SD = 1.3)
moisture holding capacity at field capacity (%)	23.5 (SD = 0.9)

Foliage temperatures were measured with an IRT (model 112 C Everest Interscience, Tustin, CA.). At the onset of the study the IRT was calibrated with sophisticated calibration equipment at the U.S. Water Conservation Laboratory in Phoenix. The IRT was calibrated before and after each use in the field with a portable source calibration unit (model 1000, Everest Interscience). The IRT model 112 C was specifically chosen since it had a 3 degree viewing angle and focused on an area 0.46 cm in diameter when held at a distance of 10.2 cm from the object being measured. The reason for requesting such a model was to facilitate temperature measurements of the very small leaves of several species. However, experimentation with the IRT showed that there were considerable temperature differences between leaves. The temperature of a leaf depends on the angle of the leaf relative to the sun. Thus, temperatures of adjacent leaves differed significantly when positioned at different angles. More meaningful values were obtained when a group of leaves was viewed from a greater distance which resulted in a composite leaf temperature measurement. IRT measurements where made from the south.

VPD was calculated from air wet and dry bulb temperature measurements made with a battery powered psychrometer (Psychro-Dyne 3312-40, Cole-Parmer Instrument Co., Chicago, IL). The psychrometer and source calibration unit were positioned in the shade, 1 m above ground, in the vicinity of the plants being monitored. Precipitation was measured with rain gauges during the study.

IRT measurements of shrubs were made at a distance of 1 to 2 m taken from the upper half of the canopy. Trees were measured at a distance of 2 to 3 m with the IRT pointed at foliage about 2 m above ground. Reproductive structures such as flowers or seed pods are warmer than leaves and if in the view of the IRT affect the accuracy of leaf temperature measurements (3). The IRT was pointed at plants in a manner to avoid these structures. Specific techniques for temperature measurements will be presented on a species basis.

In January 1987 a second infrared thermometer was purchased to serve as a back up in the event the original device needed repair. The first as well as the second thermometer needed repair on several occasions.

Irrigation System

Plants were irrigated by a drip system. There were two different emitter types; shrubs were irrigated by single port emitters and trees by multiple port emitters. Flow rates of all emitters used in the study were found to be quite variable. To decrease the variability two measures were taken. First, pressure reduction risers were all adjusted to 24 psi, the prescribed operating pressure. Second, malfunctioning emitters were replaced with new emitters. Despite these measures flow rate variability persisted. To identify which emitters did not deliver the correct amount of water, emitter flow rates were periodically checked and pressure adjustments and emitter replacements were made when necessary. Occasionally, particulate matter in irrigation water clogged emitters. To prevent this, irrigation lines were flushed out.

Since differences in the performance of irrigation equipment could significantly influence measurements, an effort was made to irrigate all plants of a particular species using the same irrigation line (station). Shrub species were controlled by a single station using no more than two reduction risers. This was possible because shrubs were planted in groups. The distance between trees was much greater than between shrubs, therefore individual treatments (irrigation frequencies) of tree species were controlled by a single station and a maximum of two reduction risers.

There were two phases in the study. In phase 1, baseline data were taken to determine if a significant relationship existed between $T_f - T_a$ versus air VPD. In phase 2, species which were suited to the CWSI were subjected to different irrigation frequencies.

Phase 1

Baselines of well watered plants were established by making foliage and air temperature measurements from 0800 hr to 1500 hr at 0.5 hr intervals. The direction of measurement was from the southeast in the morning and from the southwest in the afternoon. As a result a different part of the plant canopy was viewed as the day progressed. $T_f - T_a$ values (y axis) were then plotted at the existing VPD value (x axis). These two variables were correlated using Pearson's correlation coefficient (r) to determine the significance of the relationship. An r value greater than 0.6 was considered indicative of a meaningful relationship and that the CWSI could be applied to a species. Baseline data will be discussed on a species basis.

Initially, five IRT readings per plant for five plants per treatment (to be discussed) for each species were taken. Data from five similar plants in a group were quite variable. IRT data for *Eucalyptus* (Table 2), for example, shows the standard deviation of means for individual plants (n = 5) are less than for the mean of five plants (n = 25). This variability persisted during the study and necessitated the computation of data on a per plant basis. Therefore, the number of measurements was increased to 10 per plant and an average was calculated on a per plant basis.

TABLE 2. FOLIAGE TEMPERATURES OF FIVE <u>EUCALYPTUS</u> CONTROL PLANTS, FIVE READINGS PER PLANT.

Plant	Foliage temperature (°C)					Mean	SD
1	27.9	27.2	28.7	28.5	29.0	28.3	0.72
2	24.5	25.3	24.6	24.9	24.7	24.8	0.32
3	24.9	25.3	25.4	25.6	24.8	25.2	0.34
4	26.4	26.3	26.0	26.2	25.8	26.1	0.24
5	24.5	24.2	24.0	24.6	23.8	24.2	0.33

mean of 25 readings: 25.7 SD = 1.6

Baseline data were taken on plants irrigated according to an ADOT schedule. However, the lack of a significant baseline relationship for most species indicated the possibility that plants were not "well watered". To increase the amount of water to shrubs, single port emitters were replaced with multiple port emitters which had four ports open. Prior to the study all trees were irrigated with multiple port emitters which had two of six ports open. To increase the amount of water to trees all six ports were opened. Additionally, controllers were adjusted to increase the duration of irrigation. Increased irrigation rates resulted in improved baseline correlations for some species (to be discussed on a species basis).

For certain species baseline data were recorded several times during the study to determine if the slope and intercept of baselines differed during the year. Since CWSI values are calculated using the slope and intercept values, knowledge of changing baselines is essential. There are no reports in the literature that document seasonal baselines.

Phase 2

Species with acceptable baseline r values were subjected to three irrigation treatments. These were a well watered (control) treatment, a moderate, and a high degree of water stress. These treatments corresponded to CWSI values. Plants which reached a targeted CWSI value were irrigated until the CWSI value was in the range of 0 to 0.2.

Stress levels were initially planned to be single CWSI values such as 0.5 or 0.7. However, experience with these species revealed that the variability in CWSI values between plants of a particular treatment (irrigation frequency) did not allow for such a discrete value to be used to schedule an irrigation. For example, plants in the moderate stress treatments, targeted CWSI value of 0.5, would have values of 0.4, 0.6, 0.5, 0.7, and 0.4. Thus, a range of values such as 0.5 to 0.7 was used as target values to schedule irrigation.

IRT measurements were made approximately three times per week between 1130 hr and 1330 hr. During the same afternoon of IRT measurement, data were entered into a computer equipped with a software program which calculated CWSI values. If it was determined that a targeted CWSI range was reached, then the appropriate plants were irrigated the following morning.

A preliminary experiment was conducted to determine the influence of time of day on CWSI values. Results of this experiment (Table 3) show that CWSI values of water stressed plants were greater at 1330 hr than at 1230 hr. In contrast, CWSI values of control plants were essentially the same at both times. Therefore, each species was measured at a particular time of day.

TABLE 3. INFLUENCE OF TIME OF DAY ON CWSI VALUES. DATA COLLECTED AT 1230 HR AND 1330 HR ON 22 JULY 1987 FOR CONTROL AND STRESSED *NERIUM OLEANDER* PLANTS.

	CWSI values	
Plant	1230 hr	1330 hr
	Control Plants	
1	0.02	0.05
2	- 0.01	0.07
3	0.01	- 0.03
	Stressed Plants	
4	0.52	0.62
5	0.43	0.58
6	0.52	0.73

Plant physical appearance was monitored weekly. Criteria to assess plant appearance were leaf color, presence of wilt symptoms, density of branching, and overall appearance. Relative leaf chlorophyll content was measured for *Nerium oleander* plants using a SPAD 501 chlorophyll meter (Minolta Co., Ramsey NJ). A high correlation between SPAD 501 readings and leaf chlorophyll content expressed on a leaf area basis has recently been reported (13). Measurements were made periodically to objectively assess leaf color and physiological condition of leaves. Leaves of other species in this study were not suited to chlorophyll measurements with this instrument.

SPECIES

Acacia redolens

This evergreen species has a spreading growth habit. Although usually used as a ground cover (less than 0.5 m tall), plants commonly grow to a height of 2.0 m. Yellow flowers appear in late February followed by pods.

The variable growth forms of this plant made it difficult to select individual plants which had dense canopies as well as similar heights and widths. Additionally, the rampant stem growth enveloped emitters so that in many cases emitters could not be located. Initially, 15 plants were selected, however, it was later discovered that these plants were serviced by a station in which the irrigation rate could not be increased. In May 1987 another set of plants was selected for baseline establishment.

IRT measurements on single plants were not possible since branches of adjacent plants were intermingled and individiual plants were indistinguishable. Therefore, measurements were obtained from a group of plants.

Results

Baseline r values regardless of irrigation rate, time of year, and plant selection were less than 0.51 (Table 4) which indicated that this species is not suited to the use of the CWSI.

TABLE 4. BASELINE EQUATIONS FOR ACACIA REDOLENS.

Month	Irrigation rate (gallons/day)	Baseline[z]	r value
January	0.6	$y = -0.91x + 2.90$	0.51
March	1.3	$y = -0.90x + 3.75$	0.41
April	3.2	$y = 0.96x - 2.60$	0.40
May	11.0	$y = 0.16x - 3.01$	0.16
June	95.0	$y = -1.00x + 2.20$	0.40

[z]calculated from a group of five plants, five readings per plant.

Acacia salicina

This evergreen tree has pendulous, sparse, narrow gray-green foliage. Flowers appear in January and February followed by pods.
Only 13 trees suitable for the study were located. During the course of the study four of these were uprooted following storms. The narrow, sparse foliage of this species made it difficult to view a solid mass of foliage with the IRT.

Results

Baseline r values decreased from 0.55 in March 1987 to less than 0.1 in June 1987 (Table 5). Increasing irrigation rates did not increase r values. The lack of a significant baseline relationship indicated that this species was not suited to the use of the CWSI.

TABLE 5. BASELINE EQUATIONS FOR ACACIA SALICINA.

Month	Irrigation rate (gallons/day)	Baseline[z]	r value
March	4.5	$y = -1.50x + 2.61$	0.55
April	13.0	$y = -0.92x + 1.76$	0.54
May	23.0	$y = -0.12x - 0.09$	0.40
June	40.0	$y_1 = 0.04x - 0.31$	0.04
		$y_2 = -0.02x - 1.00$	0.02
		$y_3 = -0.01x + 0.42$	0.01

[z]y values without subscripts were calculated using data from a group of four plants (five readings per plant). y values with subscripts were calculated using data from individual plants (10 readings per plant).

Acacia saligna

This evergreen tree has pendulous branches densely covered with linear leaves which facilitated IRT measurements. Yellow flowers appear in March and persist for 1 month. Only 3 plants suitable for the study were located.

Results

Baseline slopes from April through November were positive (Table 6). Since negative slopes are required for baseline equations this species was not suited to the use of the CWSI (see results of Prosopis).

TABLE 6. BASELINE EQUATIONS FOR ACACIA SALIGNA.

Month	Irrigation rate (gallons/day)	Baseline [z]	r value
February	1.3	$y = -1.90x + 4.20$	0.64
March	1.3	$y = -1.50x - 4.60$	0.40
April	4.5	$y = 1.65x - 3.77$	0.22
May	30.0	$y = 0.04x + 0.10$	0.10
June	40.0	$y_1 = 1.40x - 5.50$	0.68
		$y_2 = 0.60x - 0.40$	0.45
		$y_3 = 1.10x - 3.40$	0.50
November	6.5	$y_1 = 3.75x - 6.10$	0.84
		$y_2 = 2.71x - 3.80$	0.75
		$y_3 = 3.16x - 5.20$	0.79

[z] y values without subscripts were calculated using data from a group of three plants (five readings per plant). y values with subscripts were calculated using data from individual plants (10 readings per plant).

Caesalpinia pulcherrima

This deciduous shrub species grows to a height of 2 to 3 m and is usually pruned to a height of 15 cm above ground level when dormant to encourage dense regrowth. C. pulcherrima has fine textured foliage and bears large clusters of orange-red flowers from May through September.

Three groups of five plants were selected from two large stands of C. pulcherrima. Plants were pruned to a height of 15 cm above ground level in March 1987. In June 1987, one of the groups was affected by extensive gopher activity and eliminated from the study. Remaining plants were regrouped into three groups of three plants.

IRT measurements commenced in late April 1987, the time when there was sufficient amount of foliage regrowth to allow for measurements. The IRT was pointed at plants in a manner which did not include flowers in the IRT field of vision.

Results and Discussion

Baseline r values increased as irrigation rate increased (Table 7). The average r values for plants irrigated with 30 and 40 gallons per day were 0.65 and 0.87, respectively. The increased r value indicated that at the 40 gallons per day rate plants transpired at or near their maximum potential and were therefore suited to the CWSI. Plants were subsequently subjected to stress treatments and CWSI calculations were made using baselines established in late June (Table 7).

TABLE 7. BASELINE EQUATIONS FOR CAESALPINIA PULCHERRIMA.

Month	Irrigation rate (gallons/day)	Baseline [z]	r value
May	12	$y = -0.16x - 1.40$	0.15
June (early)	30	$y_1 = -0.68x - 0.98$	0.37
		$y_2 = -0.86x + 0.45$	0.64
		$y_3 = -1.04x + 0.59$	0.64
		$y_4 = -0.66x - 0.16$	0.43
		$y_5 = -1.40x + 3.00$	0.85
		$y_6 = -1.30x + 3.30$	0.64
		$y_7 = -1.70x + 4.70$	0.83
		$y_8 = -1.10x + 1.30$	0.67
		$y_9 = -1.50x + 4.30$	0.79
June (late)	40	$y_1 = -1.30x + 1.70$	0.94
		$y_2 = -1.40x + 2.60$	0.91
		$y_3 = -1.50x + 2.30$	0.91
		$y_4 = -1.10x + 1.10$	0.86
		$y_5 = -1.50x + 2.20$	0.88
		$y_6 = -1.20x + 2.70$	0.77
		$y_7 = -1.30x + 1.60$	0.73
		$y_8 = -1.60x + 3.10$	0.93
		$y_9 = -1.20x + 2.80$	0.91
October	30	$y_3 = -0.56x + 0.26$	0.37
		$y_6 = -0.02x - 0.13$	0.02
		$y_9 = -0.07x - 0.23$	0.07

[z] y values without subscripts were calculated using data from a group of five plants (five readings per plant). y values with subscripts were calculated using data from individual plants (10 readings per plant).

Baseline readings were repeated in October 1987 and results (Table 7) showed that a significant baseline relationship did not exist at that time. In general, CWSI values for the three control plants were between 0 and 0.3 until late September (day 272) (Fig. 2). All plants in water stress treatments were without irrigation from 6 July (day 187) until 22 October (day 295). During that period there were nine occurrences of rainfall, which maintained plants at CWSI levels between 0.4 and 0.6 thereby making it impossible to impose different levels of stress. Plants did not show any symptoms of water stress and could not be differentiated from control plants on the basis of appearance. Similar to control plants, CWSI values of water stressed plants were erratic in late September (Fig. 2), the time at which plants began to exhibit symptoms of senescence. Kramer (10) states that stomates of aging leaves are less responsive to environmental conditions. Apparently, a change in stomatal physiology of Caesalpinia was responsible for the lack of a baseline relationship during the fall.

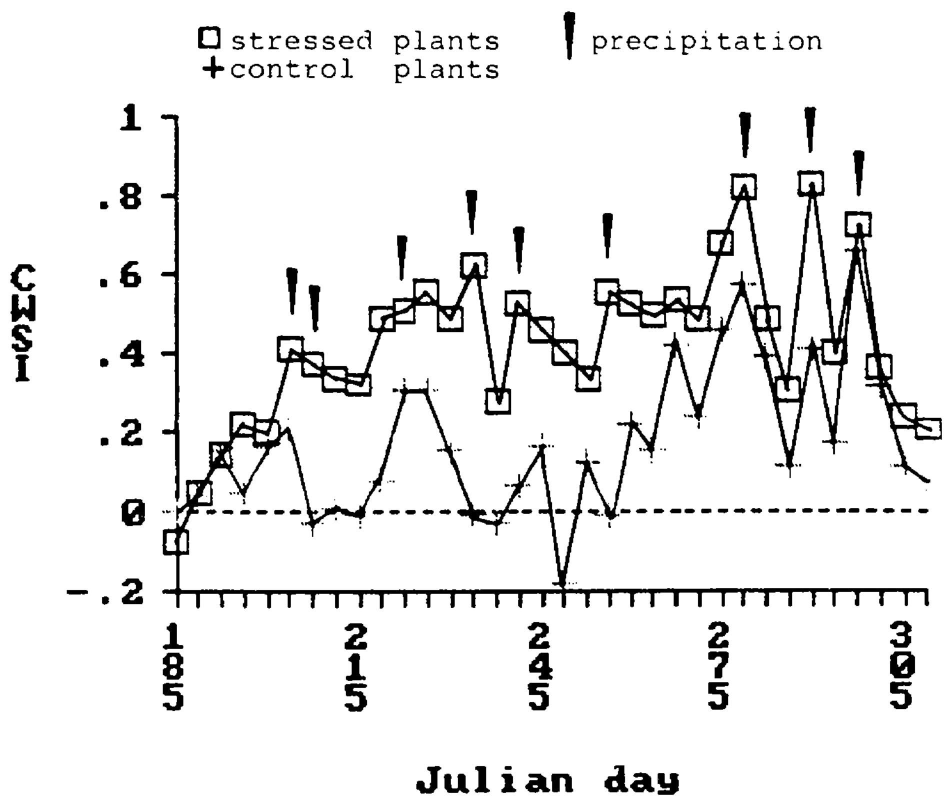

FIG. 2. MEAN CWSI VALUES OF THREE CONTROL PLANTS AND THREE WATER STRESSED CAESALPINIA PULCHERRIMA PLANTS OVER TIME.

The fact that baseline r values were acceptable and CWSI values responded to precipitation during the growing season indicated that this species was suited to the CWSI. This species can be maintained in an aesthetically acceptable condition if CWSI values do not exceed 0.6. However, since values did not exceed 0.6 in this study the possibility exists that this species may tolerate higher levels of stress. Furthermore, the lack of water stress symptoms in plants which only received water from precipitation indicated that this species is relatively drought tolerant and can be maintained with minimal amounts of irrigation water.

Cassia nemophila

This evergreen shrub, 1 to 3 m tall, has upright branches with thin, needle-like foliage and is covered by numerous yellow flowers from January through April.

Fifteen plants within a large group of this species were selected. Several study plants as well as nearby non-study plants died during the study. The causal agent was identified by a plant pathologist as the fungus Phymatotrichum omnivorum (Texas root rot). As a result the number of plants in the study was reduced to nine (three groups of three plants). To encourage dense regrowth, plants were pruned to a height of 1 m in March 1987. Shrubs developed foliage suitable for IRT readings in early May.

Results

June baseline r values were unacceptable when 40 gallons per day per plant were applied for several days before baseline readings were taken (Table 8). In an attempt to increase r values, 32 gallons per day were applied for several weeks in July before baseline readings were taken. However, this strategy was not successful. The lack of an acceptable baseline relationship suggested that the CWSI would not be applicable to this species.

Despite the lack of acceptable r values plants were subjected to stress treatments and the baseline associated with the highest r value (0.71) was used to calculate CWSI values. Even though control plants had expectedly lower values than stressed plants, values for stressed plants as well as control plants were highly erratic (Fig. 3). For example, CWSI values of control plants were - 0.8, 0, and -1.2 on days 230, 240 and 245, respectively. This finding substantiates the contention that species with low baseline r values are not suited to the use of the CWSI.

TABLE 8. BASELINE EQUATIONS FOR CASSIA NEMOPHILA.

Month	Irrigation rate (gallons/day)	Baseline[z]	r value
May	12	$y = -0.13x - 0.52$	0.18
June	40	$y_1 = -0.27x + 0.08$	0.25
		$y_2 = -0.71x + 1.90$	0.57
		$y_3 = -0.47x + 0.51$	0.45
		$y_4 = -0.58x + 0.21$	0.37
		$y_5 = -0.53x + 0.93$	0.30
		$y_6 = -1.10x + 2.30$	0.60
		$y_7 = -0.67x + 0.87$	0.50
		$y_8 = -0.70x + 0.95$	0.53
		$y_9 = -0.41x + 0.40$	0.43
July	32[y]	$y_1 = -0.07x - 0.18$	0.05
		$y_2 = 0.41x - 2.50$	0.41
		$y_3 = 0.14x - 1.50$	0.12
		$y_4 = -0.35x + 0.14$	0.38
		$y_5 = -0.39x + 0.98$	0.35
		$y_6 = -0.83x + 2.30$	0.71
		$y_7 = -0.63x + 1.20$	0.55
		$y_8 = -0.93x + 2.60$	0.69
		$y_9 = -0.31x + 0.91$	0.27

[z] y values without subscripts were calculated using data from a group of five plants (five readings per plant). y values with subscripts were calculated using data from individual plants (10 readings per plant).
[y] see text for explanation.

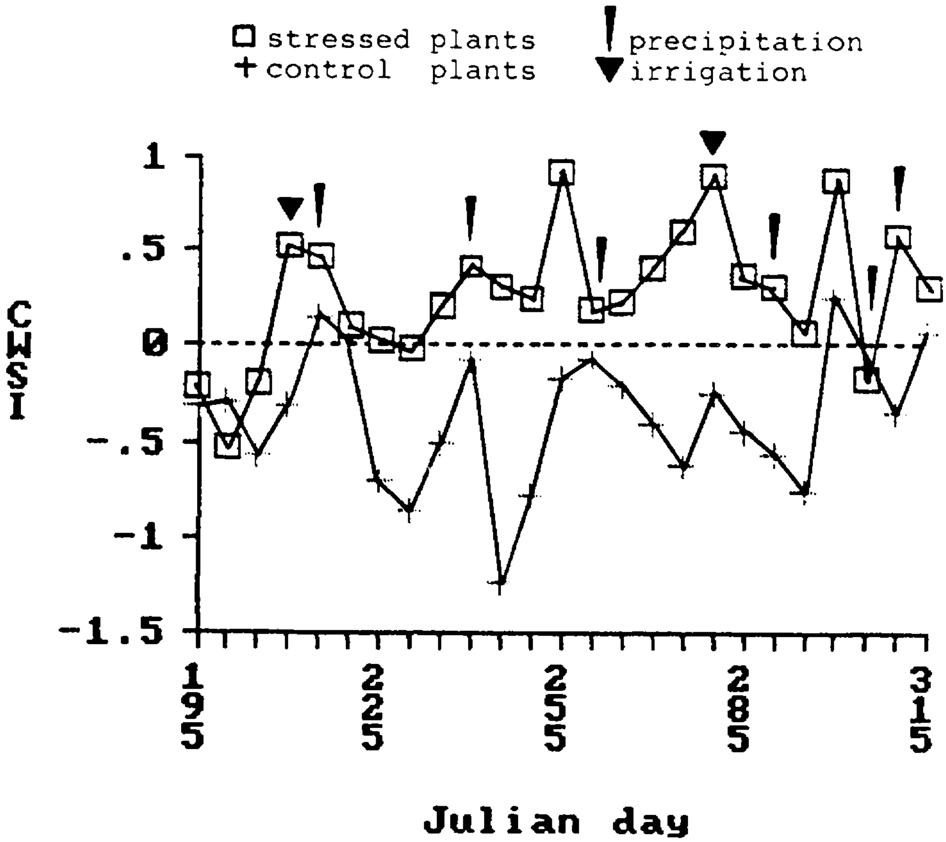

FIG. 3. MEAN CWSI VALUES OF A CONTROL PLANT AND A WATER STRESSED CASSIA NEMOPHILA PLANT OVER TIME.

Cercidium floridum

The compound leaves of this chlorophyllous stemmed deciduous tree are composed of very small leaflets which emerge in May. Numerous yellow flowers cover the branches during April.

No special selection procedures were made for this species with the exception that the first set of trees selected was replaced due to gopher activity around trees.

Due to the very small leaflet size and sparseness of foliage, accurate IRT leaf measurements could not be obtained. Despite this limitation temperature measurements were attempted by viewing leaves as well as green branches.

Results

Attempts to establish a baseline in May were unsuccessful due to highly variable IRT readings. Baseline equations (Table 9) calculated from measurements made in July had a positive slope with low r values (see baseline of *Prosopis*). This data indicated that *Cercidium* is not suited to the use of the IRT.

TABLE 9. BASELINE EQUATIONS FOR *CERCIDIUM FLORIDUM*.

Month	Irrigation rate (gallons/day)	Baseline[z]	r value
July	30	$y_1 = 0.11x - 0.55$	0.13
		$y_2 = 0.47x - 1.50$	0.51
		$y_3 = 0.27x - 1.10$	0.36

[z]calculated from individual plants, 10 readings per plant.

Eucalyptus microtheca

This evergreen tree species has a vertical form with pendulous branches covered by blue green foliage. Inconspicuous white flowers appear in May which are followed by small seed capsules.

Plants were selected primarily on the basis of state of health and foliage denseness. Tree selection was often difficult because of branching habit and narrow leaves. Branch and leaf orientation made it difficult to accurately measure foliage temperatures. Methods to overcome this difficulty such as bunching of foliage were attempted but proved to be unsuccessful. Thus, several of the plants originally selected were subsequently found unsuitable and only a few plants with a sufficiently dense canopy were used in the study.

Results

During February and October baseline r values were acceptable (> 0.7) (Table 10). In contrast, r values during warmer months were unacceptable. Attempts to increase r values by increasing irrigation rates from 1.3 to 300 gallons per day were unsuccessful. Therefore, *Eucalyptus microtheca* was not suited for the use of the CWSI.

TABLE 10. BASELINE EQUATIONS FOR EUCALYPTUS MICROTHECA.

Month	Irrigation rate (gallons/day)	Baseline[z]	r value
February	1.3	$y = -1.89x + 4.00$	0.79
April	4.6	$y = -0.63x + 0.60$	0.43
May	12.0	$y = -0.23x - 0.87$	0.36
June	48.0	$y_1 = 0.06x - 3.20$	0.07
		$y_2 = 0.08x - 2.60$	0.11
		$y_3 = -0.14x - 1.70$	0.17
July	300.0	$y_2 = -0.49x - 0.09$	0.53
		$y_3 = -0.33x - 0.63$	0.37
October	32.0	$y_1 = -1.50x + 2.50$	0.77
		$y_2 = -1.00x + 1.20$	0.76
		$y_3 = 0.39x - 1.10$	0.39

[z]y values without subscripts were calculated using data from a group of five plants (five readings per plant). y values with subscripts were calculated using data from individual plants (10 readings per plant).

The stomatal physiology of this species during warm months and not a need for more water was apparently responsible for the low r values. Woody species have been reported to close their stomates during midday in response to hot and dry atmospheric conditions and thereby reduce transpiration despite an unlimited water supply (12). Furthermore, stomatal conductances of different Eucalyptus species measured during summer and winter months were found to vary greatly between seasons (19). Szarek and Woodhouse (20) working with woody desert plants have also found similar seasonal differences in stomatal conductance. These findings could explain the lack of a baseline relationship during summer months for Eucalyptus.

Nerium oleander

This evergreen shrub has upright branches which are covered by numerous lanceolate leaves. Flowers appear April through November.

Fifteen plants, uniform in height and denseness of foliage were selected. Six plants were eliminated from the study due to very irregular IRT data, irrigation and spacing problems. Plants were pruned to a height of 1.3 m in April 1987 to encourage dense regrowth. Flowers were periodically removed to avoid being viewed by the IRT.

Results and Discussion

The baseline established during January and February had an r value of 0.81 (Table 11). During this time plants were irrigated with 0.6 gallons per day. As air temperature and VPD increased during March and April, r values decreased despite increasing irrigation rates. Baseline r values increased in May after application of 30 gallons of water per day for 5 days prior to IRT measurements. After about 30 days at that irrigation rate, r values of all study plants ranged from 0.78 to 0.96 and were used for CWSI calculations. This increase in correlation with increasing amounts of irrigation documents that a plant has to be well watered to exhibit the linear relationship needed for CWSI calculation. Baseline r values determined in October were lower than found in summer months (Table 11). The reason for the lower r values may be related to leaf age as mentioned for *Caesalpinia*.

TABLE 11. BASELINE EQUATIONS FOR *NERIUM OLEANDER*.

Month	Irrigation rate (gallons/day)	Baseline[z]	r value
January	0.6	$y = -1.4x + 4.60$	0.81
March	6.4	$y = 0.39x - 1.50$	0.37
April	11.4	$y = -0.60x + 0.75$	0.49
May	30.0	$y_1 = -0.81x + 1.00$	0.77
		$y_2 = -0.78x + 1.10$	0.56
		$y_3 = -0.76x + 1.00$	0.78
June[y]	30.0	$y_1 = -1.80x + 5.00$	0.90
		$y_2 = -1.40x + 3.40$	0.78
		$y_3 = -1.60x + 3.90$	0.87
		$y_4 = -1.60x + 4.50$	0.93
		$y_5 = -1.60x + 5.20$	0.86
		$y_6 = -1.30x + 3.10$	0.82
		$y_7 = -1.50x + 3.40$	0.96
		$y_8 = -1.70x + 5.10$	0.93
		$y_9 = -1.80x + 4.90$	0.94
October	30.0	$y_1 = -1.10x + 1.90$	0.75
		$y_2 = -1.00x + 1.50$	0.76
		$y_3 = -0.75x + 0.81$	0.70

[z]y values without subscripts were calculated using data from a group of five plants (five readings per plant). y values with subscripts were calculated using data from individual plants (10 readings per plant).

Stomates open and close in response to soil water content and atmospheric conditions such as air temperature and VPD. The extent of the influence of these factors on stomatal function depends on the physiology of a particular species (2). Stomates of well watered N. oleander have been shown to remain open when subjected to high temperatures and VPD (2). This allows Nerium to transpire at a maximum rate and for a baseline to be established. In contrast, several other species suited to arid environments experience a midday stomatal closure in response to atmospheric stress (2, 12). Midday stomatal closure causes an increase in leaf temperature even when plants are well watered (11, 12). Baseline relationships can only be established with plants whose leaves are transpiring at a maximum rate during the day. Thus, plants experiencing a midday stomatal closure do not facilitate the establishment of a significant baseline relationship.

Plants were subjected to stress treatments and CWSI calculations were made. Plants in the moderate and high stress treatments were to be irrigated when they reached targeted CWSI values of 0.5 to 0.7 and 0.7 to 0.9, respectively. However, values of plants in the high stress treatment generally did not exceed 0.6 (data not shown) apparently due to irrigation system failures.

Plants in the moderate stress treatment were irrigated when they reached the targeted value of 0.6 which occurred four times during the study (Fig. 4). Following irrigation, values decreased to approximately 0.1. The amount of time to reach the targeted CWSI value was increased by rainfall. Visible stress symptoms were not evident until plants reached the 0.6 value for the third time which occurred on 17 August 1987 (day 229). Symptoms included a dull green leaf color, stunted growth, and plants were less dense than those in the control treatment. The occurrence of these symptoms coincided with the decrease in relative chlorophyll content (Fig. 5). Chlorophyll content was greater in control plants than in stressed plants beyond 13 August 1987 (day 225). Visual quality of these plants remained acceptable for a freeway situation. Stressed plants were approximately 0.5 m shorter than control plants. This could be viewed as an advantage since these plants would require less pruning than plants on a regular irrigation schedule.

N. oleander was suited to the use of the CWSI as evidenced by acceptable baseline r values and the fact that CWSI values responded to irrigations and precipitation. This species can be maintained in an aesthetically acceptable condition if CWSI values do not exceed a value of 0.6.

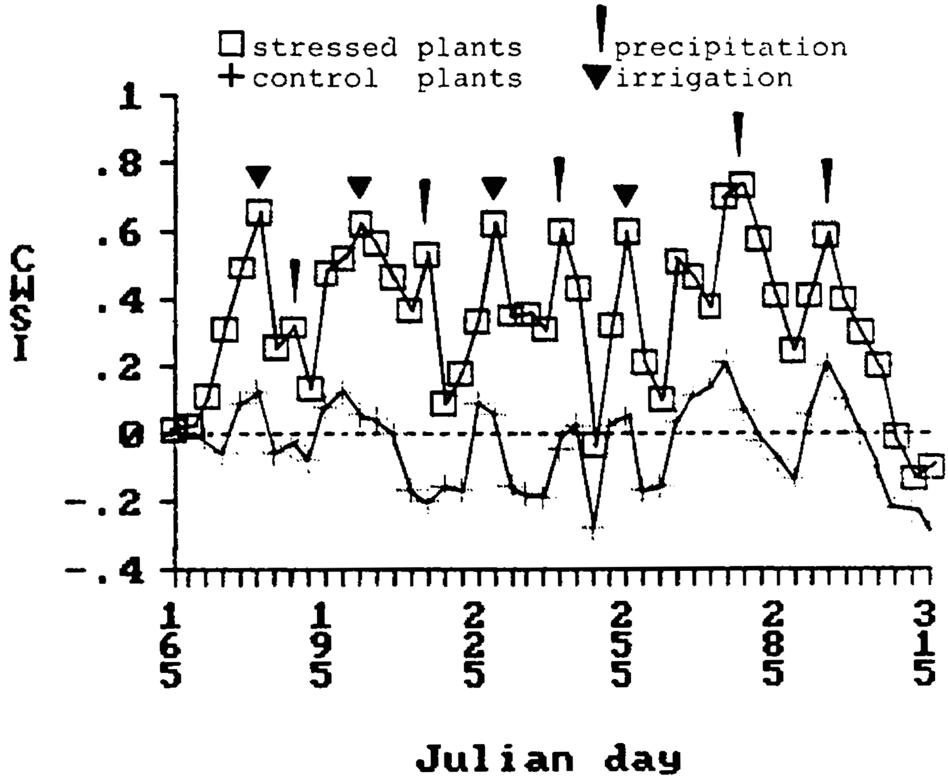

FIG. 4. MEAN CWSI VALUES OF THREE CONTROL PLANTS AND THREE WATER STRESSED NERIUM OLEANDER PLANTS OVER TIME.

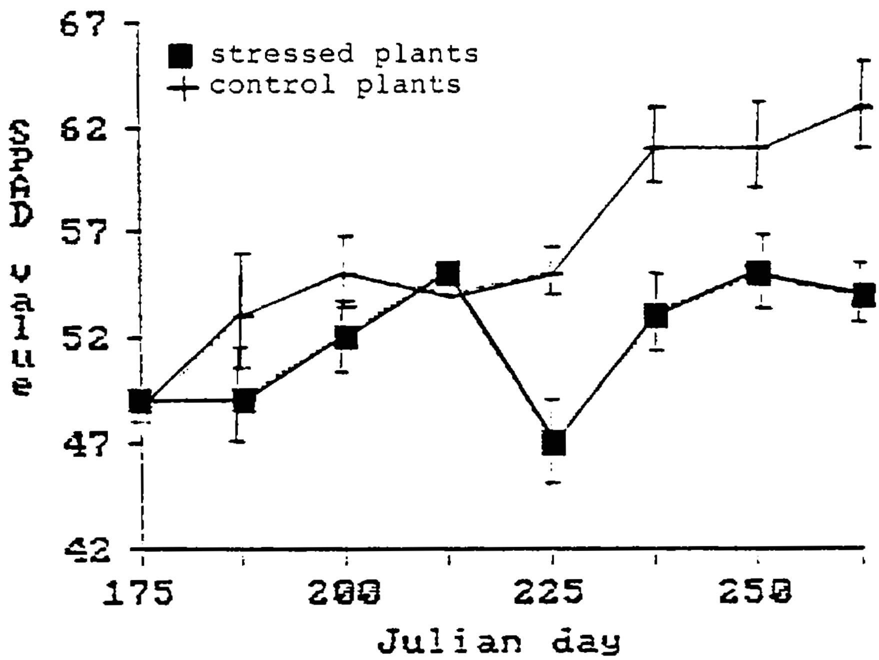

FIG. 5. MEAN RELATIVE CHLOROPHYLL CONTENT (SPAD VALUE) OF THREE CONTROL PLANTS AND THREE WATER STRESSED NERIUM OLEANDER PLANTS OVER TIME. BARS INDICATE SD, N = 9.

Prosopis chilensis

The compound leaves of this deciduous tree are composed of small leaflets and have a fern like appearance. New foliage emerges in April and is immediately followed by catkin flowers. Seed pods develop shortly after flowering and persist throughout the summer.

No special selection procedures were undertaken with the exception that a group of five trees was replaced due to irrigation problems. The fine texture of foliage made it difficult to view a solid mass of leaves with the IRT. Only trees with a sufficiently dense canopy were used to obtain baseline data.

Baseline readings commenced in May, the time at which foliage was fully developed and the flowering period ended. Foliage temperature increased as air temperature and VPD increased which resulted in baselines with a positive slope (Table 12). This increase in foliage temperature was also noted by Nilsen et al. (14, 15) who postulated that sun tracking by Prosopis leaves and midday stomatal closure was responsible for this increase. Additionally, Wendt et al. (23) working with Prosopis found that transpiration does not increase proportionally with increasing VPD which supports the previous statements. The concept of the CWSI is based on an increase in $T_f - T_a$ as VPD increases and is characterized by a negative slope.[a] The positive slope of the baseline established for Prosopis indicates that this species is not suited to the use of the CWSI.

TABLE 12. BASELINE EQUATIONS FOR PROSOPIS CHILENSIS.

Month	Irrigation rate (gallons/day)		Baseline[z]	r value
May	23	y =	0.83x - 3.30	0.62
June	50	y_1 =	0.41x - 2.54	0.71
		y_2 =	0.34x - 2.78	0.57

[z]y values without subscripts were calculated using data from a group of five plants (five readings per plant). y values with subscripts were calculated using data from individual plants (10 readings per plant).

CONCLUSIONS

Results showed that the CWSI could be applied to two of the nine species of freeway landscape plants reviewed in this study. The two species, *N. oleander* and *C. pulcherrima*, were repeatedly allowed to reach a CWSI of 0.6 and remained in an aesthetically acceptable condition. Thus, 0.6 is the threshold CWSI value at which these species should be irrigated.

Two factors were essential for the CWSI to be applicable. First, plants had to have a sufficiently dense canopy so that only leaves were viewed by the IRT. Second, well watered plants needed to transpire at a maximum rate.

Problems with the study site interfered with several aspects of the study. The main problem encountered was the variability in CWSI data between plants. Factors causing the variability were irrigation problems, gopher damage, and plant disease. Rooting and other unseen biological differences between plants may have also contributed to the variability. Kramer (9) notes that individual trees within a species can exhibit large differences in growth rate and root volume due to genetic variability.

Other notable problems were wind interference with IRT measurements and the malfunction of the IRT. The Superstition freeway is an inherently windy location. IRT data taken at wind velocities greater than approximately 10 mph were highly variable. The negative influence of wind on IRT measurements has been documented by O'Toole and Hatfield (16). One of the 2 thermometers malfunctioned during August. The causal factor was believed to be related to high air temperatures (>$^{\circ}$40 C) and insolation. The malfunction could not be repaired by the manufacturer but was not present when temperatures decreased in September. Other malfunctions occurred but were repaired by the manufacturer.

RECOMMENDATIONS

The use of the CWSI to irrigate freeway landscape plants appears to be limited based on the low proportion of plants which were suited to the index. However, a possible strategy would be to use the threshold values of species which were suited to the CWSI to irrigate all freeway plants. Further research is needed to determine if this strategy is feasible. Of prime importance is the necessity to conduct future plant studies under more controlled conditions. This would minimize the problems encountered in this study.

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