

Water Relations of Hibiscus following Pruning or Chemical Growth Regulation

Susan L. Steinberg¹, Jayne M. Zajicek², and Marshall J. McFarland³
Texas A&M University, College Station, TX 77843

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Abstract. Growth of potted hibiscus (*Hibiscus rosa-sinensis* L.) was limited either by pruning or by a soil drench of uniconazole at 3.0 mg a.i. per pot. Both treatments changed the water use of hibiscus. Five days after treatment with uniconazole, plants showed reduced water use, an effect that became more pronounced with time. Water use of pruned plants was reduced immediately after pruning, but soon returned to the level of the control due to the rapid regeneration of leaf area. Pruned or chemically treated plants used 6% and 33% less water, respectively, than the control. Chemically treated plants had a smaller leaf area, and individual leaves had lower stomatal density, conductance, and transpiration rate than control plants. Under well-watered conditions, the sap flow rate in the main trunk of control or pruned plants was 120 to 160 g·h⁻¹·m⁻², nearly three times higher than the 40 to 70 g·h⁻¹·m⁻² measured in chemically treated plants. Liquid flow conductance through the main trunk or stem was slightly higher in chemically treated plants due to higher values of leaf water potential for a given sap flow rate. The capacitance per unit volume of individual leaves appeared to be lower in chemically treated than in control plants. There was also a trend toward lower water-use efficiency in uniconazole-treated plants. Chemical name used: (E)-1-(4-chlorophenyl)-4,4-dimethyl-2-(1,2,4-triazol-1-yl)-1-penten-3-ol (uniconazole).

Control of growth has long been an important factor in the management of trees and shrubs near power lines, during nursery production, and in the urban environment. Control traditionally has been accomplished by mechanical pruning, but recently the use of growth-regulating chemicals has gained acceptance (Watson, 1987). The effects of these practices on tree or shrub water use will become increasingly important as water resources become more limited or expensive.

Both pruning and chemical growth retardants can reduce water use as a result of a reduction in the leaf area. In the former, leaf area is physically removed, while in the latter, the physiology of leaf and/or shoot growth is changed (Barrett and Nell, 1981; Sachs et al., 1975; Sterrett, 1988). There are also many reports that plants treated with chemical growth retardants exhibit a reduction in water use not related to changes in leaf area (Barrett and Nell, 1981; Mishra and Pradhan, 1972; Swietlik and Miller, 1983). The available evidence suggests that the reduced water use is due to the inhibition of stomatal opening (Orton and Mansfield, 1976) or to anatomical changes in water transport or related tissues (Gao et al., 1988; Wang and Gregg, 1989).

The objective of this study was to quantify the effect of two plant growth-regulation methods, pruning and the growth-regulating chemical uniconazole, on water use of hibiscus during well-watered and dry conditions. Transpiration rates, conductance, water potential, and capacitance of individual leaves, liquid flow conductance in the main trunk or stem, and capacitance of the plant top were measured to further the understanding of how these two methods of growth regulation affect the water relations of hibiscus.

Materials and Methods

'Ross Estey' hibiscus plants were grown in 7.6-liter pots filled with fritted clay ('Absorb-N-Dry', Balcones Mineral, Flatonia, Texas) in a greenhouse [26 ± 4C, 80% ± 11% relative humidity (RH), 400-1000 μmol·s⁻¹·m⁻² photosynthetic photon flux, 12-h photoperiod] on the campus of Texas A&M Univ. during Spring 1989. Before the beginning of the experiment, three plants were destructively sampled to obtain leaf area and count and leaf and stem dry weights (see Table 1).

The treatments were pruning (PR), uniconazole (GR), and a control (CT), with five plants per treatment in a randomized complete-block design. All plants were pruned to a uniform size by removing the last two fully expanded internodes (≈10 cm) from each growing terminal 17 days before the beginning of the experiment. The experiment was initiated on 11 Apr. [calendar day number (CDN) 101] when uniconazole (Chevron Chemical, San Francisco) was applied as a drench to five plants at 3.0 mg a.i. in 400 ml water/pot; all other plants received 400 ml water/pot. Plants of PR were allowed to grow until the branches became undesirably long. On 9 May (CDN 129), ≈10 cm of new growth was removed from all actively growing terminals. This amounted to 1260 ± 149 cm² of leaf area or 10.0 ± 1.0 g dry weight removed (data are means ± 1 SD).

During the experiment, plants in each treatment were maintained well-watered unless otherwise noted and fertilized weekly with Peters Peat-lite Special (15N-16P-17K) (W.R. Grace, Foggsville, Pa.) at 400 ppm N. Plant water use was obtained by weighing (±0.1 g) the pots daily with a Mettler PM16 balance (Mettler Instrument Corp., Highstown, N.J.). The pots were covered with plastic and weighed before and after watering; thus, weight changes could be attributed solely to transpiration.

All plants were subjected to a 6-day (Drydown 1: CDN 115-120) and a 3-day (Drydown 2: CDN 144-146) dry-down period. During these periods, the initially well-watered plants were allowed to dry until leaves of CT wilted (Drydown 1: CDN 115-118; Drydown 2: CDN 144-145) and then were rewatered (Dry-

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¹Dept. of Agricultural Engineering. Current address: P.O. Box 18272, Huntsville, AL 35804.

²Dept. of Horticultural Sciences.

³Dept. of Agricultural Engineering.

Abbreviations: CDN, calendar day number; CT, control; GR, uniconazole; PR, pruning.

Table 1. Effect of GR or PR on number of leaves, leaf area, and leaf, stem, and flower dry weights of hibiscus.^z

Day	Treatment	No. leaves	Leaf area (cm ²)	Area/leaf ^y (cm ² /leaf)	Dry wt (g)		
					Leaves	Stems	Flowers
101*		104 ± 5	4600 ± 331	122 ± 23	31 ± 2	31 ± 6	
165	GR	104 ± 19	4170 ± 854	77 ± 21	44 ± 9	46 ± 11	0.1 ± 0.2
	PR ^w	157 ± 55	6940 ± 518	118 ± 15	55 ± 5	57 ± 4	0.4 ± 0.3
	Control	150 ± 35	7320 ± 1020	119 ± 20	62 ± 11	57 ± 7	9.0 ± 4.0

^zData are means ± 1 SD. Calendar day 101, n = 3; calendar day 165, n = 5.

^yArea of uppermost fully expanded leaves.

*Before initiation of the experiment.

^wOn CDN 129, 1260 ± 149 cm² of leaf area equal to 10.0 ± 1.0 g dry weight was removed from plants in the PR treatment.

down 1: CDN 118; Drydown 2: CDN 145). To further corroborate and add detail to the daily water-use measurements, a record of sap mass flow rates in the main trunk or stem was obtained for a CT and GR plant in Drydown 1 and for a CT, PR, and GR plant in Drydown 2 using 16-mm-diameter stem flow gauges (Dynamax, Houston) (Steinberg et al., 1989, 1990).

Leaf conductance and transpiration rates were measured with a LI-1600 steady-state porometer (LI-COR, Lincoln, Neb.), and leaf water potential was measured with a pressure chamber (Scholander et al., 1965). Each day of the two dry-down periods, and on select days during the rest of the experiment, measurements were made on two fully expanded, sunlit leaves per plant of three plants per treatment (n = 6) from 1300 to 1500 HR. Leaf impressions were taken of the abaxial surface of sunlit, fully expanded leaves from three plants per treatment on CDN 151, 152, and 153 from 1300 to 1500 HR; stomatal density was obtained as described by Rice et al. (1979). The chlorophyll concentration in the third fully expanded leaf from a terminal end (n = 25) was obtained on CDN 164 from chlorophyll meter readings (SPAD 501; Minolta, Osaka, Japan) correlated to extracted chlorophyll ($r^2 = 0.98$) according to Yadava (1986).

The liquid flow conductance in the main stem or trunk, the background for which is explained in Steinberg et al. (1991), was obtained from the decrease in leaf water potential with sap flow (Schultze et al., 1985). These measurements were conducted in the greenhouse under fully sunlit conditions using well-watered CT and GR plants and were repeated three times. Leaf water potential measurements were made on two sunlit, fully expanded leaves at 0600, 1030–1130, 1330–1500, 1700–1800, and 2000 HR on each test day. The accuracy of the sap flow measurements, made with stem flow gauges on the main trunk or stem, was verified by scale measurements at the times listed above. The leaf areas of the plants were obtained immediately after the test.

Water capacitance per unit volume of individual leaves and plant tops (whole plant minus roots), a criterion explained by Steinberg et al. (1991), was obtained from the linear portion of pressure-volume curves (Hunt and Nobel, 1987). The pressure-volume curves were obtained as described by Ritchie and Roden (1985). Test plants were severed from their roots under degassed, distilled water and allowed to hydrate to full turgor at least several hours before commencement of the measurements. Individual leaves were removed from the plant, weighed to the nearest 0.001 g, and immediately inserted into a pressure chamber for water-potential measurement. Plant tops were removed from the water, free-water dried from the cut stem, and weighed to the nearest 0.01 g. Leaf water-potential measurements were

made from one to three leaves removed from the plant. The leaves and plant tops were then placed on a laboratory bench (leaves, 20C; whole plants, 25–30C; 80% RH) and allowed to transpire. The weight and leaf water potential measurements were repeated at 30-min intervals at least eight to 10 times. Capacitance measurements were made on at least three leaves and plant tops from the GR and CT treatments.

Liquid flow conductance, capacitance, and stomatal density measurements were not made on PR plants, as there was no evidence to suggest that pruning changed the basic characteristics of water transport in hibiscus.

On CDN 111, two representative, single terminal stems were tagged just below the third node from the terminal end on all GR and CT plants. On that day, and once weekly thereafter, the number of growing points per plant were counted on all plants. Total leaf count above the tag on each marked stem was taken, and the length of the stem above the tag was measured.

The experiment was terminated on 14 June (CDN 165) by destructively sampling all plants for their leaf area and count and leaf, stem, and flower dry weights. Root dry weight could not be obtained because the tight root balls on all plants prevented their separation from the potting medium. Water-use efficiency was calculated as units of water used per unit of dry matter produced (Kramer, 1983). Dry matter produced consisted of the difference in beginning and ending sums of stem and leaf dry weights.

Results

Plant growth. Over the 51 days of the experiment, the leaf count remained constant and the area decreased slightly for plants in the GR treatment (Table 1). This lack of increase in leaf count or area of GR plants was due to a reduction in both leaf expansion, as evidenced by a smaller area per leaf (Table 1), and new leaf production (Table 2) when compared with CT plants. Additionally, there was some yellowing and abscission of older leaves in GR plants. Plants in the PR treatment had ≈30% of their initial leaf area removed midway through the experiment. However, the subsequent rapid branching and new leaf production (Table 2) of plants in that treatment resulted in a leaf area similar to that of plants in the CT treatment by the end of the experiment (Table 1). The final leaf count and area of CT and PR plants were almost 33% higher than at the beginning of the experiment. Leaf and stem dry weights increased in all treatments, but the gain recorded for PR and CT plants was almost twice as large as for GR plants. Flowering was delayed in GR and PR plants (Table 1).

All leaves on the GR plants had a crinkled or cupped ap-

Table 2. Effect of GR or PR on the number of growing points per plant and stem length and leaf number above the tag on marked branches of hibiscus.^z

Type of growth	CDN 111 ^y			CDN 160 ^y		
	GR	CT	PR	GR	CT	PR
Growing points (no.)	19.4 a	20.6 a	21 a	16.8 b	16.0 b	23.4 a
Stem length (cm)	2.2 a	2.5 a		2.3 b	14.8 a	
Leaf count	3.8 a	3.8 a		5.3 b	8.7 a	

^zMean separation of growth types for each day by Duncan's multiple range test ($P = 0.05$).

^yCDN 111 = initiation of experiment, CDN 160 = termination of experiment.

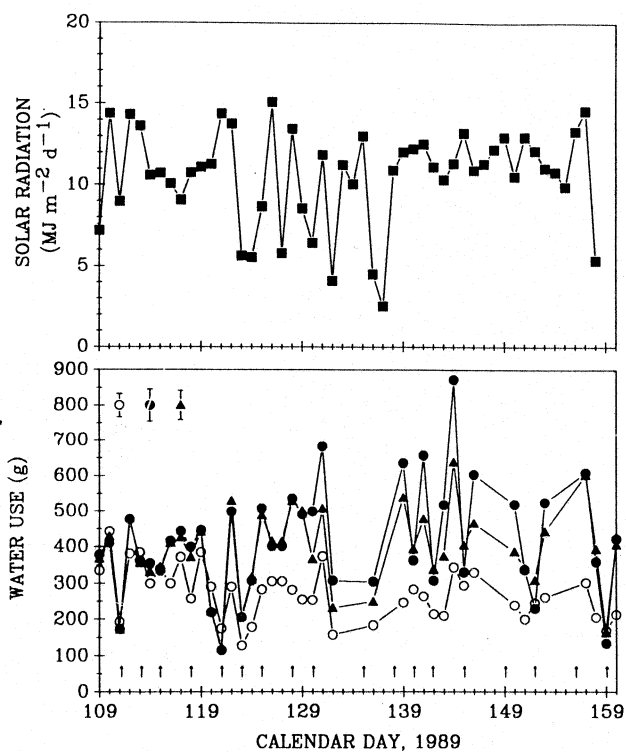


Fig. 1. (top) Total daily solar radiation at bench level in the greenhouse. (bottom) Daily water use of hibiscus plants in a control (●), uniconazole (○), and pruning (▲) treatment. Pruning was done on CDN 129. Vertical bars indicate average standard deviation ($n = 5$). Arrows denote irrigations after 1600 HR. Drydown 1 = CDN 115-120, Drydown 2 = CDN 144-146.

pearance. In addition, stomatal density on the abaxial surface of fully mature leaves was 148/mm² for GR plants and 197/mm² for CT plants. The chlorophyll concentration in leaves of GR plants was 70 $\mu\text{g}\cdot\text{cm}^{-2}$, 2.3 times that of the 30 $\mu\text{g}\cdot\text{cm}^{-2}$ in the leaves of CT or PR plants. Differences between treatments for stomatal density and chlorophyll concentration were significant ($P < 0.05$), as determined by the Student's t test for comparison of two means.

Water use. About 14 days after application of the growth regulator, daily water use of GR plants decreased below that of CT and PR plants, a difference that became more pronounced with time (Fig. 1). Even during periods of cloudy weather, when the water use of all plants was low, this difference between treatments was apparent. The daily water use of PR plants before pruning was similar to that of CT plants. After pruning (CDN 129), water use of the PR plants was significantly lower

than that of CT plants for ≈ 20 days, but thereafter it was similar for the two treatments.

Before pruning of PR plants, total water use of GR plants was 20% lower than for CT or PR plants (Table 3). After pruning of PR plants, the total water use of plants in the PR and GR treatments was significantly lower than in CT; however, PR plants still used almost twice as much water as those in the GR treatment. Total water use of GR plants was significantly lower than that of CT or PR plants for the entire 51-day experiment; plants in the GR treatment used 33% less water than CT plants. Near the end of the experiment, when daily plant water use was normalized on a leaf-area basis, CT plants lost more water per day than PR or GR plants. The range of water-use efficiency was 207-338 g of water used per gram of dry matter produced for CT plants, 214-310 for PR plants, and 262-1135 for GR plants. These data indicate a trend toward lower water-use efficiency in GR plants as compared with CT or PR plants, despite a high variation among plants in the former treatment.

Early in the experiment, when differences in water use between treatments first became apparent, all plants showed a reduction in water use as soil drying progressed during Drydown 1. Near the end of the experiment, water use of CT and PR plants decreased to the level of GR plants during Drydown 2 (Fig. 1). During Drydown 1, the mass flow rate of sap at midday remained between 40 to 70 $\text{g}\cdot\text{h}^{-1}\cdot\text{m}^{-2}$ in the GR plant (Fig. 2). Under well-watered conditions, the sap mass flow rate at midday was between 120 and 160 $\text{g}\cdot\text{h}^{-1}\cdot\text{m}^{-2}$ in the CT plant, two to three times that of the GR plant. As the CT plant dried, its sap mass flow rate decreased until it had reached the same level as the GR plant. At this time, the CT plant exhibited severe leaf wilting. The sap flow rate in the CT plant exhibited initial recovery 1 h after rewatering and had returned to near normal rates 4 to 5 h later. A similar trend was noted in Drydown 2, when sap mass flow rates were compared in plants from all three treatments (data not shown). The PR plant behaved similarly to the CT plant, but had a slightly lower sap flow rate.

Leaf water relations. Throughout the 51-day experiment, individual leaf transpiration rates and conductance of plants in the GR treatment were generally reduced below those of CT or PR plants (Fig. 3). The exceptions are noteworthy, as they represent the days during Drydown 1 and 2 when the CT and PR plants were allowed to dry until the leaves were severely wilted. In these cases, leaf transpiration and conductance remained the same in GR leaves but were greatly reduced in CT and PR

Table 3. Water use of hibiscus as affected by PR or GR.

Period	Water use ^z			Percentage of CT	
	CT	PR	GR	PR	GR
<i>Total (kg)</i>					
Whole plant					
CDN 109-128	7.4 a	7.4 a	5.9 b	100	80
CDN 129-160 ^y	9.7 a	8.5 b	5.2 c	88	54
Total (51 days)	16.9 a	15.9 a	11.2 c	94	66
<i>Average/day (g)</i>					
Per unit leaf area					
6 Days ^x	887 a	726 b	656 b	82	74

^zMean separation of water use across rows by Duncan's multiple range test ($P = 0.05$).

^yPlants in the pruning treatment were pruned on CDN 129.

^xFinal 6 days when plants were well-watered and fully sunlit. Ending values of leaf area were used for normalizing water use.

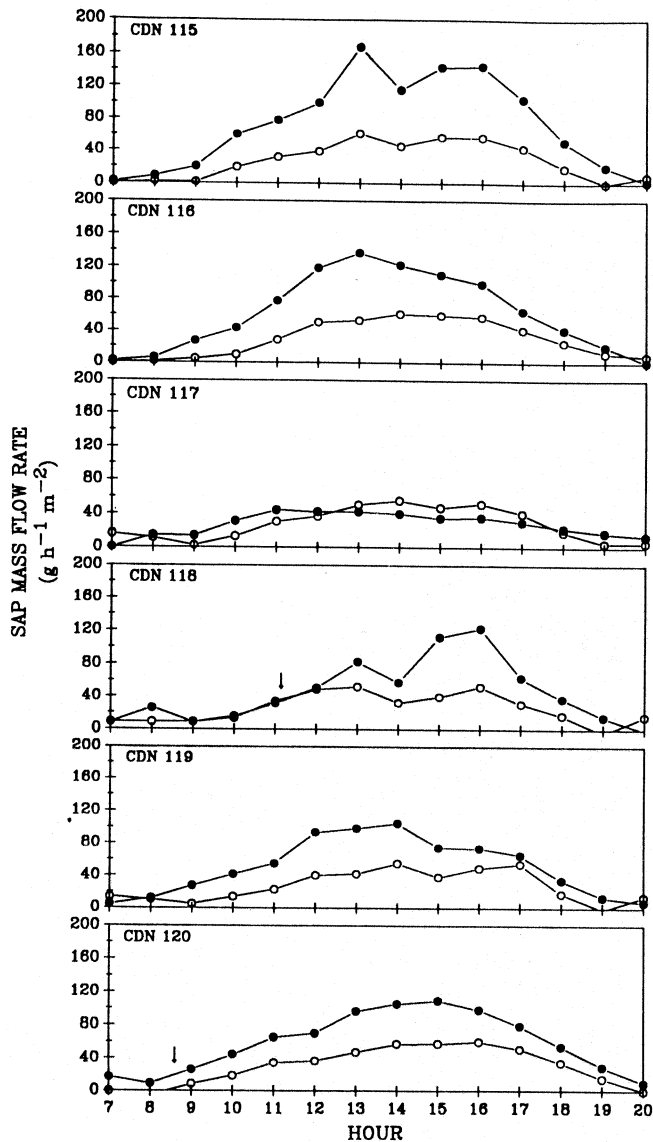


Fig. 2. Sap mass flow rates in a control (●) and uniconazole-treated (○) plant during a 6-day dry-down and rewater cycle. Plants were well-watered on CDN 115. Arrows denote irrigations.

leaves. There was no significant difference in leaf transpiration rate or conductance between the CT and PR treatments.

The water potential of leaves from the GR treatment was 0.3 to 0.5 MPa higher than that of leaves from the CT or PR treatments for most of the experiment (Fig. 4). As with leaf transpiration rates and conductance, there was little change in the leaf water potential of GR leaves during Drydown 1 and 2. This result is in contrast to that for leaf water potentials in the CT and PR treatments, which were reduced by 0.2 to 0.5 MPa. After pruning, there were several days when the leaf water potential of leaves in the PR treatment was significantly higher than that in CT.

Liquid flow conductance. The relationship of sap flow rate increase with water potential decrease for a CT and GR plant is shown in Fig. 5 for one experimental period and is summarized in Table 4. For the range of flow rates common to both treatments, leaf water potentials of the GR plants were higher than in CT plants for a given rate of sap flow. This resulted in a value of liquid flow conductance that was $\approx 2 \times 10^{-14} \text{ m} \cdot \text{s}^{-1} \cdot \text{Pa}^{-1}$ higher for plants in the GR treatment.

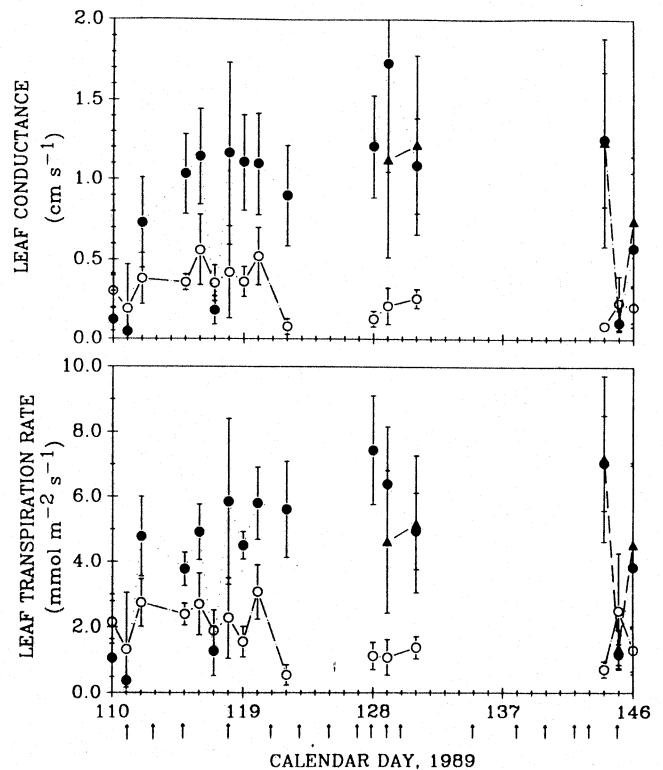


Fig. 3. Midday pattern of leaf conductance (top) and transpiration rates (bottom) for hibiscus plants in the control (●), uniconazole (○), and pruning (▲) treatments. Symbols represent the means from three or more plants and six or more measurements per treatment ± 1 SD. Data were collected between 1300 and 1530 HR. Arrows denote irrigations of all treatments.

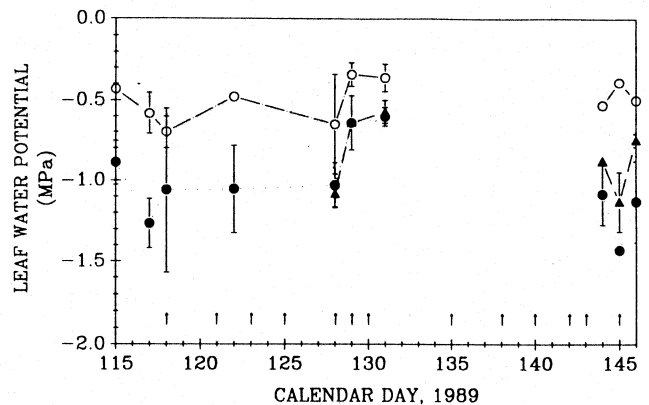


Fig. 4. Midday pattern of hibiscus leaf water potential in response to pruning or growth regulator treatment. Control (●), uniconazole (○), pruning (▲). Arrows denote irrigations of all treatments. Symbols represent means of three leaves on three plants per treatment ± 1 SD. Data were collected between 1300 and 1530 HR.

Capacitance. The capacitance of individual leaves and plant tops was similar for the CT and GR treatments, with leaves having a value an order of magnitude lower than plant tops (Table 4). When capacitance was normalized on a volume basis, CT leaves had a slightly higher value than GR leaves. This difference between treatments was not observed when stems and leaves were considered together as plant tops.

Discussion

Water use and water relations of hibiscus were affected differently when growth was regulated by pruning or by unicon-

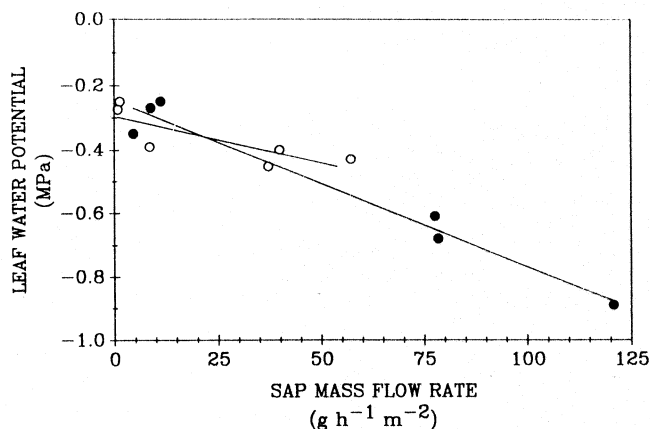


Fig. 5. Leaf water potential vs. sap mass flow rate relation for a control (●) and uniconazole-treated (○) hibiscus. Measurements were repeated three times with similar results. One data set is shown.

Table 4. Liquid flow conductance and capacitance of hibiscus as affected by GR.^z

Criterion	CT	GR
Liquid flow conductance ($\times 10^{-14} \text{ m}\cdot\text{s}^{-1}\cdot\text{Pa}^{-1}$)	5.42 ± 0.30	7.78 ± 0.25
Capacitance ($\times 10^{-6} \text{ m}^3\cdot\text{MPa}^{-1}$)		
Leaf	0.23 ± 0.1	0.23 ± 0.0
Plant top ^y	22.3 ± 3.5	16.5 ± 6.3
Capacitance per unit volume (MPa^{-1})		
Leaf	0.10 ± 0.01	0.07 ± 0.02
Plant top	0.07 ± 0.02	0.07 ± 0.02

^zData are means ± 1 SD. Conductance and capacitance ($n = 3$).

^yPlant top = whole plant minus roots.

azole. When compared with the control, total water use of GR and PR plants was reduced by 33% and 6%, respectively, during the 51-day experiment.

About 5 days after treatment with uniconazole, daily water use of plants in the GR treatment was first observed to be below that of the other two treatments, and it remained so for the duration of the experiment. In the case of PR plants, the greatest reduction in water use came immediately after pruning, as would be expected. Within 20 days, daily water use per plant in the PR and CT treatments was again similar, due to rapid regeneration of leaf area by PR plants. At the termination of the experiment, the leaf areas of PR and CT plants were equal, despite the pruning.

In contrast to PR and CT plants, which had at least a 50% increase in leaf area, the number and area of leaves of GR plants did not increase after application of uniconazole. Growth measurements showed this lack of change was due to reduced new leaf production and leaf expansion rates, an observation documented previously for hibiscus (Wang and Gregg, 1989). There was also a small amount of abscission of older leaves of GR plants. In addition, leaves of GR plants had a higher chlorophyll concentration than CT plants. There are other reports showing that uniconazole-treated plants had a higher chlorophyll concentration (Wang and Gregg, 1989) or a larger chloroplast size (Gao et al., 1988) than controls.

When normalized on a leaf-area basis, water use of PR plants was lower than that of CT plants, despite rapid regrowth after pruning. The removal of leaf area stimulated production of new

leaves. In many species, young, growing leaves have lower transpiration rates than fully mature leaves (Field, 1987), and the presence of many young leaves in PR plants may have contributed to the lower water use per unit leaf area. Water use per unit leaf area of GR plants was also significantly lower than that of CT plants, indicating that factors other than total leaf area per plant affected their water use.

Lower leaf conductance and transpiration rates in GR plants show that uniconazole had a direct effect on the water relations of hibiscus. The lower stomatal density found in GR leaves may have contributed to the change in leaf conductance. Although Gao et al. (1988) found that uniconazole increased stomatal density in wheat leaves, they noted that other factors could have produced the lower transpiration rates commonly observed in treated plants. After treatment with chlormequat or daminozide, reduced water use in tomato was attributed to both increased stomatal resistance (Barrett and Nell, 1981; Mishra and Pradhan, 1972) and differences in morphological development (Barrett and Nell, 1981). Lower leaf conductance in bean was attributed to the higher values of abscisic acid measured in plants treated with triadimefon (Asare-Boamah et al., 1986). Uniconazole was found to increase epicuticular wax in wheat, thus offering an additional mechanism for transpiration reduction (Gao et al., 1988).

The reduction in water use of GR plants appeared to be accompanied by a downward trend in water-use efficiency. Decreased water-use efficiency was also found in *Ligustrum* treated with uniconazole (Steinberg et al., 1991). Orton and Mansfield (1976) found that daminozide inhibited stomatal opening in *Commelina communis* and *Xanthium strumarium* by causing an increase in the internal concentration of CO_2 via changes in metabolism. They suggested this type of inhibition of stomatal opening would not increase water-use efficiency, but more likely would reduce it.

We found that the leaf water potential of GR plants was also consistently higher than in that of either PR or CT plants. Vaigrow-Wolff and Warmund (1987) reported similar findings for forsythia treated with uniconazole, although, in that study, transpiration rates were unaffected. For a short time and immediately after pruning, the leaf water potential of PR plants was also higher than that of CT plants. Unlike GR plants, PR plants had transpiration rates similar to those of CT plants. The increase in leaf water potential of PR plants after pruning may be the result of an increased root : shoot ratio (Blake and Tschaplinski, 1986). It is likely that lower water use by GR plants would slow depletion of the moisture in the potting medium and reduce the likelihood of transient water stress causing lower leaf water potentials between irrigations.

When the plants were allowed to dry down and were then rewatered, the leaf transpiration rates, leaf conductance, and sap mass flow rate in GR plants remained at a steady value throughout the cycle. In the CT and PR treatments, these factors were greatly reduced as the drying progressed. Plants in these two treatments were using more water than those in the GR treatment and, thus, were exhausting the reservoir of water in the potting medium at a faster rate. Swietlik and Miller (1983) also reported no reduction in transpiration of apple seedlings treated with the growth regulator paclobutrazol when water stress was induced by polyethylene glycol.

An examination of the leaf water potential-sap mass flow rate relationship showed that in the range of sap mass flow rates common to both the GR and CT treatments ($0\text{--}60 \text{ g}\cdot\text{h}^{-1}\cdot\text{m}^{-2}$), leaf water potentials were higher for a given flow rate in the

GR treatment. Thus, the liquid flow conductance in the main trunk or stem of GR plants was slightly higher than in CT plants. The leaf water potential/flow relationship has been used as an indicator of plant stress (Elfving et al., 1972), with a decrease in the liquid flow conductance attributed to water stress or temperature variations. Elfving et al. (1972) have postulated that when the transpiration flux is low, changing resistances within the plant may have a minimal effect on leaf water potential. Many researchers have found an increased root : shoot ratio in plants treated with growth retardants (Biasi et al., 1989; Fletcher and Nath, 1984; Swietlik and Miller, 1983), and Biasi et al. (1989) suggest that higher root : shoot ratios would improve water delivery potential to the shoot.

In the present study, the capacitance per unit volume of hibiscus plant tops was slightly lower than for individual leaves, but both were similar to values given for apple (Landsberg et al., 1976). While there was no difference between treatments in the capacitance of leaves or plant tops, the capacitance per unit volume of GR leaves was lower than for CT leaves. The capacitance per unit volume depends on both the bulk elastic modulus and the osmotic potential (Hunt and Nobel, 1987). Changes in cell size and cell wall thickness, both documented to occur in plants treated with growth regulators (Gao et al., 1988; Wang and Gregg, 1989), could affect the bulk elastic modulus (Nobel, 1983).

These changes in the liquid flow conductance and tissue capacitance of hibiscus suggest that uniconazole altered the pathway for water movement in some way. Wang and Gregg (1989) showed that increasing rates of uniconazole reduced the production of xylem tissue and the diameter of individual vessel elements in hibiscus. Such changes in the xylem tissue could contribute to lower transpiration rates. Stomatal density on a leaf may continue to change until the leaf is nearly mature (Field, 1987). The lower stomatal density in GR leaves could be part of the plant's response to lower transpiration requirements or a mechanism to protect the plant from water deficits that could result from a reduced capability for water transport. If a reduction in the capability for water transport were offset by a similar change in the leaf area, the small increase in liquid flow conductance reported in our study could result. The capacity for water conduction depends on both the area of the conducting system and the transpiring surface (Larcher, 1983). Yet, the question remains whether changes in stomatal density and xylem morphology are directly caused by the growth regulator or result from decreased water transport requirements.

We have shown that both pruning and uniconazole have the potential to reduce the water use of hibiscus. However, the water use of pruned plants quickly returned to the level of the control due to rapid regrowth, while the reduction in water use by GR plants was maintained over the duration of the experiment. The reduced water use of GR plants may confer a greater ability to withstand periods of drought in a landscape setting by slowing depletion of soil moisture. These plants may also require fewer water resources than pruned plants during nursery production. The leaf crinkling, or cupping, observed in GR plants has been previously documented for high application rates of uniconazole on hibiscus (Wang and Gregg, 1989). Further

research is needed to determine if lower rates of uniconazole can provide similar changes in hibiscus water relations without adversely affecting leaf and flower development.

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