Promotion of Leaf Abscission in Intact Ficus benjamina by Exposure to Water Stress

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Abstract. Leaf abscission was promoted in Ficus benjamina L. (weeping fig) by withholding water from plants growing in sand and by the addition of polyethylene glycol 6000 to hydroponically-grown plants. Leaf shedding occurred when plant water potential decreased below about −6 bar in sand and below −3.5 bar in water culture. Shoot and root environmental conditions modified the water status of plants. Leaf shedding can be dramatically reduced by manipulating environmental conditions to maximize water absorption and minimize transpiration.

We thank Dr. Charles Conover, Agricultural Research Center, Apopka, Florida for the benefit of his special expertise in foliage plant acclimatization.

Materials and Methods

Experiments were conducted using water and sand culture systems, and rooted cuttings (15-20 cm) from a single clone.

Water culture

Four circulating water culture systems were developed to quantify relationships between measurable root water stress and leaf abscission. Each used twenty 0.94 liter containers. Thirty liters of Arnon and Hoagland (19) nutrient solution were aerated and continuously circulated in each system.

Water stress was imposed by adding polyethylene glycol (PEG) MW 6000 to the nutrient solutions. Solution osmotic potentials were calculated using a modification of the Van’t Hoff equation (33) and a table of osmotic potential values for PEG at various concentrations and solution temperatures (B. L. Michel and M. Kaufmann, Department of Botany, University of Georgia).

Experiment I. This was conducted in an unshaded greenhouse with light intensities of about 35-50 klx and air temperature of 24-28°C. Four weeks after rooted cuttings were transplanted to the nutrient solution, PEG was added at rates of 0, 50, 100 or 300 g/kg of water. Respectively, solution osmotic potentials were calculated to be −0.91, −1.52, −2.38, and −10.75 bar at 39°C. Solutions were circulated for 24 hr, each system was drained and flushed with 15 min with tap water, then refilled with nutrient solution alone. Leaf shedding was monitored for 13 days after the beginning of osmotic stress.

Experiment II. The first experiment was repeated to examine a more uniformly divided range of osmotic potentials. PEG at rates of 0, 150, 250, or 300 g/kg of water was added to one of each of the 4 systems to obtain solution osmotic potentials of −0.89, −5.14, −8.99 and −12.03 bar at 21°C, respectively. Solution handling and leaf drop monitoring were conducted as described above.

Experiment III. Water culture systems were placed in a controlled environment to provide more precise regulation of environmental conditions.

One-half strength nutrient solution was used, relative humidity (RH) was about 65%, temperature was 25.5±0.5°C and light intensity at plant apex was 2.16 klx (supplied with G.E. cool white fluorescent tubes) with 14 hr light and 10 hr dark. After 5 weeks RH was reduced to 33%-±5% and 0, 150, 250, or 300 g PEG/kg water was added to the culture systems to produce osmotic potentials of −0.51, −3.95, −8.41 and −11.55 bar, respectively at 24°C. After 48 hr each system was drained, flushed with tap water and refilled with one-half strength nutrient solution, and the RH increased to about 65%.

Four groups of 5 plants in each system were randomly selected and 3 groups were used to measure diffusive resistance and plant water potential prior to the addition of PEG, 48 hr later (before solutions containing PEG were drained) and 96 hr after PEG was first added. One measurement of plant water potential and diffusive resistance was made for each plant within every group using a PMS pressure chamber and LiCor LI-65 autoporometer. Excised shoots 12 cm long were used for plant water potential measurements.

The fourth group of 5 plants was monitored for leaf abscission for 2 wk following the onset of the stress treatment.

Sand culture

Sand culture was used to examine the relationship between leaf abscission and water stress imposed by withholding water.

Rooted cuttings (15-20 cm) were potted in 3.8 liters (1 gal) polyethylene pots containing washed, coarse, builders sand. Plants were placed in an unshaded greenhouse at a minimum night temperature of 20°C. Full strength nutrient solution (19) was supplied through an automatic irrigation system.

Experiment I. One hundred rooted cuttings (15-20 cm) were grown for 7 weeks under moist conditions, irrigated to contain capacity, randomly separated into 10 treatment groups of 10 plants per group and the weight of each plant determined. Each treatment group was divided into 2 sampling groups of 5 plants each, one for monitoring leaf abscission and one for...
measurement of diffusive resistance and plant water potential. Nine of the 10 treatments were shifted to a controlled environment in which light intensity was 3.42 klx at plant apex (supplied with G.E. cool white fluorescent tubes for 24 hr/day), temperature was 21.5°±1.5°C, and RH 21±9%. Plants were not watered.

Treatment group I was the control. One-half the plants were used to measure diffusive resistance and plant water potential when the other 9 treatments were shifted to the controlled environment. The other 5 plants remained in the greenhouse.

On days 1-7, 9, and 12 a treatment group was removed from the controlled environment and each plant was weighed. Five of the 10 plants were returned to the greenhouse, irrigated immediately and monitored for leaf abscission for a minimum of 2 weeks. Diffusive resistance and plant water potential measurements were taken on the remaining 5 plants prior to removal from the controlled environment.

Experiment II. A second experiment was conducted to determine whether different degrees of water stress during growth influenced leaf abscission when plants were exposed to subsequent water stress.

Three irrigation systems, equipped independently with electronic scale mechanisms for regulating frequency of irrigation, supplied water to 70 plants each. Plants were grown for 2 weeks under moist conditions, and irrigation frequencies were then adjusted to establish wet, moderate, and low moisture regimes. Plants were grown for 7½ weeks under 3 different moisture regimes, then supplied with nutrient solution excess to saturate the sand to container capacity. Each of the 3 treatment groups (wet, moderate, low) was divided into 7 subtreatments, each containing 10 plants and each subtreatment group separated into 2 sampling groups of 5 plants. One sampling group was used to monitor leaf shedding while the other was used to collect data on diffusive resistance and plant water potential. Six of the 7 subtreatment groups in each treatment were transferred to a controlled environment with conditions as described in Experiment I.

One subtreatment group (10 plants) from each of the 3 treatments was removed from the controlled environment on days 2, 4, 6, 8, 12, or 16. Plants were weighed, one sampling group (5 plants) from each subtreatment was returned to the greenhouse, irrigated and monitored for leaf drop, and the other sampling group from each subtreatment was used to measure diffusive resistance and plant water potential. Plants returned to the greenhouse were irrigated frequently and monitored for a minimum of 2 weeks.

Results and Discussion

Water culture

Experiment I. During the 14 days following PEG treatment, only plants exposed to the highest concentration of PEG (300 g/kg) shed leaves. An average of 5.5% of the leaves abscised. Leaves which abscised were mostly the oldest but a few young, unexpanded terminal leaves were also shed. This percentage is low compared to other reports (11, 12, 34). However, considering the small size of these plants this percent may be quite meaningful, since greater numbers of both chronologically and physiologically “older” leaves are found on larger plants, and under most conditions it is primarily the older leaves that abscise (10, 34).

Experiment II. When PEG was added to the nutrient solutions the light intensity was much lower and conditions were not as conducive to rapid transpiration as in Experiment I. Only plants exposed to the greatest amount of stress wilted, but no leaf abscission occurred during the first 14 days. The lack of abscission may have been a result of the low light intensity and humidity not favoring high transpiration rates.

Experiment III. Plant water potentials (Fig. 1) and diffusive resistances (Fig. 2) in treated plants followed a similar pattern, increasing to a maximum 48 hr after exposure to the osmoticum, then returning to normal after removal of PEG. After 96 hr neither water potential nor diffusive resistance values returned to pre-stress levels. These data support previous studies (36, 37, 40) showing that plant water potentials respond to changes of water potential of the root medium. The cause of failure of water potential levels to return to pre-stress levels 48 hr after removal of PEG was not determined, although the residual aluminum and iron levels contained in PEG were below levels considered to be phytotoxic. Abscisic acid (ABA) may have been a factor, since increases in levels of ABA associated with water deficits have been documented in numerous studies (2, 6, 13, 18, 20, 41, 42, 43), and ABA induces changes in permeability of cell membranes to water (17).

![Fig. 1. Changes in shoot water potential of F. benjamina exposed to water stress by addition of 0, 150, 250 or 300 g PEG 6000 per kg water to the water culture system. Stress was imposed at hour 0 and relieved after 48 hr by removal of PEG.](image1)

![Fig. 2. Changes in diffusive resistance of F. benjamina exposed to water stress by addition of 0, 150, 250 or 300 g PEG 6000 per kg water to the water culture system. Stress was imposed at hour 0 and relieved after 48 hr by removal of PEG.](image2)
Fig. 3. Changes in shoot water potential of *F. benjamina* with time resulting from the imposition of water stress by withholding water from plants growing in sand \( r = 0.9749, \text{PWP}_{\text{L}} = 1.58 + 2.16 \text{(time)} - 0.35 \text{(time}^2\text{)} + 0.02 \text{(time}^3\text{)}, \text{PR} > F: 0.0101 \).

At 48 hr after removal of PEG, diffusive resistance values remained about 8-10 times greater than those recorded before stress was imposed. This may be a result of mechanisms controlling stomatal aperture, since guard cell activity is related to internal water status of plant tissue (6, 25, 26, 35). Water stress brings about stomatal closure and stomatal reopening when the stress is removed. Reopening usually occurs after a lag period which is proportional to the intensity of the prior water deficit (4, 14). This after effect has been linked to increases in ABA content within leaf tissue (28, 32). Such a residual effect was observed in this experiment.

Leaf abscission occurred on all plants treated with PEG. In systems 2, 3, and 4 about 39, 23, and 42%, respectively, of the foliage abscised but there was no significant difference among these 3 groups. Most leaf loss occurred within 7 days after exposure to the osmoticum and the older leaves made up most of this loss.

These results support those of Gates (16) and McMichael et al. (29, 30) and indicate that water stress can promote leaf abscission in *Ficus benjamina*.

Fig. 4. Changes in diffusive resistance to *F. benjamina* with time resulting from the imposition of water stress by withholding water from plants growing in sand \( r = 0.8272, \text{DR}_{\text{NT}} = 0.13 + 16.41 \text{(time)} - 3.85 \text{(time}^2\text{)} + 0.29 \text{(time}^3\text{)}, \text{PR} > F: 0.0025 \).

Fig. 5. Percent leaf abscission among *F. benjamina* plants exposed to water stress by withholding water from plants growing in sand.

Fig. 6. Changes in shoot water potentials resulting from withholding water among treatment groups exposed to different watering regimes. [low moisture regime, \( r = 0.9940, \text{PWP}_{L} = 0.63 + 0.45 \text{(time)} - 0.09 \text{(time}^2\text{)} + 0.01 \text{(time}^3\text{)}]; \text{moderate moisture regime, } r = 0.9971, \text{PWP}_{M} = 0.42 + 0.65 \text{(time)} - 0.13 \text{(time}^2\text{)} + 0.01 \text{(time}^3\text{)}; \text{wet moisture regime, } r = 0.9978, \text{PWP}_{W} = 0.45 + 0.61 \text{(time)} - 0.13 \text{(time}^2\text{)} + 0.01 \text{(time}^3\text{)}].
increased to day 3 (Fig. 3 and 4). This activity was attributed to medium produced a water deficit. Between days 6 and 12, availability decreased, plant water potentials decreased and diffusive resistance increased. Superficial water potentials for these 3 groups were — 6.38, — 6.48, — 6.68 bar or lower would result in abscission under these conditions. Water potential measurements for these 3 groups removed on day 6 from the controlled environment. Among the 3 sub treatment groups removed on day 6, abscission was 22.3, 11.6, and 28.6% respectively, but these values were not statistically significant. As an apparent consequence of plant size and different rates of moisture loss among the 3 treatment groups, corresponding plant water potentials for these 3 sub treatment groups varied considerably. Plant water potentials for the 3 sub treatments from the wet, moderate, and low treatment groups were — 8.2, — 8.0, and — 5.7 bar respectively. Since these values were so different it was not possible to differentiate pre- and post-stress effects.

The range of water potentials at which leaf abscission was promoted (— 5.7 to — 8.2 bar) corresponds generally to those levels at which leaf abscission was observed in the sand culture experiment. These findings, as well as those of the previous experiment, concur with results of Jordan et al. (21) which indicate that leaf abscission in cotton occurred when levels of internal stress reached — 5 to — 6 bar. We suggest the physiological mechanism controlling leaf abscission in cotton and Ficus may be similar.

This experiment did not determine whether exposure to water deficits during the growing period affects leaf abscission when Ficus is exposed to subsequent severe water deficits. It does provide additional evidence supporting the hypothesis that water stress can promote leaf abscission in Ficus benjamina.

Leaf abscission was observed on plants whose water potential decreased below about — 6 bar in sand and below — 3.5 bar in water. Loss of foliage in response to water stress may be an inherent characteristic of Ficus. The plant is native to the South Pacific (9), a region in which many tropical trees undergo a loss of foliage during periods of drought (31).

Water deficits drastically reduce photosynthetic activity as a result of stomatal closure and disruption of metabolic activities due to cytoplasmic and cell membrane dehydration.

Sand culture

Experiment I. There was a strong correlation (r=0.9749) between duration of low humidity and withholding of irrigation and decreasing plant water potential values (Fig. 3).

Plant water potential decreased and diffusive resistance increased to day 3 (Fig. 3 and 4). This activity was attributed to conditions in the shoot environment, primarily low humidity. At that time water potential and diffusive resistance values leveled off until day 6, when sufficient moisture loss from the growing medium produced a water deficit. Between days 6 and 12, internal water potentials decreased and diffusive resistance again increased.

These data illustrate how conditions in both the shoot and root environments may influence the internal water status of a plant. They suggest the importance of the shoot environment and indicate that abscission might occur under conditions of extremely low humidity, rapid air movement, high temperature, and high light, and that it might be promoted with optimal moisture in the growing medium.

Data for diffusive resistance values corresponded to plant water potential data. No leaf abscission was observed for the first 7 treatment groups removed from the controlled environment on days 0-6 (Fig. 5). Treatment groups removed on days 7, 9 and 12 exhibited 4.7, 8.2 and 35.6% leaf drop, respectively. Water potential measurements for these 3 groups were — 6.38, — 7.90 and — 10.88 bar, suggesting that a water potential of about — 6 bar or lower would result in abscission under these conditions.

Sand culture II. Responses among each treatment group (wet, moderate, low) with respect to changes in plant water potentials (Fig. 6), diffusive resistances (Fig. 7), and leaf abscission were similar throughout this experiment. As soil moisture availability decreased, plant water potentials decreased and diffusive resistance values increased.

Analysis of the significant differences among the 3 treatments is difficult. Variations in soil moisture availability among the treatment groups during the growing period were associated with different growth rates. Plants with the greatest amount of available soil moisture were considerably larger than those having moderate or low soil moisture supplies. Differences in plant size altered the rate of moisture loss among each treatment group (Fig. 8); consequently, each group was exposed to different levels of water stress at similar times.

Leaf abscission was observed only in those sub treatment groups removed on day 6 from the controlled environment. Among the 3 sub treatment groups removed on day 6, abscission was 22.3, 11.6, and 28.6% respectively, but these values were not statistically significant. As an apparent consequence of plant size and different rates of moisture loss among the 3 treatment groups, corresponding plant water potentials for these 3 sub treatment groups varied considerably. Plant water potentials for the 3 sub treatments from the wet, moderate, and low treatment groups were — 8.2, — 8.0, and — 5.7 bar respectively. Since these values were so different it was not possible to differentiate pre- and post-stress effects.

The range of water potentials at which leaf abscission was promoted (— 5.7 to — 8.2 bar) corresponds generally to those levels at which leaf abscission was observed in the sand culture experiment. These findings, as well as those of the previous experiment, concur with results of Jordan et al. (21) which indicate that leaf abscission in cotton occurred when levels of internal stress reached — 5 to — 6 bar. We suggest the physiological mechanism controlling leaf abscission in cotton and Ficus may be similar.
(38). Kriedemann and Smart (26) reported a linear relationship between decreasing photosynthesis and leaf water potential below ~5 bar. Reduced photosynthesis, which influences carbohydrate supply can check growth (22). Growth of Pinus strobus and P. taeda decreased at soil water potentials of about ~1 bar and lower (23). Older and very young, unexpanded leaves, which require an external energy source, were shed and the most photosynthetically active leaves were retained. Such response would enhance chances of survival of the plant.

Environmental conditions in the shoot and root environment influenced water status of plants. Plant water potentials were reduced under conditions which increased transpirational moisture loss, by conditions limiting water absorption. If water deficits are to be avoided in order to minimize leaf abscission, care must be exercised to minimize water loss and maximize uptake. The following cultural practices may help maximize water absorption and reduce moisture loss: F. benjamina should be maintained in a high humid environment to avoid rapid transpiration. The warmer the air temperature and the higher the light intensity, the greater should be the RH. Cold soil temperatures combined with warm air temperatures should be avoided. Conditions in the growing medium should maximize water absorption. The growing medium should have a high water holding capacity yet contain sufficient air spaces to avoid anerobic conditions. Growing medium compaction resulting from expansive root growth which reduces water-holding capacity should be avoided and compensated for by selection of appropriate size containers. Fertilizer content of the growing medium should be lowered by reduced applications or by leaching when nutrient uptake will be reduced. This should be done toward the end of a production period, prior to shipping of plants and/or transfer to an indoor environment because as the plants are moved to a lower light intensity, growth slows and nutrient uptake decreases. Large amounts of fertilizer should be avoided. Finally, an adequate supply of soil moisture should always be maintained.

The relationships between decreased plant water potentials and increased diffusive resistance values and the onset of leaf abscission might provide a method for monitoring plants to avoid leaf shedding. Monitoring plant water potential would give an indication of the internal plant water status. Should plant water potential values decrease, environmental conditions in the root and/or the shoot zone should be modified to reduce the internal stress which might promote leaf abscission. Monitoring diffusive resistance might also be used to monitor the lack of stress but the influences of light upon guard cell activity would also have to be considered.

Varying the amount of water stress to which plants were exposed during production did not influence the onset of leaf abscission when plants were subjected to severe water deficits. There was a marked reduction in growth of plants associated with plant deficits during production. Since growth rates were dramatically reduced and leaf abscission was not appreciably reduced, preconditioning by exposing plants to water stress does not seem to be a worthwhile procedure.

**Literature Cited**


Alterations in Abscisic Acid Content of *Ficus benjamina* Leaves Resulting from Exposure to Water Stress and its Relationship to Leaf Abscission

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Abstract. Relationships were examined among water deficits, ABA content of leaf tissue, and leaf abscission in intact *Ficus benjamina* L. (weeping fig). Water deficits were imposed by withholding water from plants growing in sand and by raising the osmotic potential of water culture solutions through the addition of PEG 6000. Unconjugated ABA was quantitatively analyzed using gas chromatography. A strong inverse linear correlation existed between ABA content of leaves and plant water potential. No relationships between ABA content and leaf abscission were observed. ABA content in leaves collected from plants growing in a greenhouse, having a plant water potential of —0.5 bar, was about 75 fold greater than the ABA content of leaves collected from plants maintained in a controlled environment room, having plant water potentials of —8.0 bar. Results indicate that ABA does not independently regulate leaf abscission in *Ficus benjamina*.

Leaf abscission has been a serious problem associated with the handling and maintenance of the tropical foliage plant *Ficus benjamina*. Investigations by Conover and Poole have indicated that the availability of light in the production area and indoor environment can influence leaf shedding (6, 7, 8, 9). More recently, we have demonstrated that water stress can promote leaf shedding in this tropical plant (31). Regardless of which environmental factor might be responsible for triggering leaf abscission in *Ficus benjamina* and other plants, the nature of the physiological mechanisms which regulate leaf abscission are not yet fully understood.

One regulatory mechanism controlling leaf abscission might be alterations in levels of ABA in leaf tissue. Some of the earliest evidence for the support of this concept arose from work by Ohkuma et al. (30) in their search for an accelerator of abscission. They reported isolating an active substance which was hereby marked "advertisement" solely to indicate this fact.

Materials and Methods

Two cultural techniques, water culture and sand culture, were utilized in this study.

Water culture. Four circulating water culture systems, designed to maintain 20 plants per system, were constructed and installed in controlled environment room. Eighty 15-20 cm cuttings, rooted in sand, were transferred to the water culture systems and maintained on half-strength Arnon and Hoagland (19) nutrient solution for 5 weeks under 2160 lux at plant tops (supplied with G.E. Cool White fluorescent tubes for 14 hr/24 hr at a temperature of 25.5°C (± 0.5°C) and a relative humidity of 65 ±5%.

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