METHODS FOR MEASURING WATER STATUS AND REDUCING TRANSPIRATIONAL WATER LOSS IN TREES[1]

by Bruce R. Roberts

Although water is often considered an inexhaustible natural resource in this country, there is mounting evidence to suggest that this is not the case (44). Almost 60% of the aquifer that supplies water to the midwestern U.S. has disappeared over the past 60 years, and falling water tables have resulted in crisis situations in the Southwest, the Northeast, and in southern California (1). Those involved in the green industries, and particularly those of us involved in growing and maintaining woody vegetation in urban and suburban environments, should begin thinking about new and innovative ways to conserve water. In the near future it seems inevitable that large water users will have to appear before a local water control board (or its equivalent) to justify their allotment of water. Obviously, users who can document their water requirements will have a better chance of being allotted adequate supplies of this critical resource.

One of the problems encountered in accurately assessing the water status of individual trees is the oftentimes poor correlation that exists between soil moisture and plant growth (50). Because the absorption of water by tree roots is not an independent process but is largely controlled by the rate at which water is lost in transpiration, moisture deficits can develop in trees even in moist soils. In addition, trees planted in wet sites (a condition which occurs frequently in aboveground containers and in other restricted-space planting sites) may experience water deficits because of saturated soil conditions which result in poor aeration and subsequent reductions in water absorption (21). Thus, soil moisture status is *not* always a good indicator of plant water status, and the only reliable measurement of the latter involves estimates made on the plants themselves (22).

If, as stated previously, large water users may be required to justify their need for water in the future, then the arborist/urban forester must be in a position to document the moisture requirements for urban trees. As part of this documentation process, and as part of making intelligent management decisions regarding the prudent use of limited water resources, it is important to understand the moisture requirements of urban trees and to have a working knowledge of the methods available for measuring the water status of woody perennial plants. This paper describes some field techniques for measuring plant water status and for reducing the transpirational water loss in urban trees.

Field Techniques for Measuring Plant Water Status

Before reviewing some of the individual methods available for measuring the water status of urban trees, it is important to emphasize that consideration must be given to sampling procedures such as the age and location of the tissue being sampled as well as the time of day sampling occurs. Substantial errors can result by comparing samples of different ages from different exposures, or by comparing samples collected at different times of day (22). Precaution must also be taken to insure that samples are handled properly and measured as quickly as possible after collection.

Measurement of relative water content. Water content, the amount of water in a plant, is probably the most common method used to determine plant water status (42). However, expressing the amount of water in plant tissue by itself is impractical because it cannot be compared with

1. Presented at the annual conference of the International Society of Arboriculture in San Antonio, TX, in August 1986.

measurements made from other plants or from other tissue on the same plant (3). Consequently, a common frame of reference is needed and turgid weight (the maximum amount of water the tissue will hold) is frequently used as this reference point (4, 16). Relative water content (RWC) is readily determined by obtaining the fresh weight or field weight of plant tissue (either leaf discs or entire leaves) and then measuring its turgid weight after equilibration (floating tissue on water or placing it on water-saturated polyurethane foam in a moist chamber) for a prescribed period of time. The same tissue is oven-dried to a constant weight and RWC calculated from the following equation:

$$\text{RWC} = \frac{\text{Fresh weight} - \text{Oven-dry weight}}{\text{Turgid weight} - \text{Oven-dry weight}} \times 100$$

If the assumption is made that negligible changes occur in turgid weight and dry weight between sampling periods, it may be possible to eliminate the time-consuming process of oven drying the tissue and to estimate RWC directly from the ratio of fresh weight to turgid weight (22).

Although there may be some difficulty encountered in achieving accurate turgid weight measurements, RWC is probably one of the most widely accepted expressions of plant water status in use today (36, 40). It is a simple determination to make, it can be used readily in the field, and it indicates water content relative to the maximum water-holding capacity of the tissue (100% RWC = zero plant water deficit).

Measurement of water potential by thermocouple psychrometry. Water potential describes the physiochemical activity of water in a plant system relative to water at some standard reference state and, as such, is probably the single best measure of plant water status currently available (7, 23, 25). In recent years, psychrometers have come into general use and commercial units are available for measuring water potential in the field (49). Briefly, measurements are obtained by recording the equilibrium relative humidity in a small, sealed chamber containing the sample and reference thermocouple. The newer psychrometer units employ thermocouple transducers which eliminate the need for precise temperature control and make the instruments more practical for use in the field.

There are several possible sources of error associated with the psychrometric method (42). Of particular importance, for measurements involving trees, would be the resistance to water vapor transport from heavily cutinized tree leaves (8), the heat of respiration generated by the bulky nature of most woody plant leaf tissue (2), and the lengthy time required for equilibration (38). However, these disadvantages can be largely overcome by modifications of existing technology (2, 8), and the fact remains that thermocouple psychrometry is considered to be the most accurate method for measuring plant water potential. It should also be mentioned that modifications of existing equipment have been made to permit water potential measurements to be made on tree trunks as well as on intact leaves and roots (6, 9, 22, 28).

Measurement of water potential by pressure equilibration. An excellent method for measuring water potential of woody plants, particularly in the field, is the pressure equilibration or pressure bomb technique. This procedure, first introduced by Scholander et al. (34), has enjoyed wide use in recent years. In actual operation, a single leaf or leafy shoot is sealed in a pressure chamber with the cut end of the sample protruding outside the chamber and exposed to atmospheric pressure. Pressure is applied to the chamber from a tank of compressed gas until xylem sap appears at the cut end of the sample. The amount of pressure required to force water out of the leaf cells into the xylem and up to the cut surface is regarded as approximately equal to the water potential originally existing in the cells. The apparatus has been adapted for use in the field (47), and has been shown to closely approximate measurements made with thermocouple psychrometers over a wide range of water potential values (30).

Most of the errors associated with use of the pressure equilibration technique are procedural in nature and include: seal damage to vascular tissue (35), rate of pressurization (30), relative amounts of tissue inside vs. outside the chamber (19), elapsed time following excision of the sample (5), and loss of moisture from the sample during sealing and pressurization (31). Although these potential sources of error can be significant on occasion, the pressure equilibration method still constitutes the simplest and most rapid technique available for estimating leaf water potential (42). If consistent sampling and measuring procedures are followed, this method should give reliable information on the water status of urban trees.

The three techniques described above represent procedures that have enjoyed wide acceptance by plantsmen over the years. This does not mean that there are not other methods available for measuring plant water status (14, 20, 37, 39, 48), but most of these techniques have disadvantages which limit their usefulness for woody plants in the field. In addition to the aforementioned procedures, there are a number of more recent innovations for measuring or estimating plant water status which may have applicability for use with urban trees. These procedures are described briefly below.

Plant water status as measured by changes in stem diameter (Ceres device). This procedure, developed by scientists at Battelle Memorial Institute (personal communication), is based on the physiological principle that as water moves out of living cells into the transpiration stream, it causes the cells to shrink. This shrinkage in cell size causes a small but detectable decrease in stem diameter. The Ceres device measures these changes by means of strain gauges and a pressure transducer. As stress increases within the strain gauges, electrical resistance also increases, yielding data on sensitive alterations in stem diameter. This particular instrument is connected to a microprocessor and a recording system, and is portable enough for use in the field. The Battelle aparatus is not unlike instrumentation described earlier by Namken et al. (27) for use on cotton plants in the field.

The concept behind the Ceres device and similar measuring systems is based on the cohesion theory (13), wherein water molecules confined in small capillaries can withstand very low negative pressure potentials because of the strong attractive forces that exist between water molecules. Thus, microcontraction of the water conducting elements occurs when moisture in the plant is subjected to a water potential gradient, the amount of the contraction being proportional to the degree of stress. Although the concepts are not new, the technology associated with measuring microchanges in stem diameter have advanced in recent years. However, more information is needed on the relationship between stem contraction and leaf water potential before this procedure can be put to practical use in the field.

Plant water status as reflected by changes in leaf temperature. It has been suggested that relative differences in moisture stress between plants can be estimated by measuring leaf temperature (43). This concept can be particularly useful in establishing irrigation regimes for landscape plants in urban and suburban environments (32). Energy balance considerations have shown that if transpiration decreases, assuming radiation flux and wind structure remain relatively constant, the decrease in latent heat exchange between the plant and the atmosphere will result in an increase in leaf temperature. Thus, a sensitive measure of temperature differences between plants (preferably between plants known to be well watered and others) may provide an indication of transpirational differences and, hence, differences in plant water status (10). This principle has been employed by Sachs et al. (32) and Menoux-Boyer et al. (26) to measure the relative water status of plants in the field.

One of the problems associated with using leaf temperature to estimate plant water status is the difficulty in obtaining uniform samples. It stands to reason that a leaf perpendicular to incident solar radiation will be at a substantially higher temperature than one with a large angle of incidence or one that is completely shaded. As a result of this sampling difficulty, investigators in the past have used the difference between leaf and air temperature to predict relative water stress (17). However, micrometeorological studies have shown that leaf and air temperatures are not always correlated. Leaves are often warmer than the surrounding air during the day and cooler at night (43). Recent developments in infrared thermometry have largely surmounted many of these sampling problems, and leaf temperature measurements may ultimately become a very useful technique for estimating the relative water status of urban trees.

Plant water status as reflected by computer

modeling of transpiration. In this age of computer technology it seems only fitting that one of the available techniques for estimating plant water status involves computer modeling of moisture loss from individual tree crowns. A study reported by Vrecenak and Herrington (45) using two species of maple suggests that this technique may have practical application for problems associated with tree maintenance, especially in formulating irrigation strategies for landscape plantings. Their model computes transpirational water loss (E) using the following equation:

$$E = \frac{R_{net} - H - C}{\lambda}$$

Where R_{net} = the net flux density of incident radiation; H = convectional energy loss; C = conductional energy loss; and λ = the latent heat of vaporization of water. The authors suggest that the model functions best when the modeled trees are under relatively low levels of soil moisture stress.

In California, estimates of water use based on evapotranspiration data have been used successfully for irrigation management (48). The basic concept of this methodology is that water consumption can be estimated using a regional reference value for evapotranspiration (ET_O) and a multiplication factor for efficiency (K_C) that adjusts the reference value to a specific crop. The K_C values vary during a growing season to account for such differences as irrigation frequency, crown size, and crop physiology. Daily estimates of evapotranspiration (ET_C) are calculated from the following equation:

$$ET_C = ET_O \times K_C$$

Although this particular system was developed to provide irrigation management information for field crops, the basic principles appear to be adaptable for use with other vegetation types. In like manner, the Department of Water Conservation in California has used average daily evapotranspiration rates to develop a lawn watering guide for homeowners to help conserve water by eliminating wasteful watering practices (29). With the appropriate information it would seem logical that a similar guide could be developed to assist arborists in irrigation scheduling for landscape trees and shrubs.

Reducing Transpirational Water Loss in Trees

It is virtually impossible to discuss the water relationships of urban trees without mentioning transpiration. Transpiration can be regarded as the dominant process in plant water relations since it produces the energy gradient principally responsible for the movement of water into and through the plant. But, because it is an inefficient process, transpiration also is responsible for the loss of tremendous quantities of water from individual trees (33). In fact, about 95% of all water absorbed by plants is lost in transpiration, and only 5% is used in metabolism and growth (22). If transpiration could be eliminated, or substantially reduced, urban tree maintenance problems would be simplified and the successful establishment of new transplants greatly enhanced. These potential advantages form the basis for considering the use of antitranspirants to improve the moisture balance of urban trees, especially in situations involving chronic or acute water shortages.

There are two basic approaches to use of antitranspirants. One approach involves the application of substances that will result in stomatal closure (metabolic antitranspirants). The other approach involves the application of materials that cover the leaf surface, thereby reducing the loss of leaf moisture (film-type antitranspirants). The immediate problem associated with either of these approaches is quite obvious—any treatment that reduces the loss of water vapor from leaves will also reduce the entry of carbon dioxide, thus decreasing photosynthesis. The use of antitranspirants is based on the assumption that a change in leaf surface resistance will reduce transpiration to a greater degree than it will reduce photosynthesis. In theory, at least, there is justification for this assumption (22).

The use of metabolic antitranspirants such as phenylmercuric acetate, decenylsuccinic acid, and abscisic acid (ABA) to control moisture loss in woody plants has met with only limited success. With the possible exception of ABA (12), metabolic antitranspirants have generally proven toxic to trees (11, 18, 46). Even ABA may adversely affect photosynthesis, although this does not represent a major problem for most landscape trees where wood production is not a major consideration. Film-type transpiration suppressants have also been utilized with varying degrees of success. A number of film-forming compounds have been found to significantly reduce transpiration in woody plants (15, 24). However, the long-term effects of these substances on growth may make them unsuitable for use with certain tree types (12). While many of the inconsistencies associated with antitranspirant use may originate with the application techniques and the environmental conditions during treatment, it appears that these substances have only limited practical application for the arborist. Certain circumstances may warrant their use in the urban environment (i.e., reducing winter injury; reducing transplanting shock), but routine applications of antitranspirants to improve the water balance in urban trees seems unlikely with the chemicals presently available.

Summary

The growth and development of urban trees is probably influenced more by plant moisture than by any other single factor. In a time when water resources are becoming scarce, prudent use of existing water supplies becomes an important management decision for the arborist. Part of this decision process involves understanding the moisture requirements of urban trees and acquiring knowledge of the available methods for accurately estimating the water status of woody plant tissue. Relative water content, thermocouple psychrometry, and pressure equilibration are recommended as readily adaptable field techniques for measuring plant water relationships in urban trees. Monitoring sensitive changes in stem diameter, leaf temperature, and transpirational water loss are also suggested as potentially useful methods for estimating plant water status.

The inefficiency of most plants in regulating internal moisture supplies can be attributed to the process of transpiration. Although numerous antitranspirants have been tested for their effectiveness in reducing transpirational water loss from leaves, current evidence indicates that the long-term effects of these substances on physiological activity (i.e., photosynthesis) may preclude their usefulness in the field except under special circumstances. The need exists to develop antitranspirant chemicals that reduce transpiration without appreciably affecting carbon dioxide exchange.

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