
9

Plant water status, hydraulic resistance and capacitance

*Roger T. Koide, Robert H. Robichaux, Suzanne R. Morse
and Celia M. Smith*

9.1 INTRODUCTION

Many excellent reviews have been written about plant water status and its measurement (e.g. Slatyer, 1967; Barrs, 1968; Boyer, 1969; Brown and van Haveren, 1972; Slavik, 1974; Turner, 1981). The reader is referred to these sources for a more complete review, particularly of the older literature. In this chapter, our major goals are to introduce the reader to the concept and measurement of plant water potential and its components, and then to discuss the consequences of gradients in these components within the plant. First, we describe the most commonly used techniques for measuring the water potential of higher plants growing under field conditions, specifically the psychrometric and pressure chamber techniques. Second, we describe methods for measuring the components of water potential, particularly turgor pressure and osmotic potential, and water content. Since the transpirational path of the plant can be regarded as a hydraulic resistor, transpirational fluxes occur only when gradients in the various components of water potential exist within the plant. Thus, the third concept that we introduce is hydraulic resistance. Techniques

for its calculation are described for steady-state transpiration, when root water absorption equals shoot evaporation. Nonsteady-state flux occurs when there is a net movement of water between the transpirational path and tissues adjacent to it. Such tissues are regarded as capacitors, the final topic of our discussion.

9.2 WATER POTENTIAL AND ITS COMPONENTS

The thermodynamic parameter commonly used to describe the energy status of water in plants is the water potential (Slatyer, 1967; Passioura, 1982; Nobel, 1983). This parameter, designated Ψ , is defined as:

$$\Psi = \frac{\mu_w - \mu_w^*}{\bar{V}_w} \quad (9.1)$$

where μ_w is the chemical potential, or free energy per mole, of water at some point in the system at constant temperature and pressure, μ_w^* is the chemical potential of pure water at the same temperature and at atmospheric pressure, and \bar{V}_w is the partial molal

volume of water. The quantity, $\mu_w - \mu_w^*$, in Equation 9.1 represents the work involved in moving one mole of water from some point in the system to a pool of pure water at the same temperature and at atmospheric pressure. In plants, Ψ varies from zero to negative values. The units of Ψ are those of pressure, with the common units being MPa (megapascals). Alternative units are bars (1 MPa = 10 bars) and J m^{-3} (1 MPa = 10^6 J m^{-3}).

For a plant cell, Ψ may be expressed as the sum of three components:

$$\Psi = P + \pi + \tau \quad (9.2)$$

where P is the hydrostatic pressure (or turgor pressure), π is the osmotic potential and τ is the matric potential (Tyree and Jarvis, 1982). At equilibrium, Ψ is the same across the heterogeneous phases of the cell, i.e. across the vacuole, cytoplasm and cell wall. However, the components of Ψ may differ markedly across these phases. For water in the vacuole and cytoplasm (the symplasmic water), the dominant components are usually P and π , with P usually having a positive value. In a cell at equilibrium, P and π are probably uniform throughout the symplasm, since it is unlikely that significant pressure gradients can exist across the bounding membranes of the vacuole and cytoplasmic organelles (Tyree and Jarvis, 1982). However, the particular solutes contributing to the reduction in π may differ between the various symplasmic compartments. For water in the cell wall (the apoplasmic water), the dominant component is usually P , with π and τ contributing to Ψ mainly in the region immediately adjacent to the charged wall surface (Tyree and Karamanos, 1981). In this latter region, which is often less than 3 nm wide, P may be positive. For most of the water in the cell wall, however, P is negative. In some halophytes, both P and π may be important components of Ψ in the apoplasm.

Within a tissue, the symplasmic values of P and π may vary significantly from cell to cell, even at equilibrium. Given this variation, the

most appropriate parameters for describing the water relations of the tissue symplasm are the bulk, weight-averaged values of P and π (Tyree and Hammel, 1972). These weight-averaged values, designated \bar{P} and $\bar{\pi}$, respectively, are defined as:

$$\bar{P} = \sum_{i=1}^n \frac{w_s^i}{W_s} P^i \quad (9.3)$$

and

$$\bar{\pi} = \sum_{i=1}^n \frac{w_s^i}{W_s} \pi^i \quad (9.4)$$

where P^i , π^i , and w_s^i are the turgor pressure, osmotic potential and weight of symplasmic water respectively in the i th cell in the tissue, W_s is the total weight of symplasmic water in the tissue and n is the number of cells in the tissue (Tyree and Jarvis, 1982). Thus, at equilibrium, Ψ in the tissue symplasm may be expressed as:

$$\Psi = \bar{P} + \bar{\pi} \quad (9.5)$$

(Compared to the symplasmic values of \bar{P} and $\bar{\pi}$, the symplasmic value of τ is negligible.) Analogous weight-averaged values may also be defined for the components of Ψ in the tissue apoplasm. In addition to water in the walls of living cells, the tissue apoplasm includes water in the walls and lumina of dead cells, such as vessel elements, tracheids and fibers. The dominant component of Ψ in the tissue apoplasm is usually \bar{P} . At equilibrium, Ψ in the tissue apoplasm equals Ψ in the tissue symplasm.

A gravitational term is often included as a component of Ψ . As emphasized by Passioura (1982), however, the definition of Ψ in terms of μ_w ignores external force fields. Hence, it is preferable to use a separate gravitational potential, Ψ_z , in evaluating the effects of gravity. The total water potential may then be defined as $\Psi + \Psi_z$. The value of Ψ_z increases with height at a rate of 0.0098 MPa