Matric Potential

Melvin T. Tyree
United States Department of Agriculture (USDA), Burlington, Vermont, U.S.A.

INTRODUCTION

Matric potential, τ, is a component of water potential, Ψ, but has different meanings in plant physiology vs. soil science. A rigorous definition of τ requires a reference to principles of thermodynamics (both classical and irreversible thermodynamics). A rigorous treatment is beyond the scope of this brief overview. Readers interested in a detailed definition are advised to read the article of Ref. [5], but should be prepared to wade through 227 equations in a terse, 25-page article requiring a firm grasp of thermodynamics. Less detailed treatments can be found in Ref. [6] for soils and Ref. [7] for plant tissue.

MATRIC POTENTIAL IN PLANT PHYSIOLOGY

Water potential, Ψ, is the chemical potential of water expressed in pressure units. In plant tissues, Ψ is traditionally written as the sum of three components:[4]

$$\Psi = P + \pi + \tau$$

where P, π, and τ are the pressure, osmotic, and matric potentials, respectively. Ψ and its components are intensive variables that vary from point to point in a cell and tissue.[10] Some people have attempted to define τ in terms of a measuring procedure without regard to thermodynamic principles (e.g., Refs. [1,9,11]), but such attempts have been unsatisfactory because the approaches were derived from tissue properties obtained by volume or weight averaging over the heterogeneous phases of vacuole, cytoplasm, and cell wall. A satisfactory definition of τ must be based upon the consideration of it as an intensive property acting at a point. A more correct approach has been taken in Ref. [8] for plant tissues, and in Ref. [3] for soils.

The forces contributing to τ are short range, and influence only a small fraction of the total water in plants when the water is near a solid surface. At uncharged surfaces, the force interactions are largely London–van der Waals forces or hydrogen bonds and extend for only one or two water molecules, 0.3 nm–0.6 nm. At charged surfaces, e.g., cell walls, there is a concentration of negative charges that tends to cause an aggregation of cations in the surrounding electrolyte solution and contributes to low localized values of π, which equals $-RTC$, where R is the gas constant, T, the Kelvin temperature, and C, the localized concentration of all solutes including electrolytes in $\mathrm{osmol\,kg^{-1}}$. The impact of the charged surfaces on π has been calculated by using the Gouy–Chapman theory, which predicts the influence of fixed charges on ion accumulation near the charges. Tyree and Karamanos[8] have shown that the localized concentrations can exceed $2M$ resulting in π below $-5\,\mathrm{MPa}$. Soil scientists tend to include most of π and some other effects in τ (discussed below) but this is not done by plant physiologists. The argument is that if pressure and concentration are already accounted for in P and π, then τ ought to be something independent.

Within the electric fields of the surface charge, there is another effect that reduces the energy of water molecules, i.e., the interaction of the water dipole with the electric field. As both plant cell wall surfaces and clay surfaces have a net negative charge, the water dipole tends to be oriented with the positive (hydrogen) end aligned nearer the charged surface than the negative (oxygen) end of the dipole. The net effect is a lowering of the free energy of the water molecules within the electric field. In terms of water potential, the magnitude of the effect is given by

$$\tau = -\left(\frac{N_0{}^2 P_0{}^2}{3V_{\mathrm{w}}RT}\right)F^2$$

where N_0 is the Avogadro number, V_{w}, the volume of a mole of water, P_0, the dipole moment of water, and F, the electric field at the point where τ is evaluated.

Fig. 1 shows the magnitudes of the components of Ψ near a charged surface computed from the Gouy–Chapman theory for a charged surface with a net charge of $-0.4\,\mathrm{C\,m^{-2}}$ in equilibrium with $10\,\mathrm{m}M$ NaCl solution at $\Psi = -1.5\,\mathrm{MPa}$. A large positive pressure develops near the charged surface because of the force with which water molecules are drawn towards the charged surface. Given that both π and τ are very negative near charged surfaces, large positive values of P are necessary to make $\Psi = -1.5\,\mathrm{MPa}$ everywhere. Tyree and Karamanos[8] go on to argue that even in cell walls, where the ratio of charged solids to water is about 1:1 that the influence of τ extends only to a small fraction of the water volume, and

DOI: 10.1081/E-EWS 120010175

Marcel Dekker, Inc.
270 Madison Avenue, New York, New York 10016

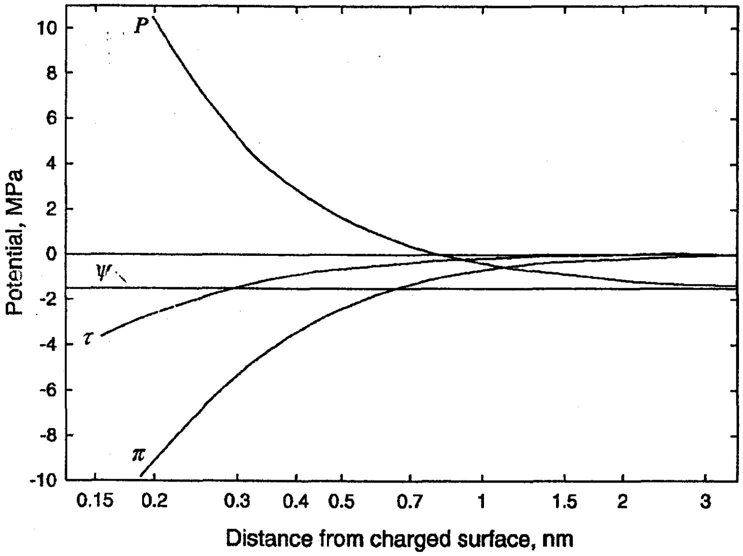

Fig. 1 The components of water potential near a charged surface according to the Gouy–Chapman double layer theory with a surface charge of $-0.4\,\mathrm{C\,m^{-2}}$. The univalent ion concentration outside the double layer is taken as $10\,\mathrm{m}M$. π and τ are calculated at distances from the charged surface from the calculated electrical potential and electric field, respectively. $P = \Psi + \pi + \tau$ with $\Psi = -1.5\,\mathrm{MPa}$. (From Ref. [8].)

will begin to influence measures of Ψ only when water potentials approach $-14\,\mathrm{MPa}$, at which point most plants are dead anyway. So, as defined by plant physiologists, τ can usually be ignored.

MATRIC POTENTIAL IN SOIL SCIENCE

Matric potential in soil science, τ_s, was originally defined in terms of the instrument(s) used to measure τ_s. Note that the subscript, s, is used in τ_s in soil science to distinguish it from the τ in plant physiology. In situ measurement of τ_s in soils is made with a tensiometer, which consists of a water-filled tube with an attached pressure sensor. The fluid in the tube makes contact with the soil water through a porous plate (often ceramic). When the soil is wet, the fluid in the tensiometer is in good contact with the soil water and is at a pressure of $0\,\mathrm{MPa}$ relative to atmospheric pressure. As the soil dries, the fluid pressure drops below atmospheric. When the pressure drops below that of a perfect vacuum ($-0.1013\,\mathrm{MPa}$), the water column usually cavitates, i.e., an air bubble forms because of a breakdown in the adhesion of water to the solid surfaces of the tensiometer. Cavitations limit the range of useful measurement of τ_s using tensiometers, as most plants can function well to $\tau_s < -1.5\,\mathrm{MPa}$. It is possible to make fluid-filled pressure-measuring devices (called cell pressure probes) that can measure fluid pressures down to $-1\,\mathrm{MPa}$ in plant cells, but these have never been used in soils and probably would not work reliably.

In order to measure τ_s below $-0.1\,\mathrm{MPa}$, the soil samples have to be removed and placed in another apparatus. One such system is a pressure plate apparatus. The soil is placed at the bottom of a pressure chamber. The bottom of the chamber is porous so that water can pass through the porous plate when air pressure above the soil is increased high enough to extract water from the soil. The value of τ_s is equated to $-$(the applied pressure) at an incipient water extraction. Water can also be extracted from the soil in a centrifuge. The soil is spun in the centrifuge tube with a porous bottom until the centrifugal force (expressed in pressure units) is sufficient to extract water and τ_s is equated to $-$(the centrifugal force).

A number of papers have been written to discuss what, based on thermodynamic theory, is measured by the instruments described earlier. Passioura[6] equates τ_s approximately with Ψ. To be precise, $\tau_s = \Psi - \pi_D$, where π_D is the osmotic potential of the "equilibrium dialysate," i.e., the osmotic potential of the soil solutes that can pass through the porous plate of the tensiometer or pressure plate apparatus or centrifuge tube. The ions in solution in the ion "cloud" near the charged surface of soil particles would not be included in π_D, because these ions are not extractable. In most soils, π_D is usually $\geq -0.02\,\mathrm{MPa}$; hence in drying soils, $\tau_s \cong \Psi$ within good tolerance. In a more recent exhaustive treatment of the theory behind τ_s, it appears that τ_s is identified exactly with Ψ in the equilibrium vapor phase of soils, i.e., see Eq. 202 in Ref. [5]. Hence, this meaning of τ_s is identical to the meaning of Ψ, which is often also measured on plant tissue by using the equilibrium vapor phase.

CONCLUSIONS

Matric potential as used by soil scientists is nearly identical with water potential as used by plant physiologists. The main difference is that plant physiologists divide water potential into two quantities that frequently can be measured independently, i.e., pressure potential, P, and osmotic potential, π. Soil physicists like to equate matric potential in plants with "capillary or adsorption forces which in a plant are forces such as those at the cell walls."[2] However, this definition is equivalent to water potential, Ψ, and does nothing to help elucidate the osmotic relations of living cells that can be quantified only by independent measures of P and π. In the older plant physiology literature, some people attempted to come up with a different meaning of matric potential, but this approach has been discredited.[7,8] It is unfortunate that these two closely allied sciences should use different words to describe the same quantity (matric potential vs. water potential), but the attentive reader can usually distinguish the meaning of matric potential from the context of scientific reports.

REFERENCES

1. Acock, B. An Equilibrium Model of Leaf Water Potentials Which Separates Intra- and Extracellular Potentials. Aust. J. Plant Physiol. **1975**, *2*, 253–263.
2. Baver, L.D.; Gardner, W.H.; Gardner, W.R. *Soil Physics*, 4th Ed.; Wiley: New York, 1972; 293–295.
3. Bolt, G.H.; Miller, R.D. Calculation of Total and Component Potentials of Water in Soils. Trans. Am. Geophys. Union **1958**, *39*, 917–928.
4. Dainty, J. Water Relations of Plant Cells. In *Encyclopedia of Plant Physiology N.S.*; Lüttge, U., Pitman, M.G., Eds.; Springer-Verlag: Berlin, 1976; Vol. 2A, 12–35.
5. Nitao, J.J.; Bear, J. Potentials and Their Role in Transport in Porous Media. Water Resour. Res. **1996**, *32*, 225–250.
6. Passioura, J.B. The Meaning of Matric Potential. J. Exp. Bot. **1980**, *31*, 1161–1169.
7. Tyree, M.T.; Jarvis, P.G. Water in Tissues and Cells. In *Encyclopedia of Plant Physiology N.S. Physiological Plant Ecology*; Lange, O., Nobel, P.S., Osmond, C.B., Eds.; Springer-Verlag: Berlin, 1982; Vol. 12B, 35–77.
8. Tyree, M.T.; Karamanos, A.J. Water Stress as an Ecological Factor. In *Plants and Their Atmospheric Environment*; Grace, J., Ford, E.D., Jarvis, P.G., Eds.; Blackwell: Oxford, 1980; 237–261.
9. Warren Wilson, J. The Components of Leaf Water Potential. Aust. J. Biol. Sci. **1967**, *20*, 329–347.
10. Weatherley, P.E. Some Aspects of Water Relations. Adv. Bot. Res. **1970**, *3*, 171–206.
11. Wiebe, H.W. Matric Potential of Several Plant Tissues and Biocolloids. Plant Physiol. **1966**, *41*, 1439–1442.

Marcel Dekker, Inc.
270 Madison Avenue, New York, New York 10016