VOLUMETRIC WATER CONTENT—MATRIC POTENTIAL RELATIONSHIPS

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Contents

Summary

When the variables defining volumetric water content–matric potential relationships are considered, the matric potential element is the most difficult to understand. This article, therefore, briefly reviews the different potentials that are important in the retention of soil water. Most of our discussion will be at the macroscopic level at which measurements are generally being made. To explain the nature of the matric potential more fully, however, we will defer to the microscopic level and show potential distributions in the liquid phase adjacent to a solid particle in case of a convex gas/liquid interface. Even when an adsorptive part is present, measured matric potential values are nevertheless often referred to as "pressure potential" or "pressure head" values. Although this usage is, strictly speaking, incorrect it has been entrenched in our scientific jargon for many years. The direct determination of volumetric water content–matric potential relationships is presented in a generalized manner. The more commonly used methods are discussed briefly and the most popular parametric models to describe

these relationships are introduced. Finally, we briefly discuss property-transfer models and inverse methods of determining water content–matric potential relationships.

1. Introduction

The relation between a fluid's content or saturation and its associated matric potential is one of the fundamental hydraulic properties of a porous medium, the other being the hydraulic conductivity–water content relation. These two relations are needed to predict water flow and chemical transport in porous media, such as soils and the vadose zone, for different boundary and initial conditions.

If two fluids are present, one fluid will be attracted more strongly to the solid phase particles than the other will. The former fluid is referred to as the *wetting fluid*, the latter the *non-wetting fluid*. If three fluids are present, one of them is characterized by intermediate-wetting characteristics. In the soil science literature, the fluids considered are usually water and air. For most soils, water is the wetting fluid and air the non-wetting fluid. Under certain conditions, however, soils may become hydrophobic, in which case air is the wetting and water the non-wetting fluid. The relation between water content and matric potential is referred to by various names, such as water retention curve, water characteristic curve, water content–capillary pressure curve, and capillary pressure–saturation relation. The function relates a capacity factor (the water content) to an intensity factor (the energy state of the soil water). The energy state is expressed by terms such as suction, tension, capillary pressure or capillary pressure head, matric potential, soil water pressure head, and matric pressure head. For unsaturated soils, values for suction, tension, and capillary pressure (head) are positive, while those for matric potential and pressure head are negative.

We hold the view that the soil water matric potential is the result of pressure and adsorptive forces. If clay particles are present, the adsorptive forces include osmotic forces resulting from the high concentration of constrained cations in the diffuse double layer associated with the negative charge of the solid phase. We will treat the matric potential as a component of the total mechanical potential, the latter including the gravitational potential. The spatial gradient of the total mechanical potential is known to be the driving force causing water movement in soils.

2. Concept of Capillarity

The Young and Laplace equation, which relates the pressure difference ΔP across the gas/liquid interface in a unsaturated porous medium with its mean radius of curvature r_c, can be expressed as

$$\Delta P = \frac{2\sigma}{r_c} = \frac{2\sigma \cos \beta}{r} = P_l - P_g \tag{1}$$

where σ is the surface tension (N.m^{-1}), β is the contact angle between the liquid and the solid phase, r is the maximum liquid-filled pore radius (m) for the unsaturated porous medium (by convention $r < 0$ if the radius of curvature is in the gas phase, and > 0 if in the liquid phase), P_l is the water pressure (N.m^{-2} or Pa), and P_g is the gas phase pressure

(N.m^{-2} or Pa). Outside the region of influence of the adsorptive forces the matric pressure head (matric potential on a weight basis), h_m (m), is defined by

$$h_m = \frac{\Delta P}{d_l g}$$ (2)

where d_l is the density of water (kg m^{-3}) and g is the gravitational field strength (N kg^{-1}).

3. Matric Potential

It should be noted that Eq. (2) no longer applies if the water molecules are under the influence of adsorptive forces: in other words, when water exists as thin films attached to the solid surfaces of soil particles. In those cases h_m is the result of the negative adsorptive potential and the positive pressure potential. (Eq. (1) still applies across the gas/liquid interface: see Section 5.) Our measurement techniques, however, do not distinguish between pressure and adsorptive forces, and the methods described in this chapter always yield the matric potential or matric head. This is usually referred to as h_m, albeit not always defined by Eq. (2), depending on whether or not adsorptive forces play a role. It should also be noted that under normal field conditions $P_g = 0$ (atmospheric pressure). If it does not, a correction should be made for the added gas pressure as it is not a part of the matric potential.

4. Relations Between Potentials on a Mass, Volume, and Weight Basis

In general terms, let E be the potential or potential energy (J) of a volume V (m^3) of a fluid, so that

$$\psi = \frac{E}{V} \qquad \text{(J.m^{-3} or N.m^{-2} or Pa)}$$

Hence, energy per unit volume has the same units as pressure. If d_f (kg.m^{-3}) is the density of the fluid, then the mass of fluid volume V is $d_f V$ (kg). Therefore, the potential energy per unit mass is

$$\phi = \frac{E}{d_f V} \qquad \text{(J.kg^{-1})}$$

Finally, for a gravitational field strength g (N.kg^{-1}), the weight of fluid volume V is equal to $d_f g V$ (N). Hence the potential energy per unit weight is

$$\Omega = \frac{E}{d_f g V} \qquad \text{(m)}$$

For most soil water applications, the use of energy per unit weight—referred to as *head*—is the more convenient choice because it results in units of length. The matric head is thus expressed as the height of a fluid column of a given density. The fluid is

usually water at the ambient temperature of the soil water system. The three potentials are related as

$$\left\{\frac{E}{V} = \psi\right\} = d_f \left\{\frac{E}{d_f V} = \phi\right\} = d_f g \left\{\frac{E}{d_f g V} = \Omega\right\}$$

or

$$\psi = d_f \phi = d_f g \Omega \tag{3}$$

Eq. (3) can be used to make conversions between energy on a mass, a volume, and a weight basis.

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Biographical Sketches

Dr. Jacob H. Dane is an alumni Professor of Soil Physics in the Agronomy and Soils Department at Auburn University. He has a B.S. degree in Agricultural Engineering from Wageningen Agricultural University, the Netherlands, an MS degree in Soil Physics, with a minor in Civil Engineering, from New Mexico State University, and a Ph.D. degree in Soil Physics, with a minor in Mathematics, from Colorado State University. Dr. Dane's research interest is in flow and transport through porous media. He is specifically interested in three topics: the determination of soil hydraulic properties by direct and indirect

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