

thermocouple psychrometry in soil and plant science

Measuring the energy state of water in soil and plant materials –
a complementary measurement to that of water content by radiation methods.

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Radiation techniques involving attenuation or scattering of neutrons or low energy gamma rays by water now occupy an important and indispensable place in studies of water in soil and other porous materials. These are the only non-destructive methods available which are not affected by uncertainties arising from non-unique water content-energy relationships for water held in porous materials. Volumetric water content measurements using radiation techniques have some limitations but, nonetheless, have provided the best information on how much water is in the soil as a basis for estimating irrigation needs and the extent of the water supply available to growing plants. Such measurements also have been highly useful in a variety of ways to engineers building upon soil and other porous materials whose water content or density have importance. However, volumetric water content alone, important as it is, does not fully characterize a porous material with respect to its wetness. More important in many ways is the tightness with which water is held by the porous material. And, in fact, whether a porous material feels dry or feels wet depends more upon how tightly it holds water than upon how much is present. A particular soil – or building material – may feel wet with only 5% of its volume being occupied by water, whereas another soil or material having finer texture and finer pores may not feel wet until 20 or 30% of its volume is water. However, they will likely feel similarly wet if the energy state of the water, or the tightness with which the water is held, is about the same. This general idea is important as it applies to plants growing in soil, and equally important as it affects the engineering properties of porous materials.

Relationships do exist between water content and the energy state of water held by a porous material. However, these vary greatly with porosity and with wetting properties. Furthermore, porous materials do not wet the same each time water is added and considerable differences in the water content-energy relationship can exist, depending solely upon wetting history. In some instances differences are sufficiently small so that useful inferences about energy-dependent properties of wet porous materials may be inferred from water content measurements alone. However, this is not always the case and frequently the differences are sufficiently large that gross errors would result from such assumptions. Thus, it is evident that at least two water-related properties of wet porous materials are important, the water content and the energy required to remove the water.

This article concerns a relatively new psychrometric method for measuring the energy status of soil water, a complementary property to volumetric water content which may be determined using radiation techniques. However, a little background on traditional methods of measurement is appropriate. The most simple apparatus for determining how tightly water is held in soil, the tensiometer, involves a porous cup and a hanging water column as shown in the Figure I. Water is held tightly in the fine pores of the cup against the pull of the hanging column of water, h . Water can move out of or into the cup from the soil until equilibrium is established, at which time the height of the water column, h , is an index of the energy required to remove water (potential energy per unit volume is given by ρgh where ρ is the density of water, g the acceleration of gravity and h the height of the water column). The hanging water column may be replaced by a mercury manometer or a vacuum gage which may be placed more conveniently above the soil surface. This is a useful technique in wet soil but as the soil dries out problems of cavitation in the hanging water column limit the height which can be supported in the manometer without the column breaking. Hence, a sizeable part of the range of interest is out of reach. A laboratory method which avoids this problem by using positive pressures is available for samples, but this cannot be used "in situ".

The psychrometric method for making water-energy measurements is based upon the fact that the vapor pressure in a porous material containing only pure water also depends upon how tightly water is held on the surfaces and in the fine pores of the material, in the same way as does the height of the hanging water column of the tensiometer. Thus, measurement of the vapor pressure in the porous system is a similar measurement with potential bearing given by the equation in the Figure I. The ratio p/p_0 will be recognized as the relative humidity and the place of the psychrometer becomes obvious. If soluble materials are present in the soil water this also affects the energy status and the potential measured becomes the sum of the "matric plus osmotic" potential. The tensiometer measures only the matric potential inasmuch as solutes are free to move through the porous cup. With an osmotic membrane it too would measure matric plus osmotic potentials. However, such a membrane would slow the reaction time of the instrument to impractical levels and it is not used in this way.

The psychrometer used in the soil differs appreciably from the conventional one used for measuring atmospheric humidity. This is due to the fact that the entire range of interest in most porous materials is very near to 100 per cent R. H., the range where extremely high precision is required. Furthermore, the nature and dimensions of the psychrometer sensing element must be appropriate to burying the unit in soil. The psychrometer used is shown diagrammatically in the Figure I. It consists of a chromel-constantan thermo-couple, made from fine wire under a microscope and then placed in a porous cup. The reference junctions for this thermocouple are in the base of the unit so that when water is placed on the thermocouple junction and evaporation takes place the temperature difference measured is the conventional wet-bulb depression required for use of hygrometric tables. Temperatures of the order of thousandths of a degree Celsius must be measured, hence a sensitive d. c. microvoltmeter is required. To wet the thermocouple junction a small d. c.

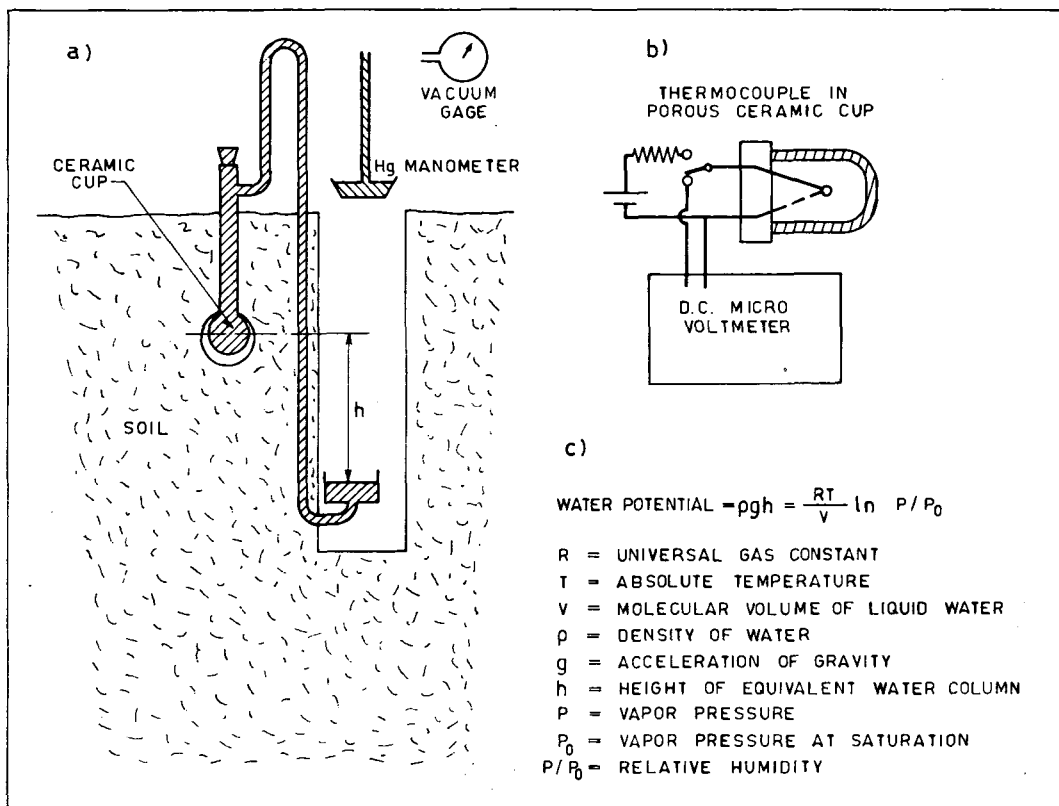


Figure I a) diagram of a tensiometer
b) diagram of a psychrometer
c) an equation for water potential

current (ca. 3 to 8 ma) is passed through the thermocouple for about 10 seconds in a direction to cool the junction (Peltier cooling). The junction is cooled below the dew point and water is condensed on the junction. When the cooling current is cut off the water evaporates from the junction back into the atmosphere at a rate dependent upon the relative humidity of the atmosphere. The temperature difference between the junction and the references in the base of the unit during the early part of this evaporation process is the wet-bulb depression. The unit does not quite meet the requirements for a perfect psychrometer, for which standard tables are available (and tables with sufficient precision in the near-saturation range are not available anyway), so the instrument generally is calibrated directly in appropriate potential units using standard atmospheres provided by osmotic solutions.

The soil psychrometer is temperature sensitive so that the unit must be placed deep enough in soil so that temperature fluctuations are small. However, by placing similar psychrometer units in close proximity to large thermal masses (say, a 2x2x3 cm. block of aluminium), "in situ" measurement of water potentials in growing leaves are made. The instrument also is used on samples of soil and plant tissues in the laboratory. One increasingly common use of the laboratory unit is to make osmotic potential measurements on juices crushed or frozen from plant tissues.



A psychrometer at work on plant leaf and in soil.

As with many instruments it is difficult to fix date of discovery and to give proper credit. However, it appears that the earliest use of psychrometry for soil water measurements was in about 1938 by L. A. Richards at the U.S. Salinity Laboratory in Riverside, California. Richards applied water to a small junction with a micropipette with everything being under precise temperature control in a special bath. In about 1951 D.C. Spanner in England used the Peltier effect to put water on the thermocouple, thus eliminating the necessity for direct access to the thermocouple and avoiding temperature disturbances. This eliminated one of the most difficult obstacles to practical use and made "in situ" measurements possible. Development of techniques and the application to plant-soil problems accelerated in the early 1960's, with much of the impetus coming from a discovery by S. L. Rawlins at the U. S. Salinity Laboratory that temperature problems could be nearly eliminated if the psychrometer thermocouple were placed inside of a small porous cup and buried in the soil where the rate of temperature change was small. By this time numerous laboratories had become interested and tremendous strides have been made during the past few years.

The practical value of psychrometry for measurements on soil and plants relates to the importance of following the energy change as water moves through the soil, into and through the plant and out into the atmosphere, and to the need for identification of the water property associated most directly with plant growth. It has long been known that the effect of water on plant growth related more to tightness with which water was held in soil and in tissues than with the actual water content. However, methods for measuring energy state were cumbersome at the best and "in situ" measurements were impossible. With the development of soil and plant psychrometry such things now are comparatively easy. Widespread use of psychrometry is leading to important new ideas and a more complete understanding of the soil-plant-atmosphere continuum as well as to many applied results relating to improvement in management of plant growth to produce more and higher quality food products. Interesting relationships between plant growth and the water potential of leaf tissues are being found on such plants as wheat and potatoes in the author's soil physics Department of Agronomy and Soils, at Washington State University in the United States and in many laboratories elsewhere. Speculation on possible economic benefits of such information is dangerous. However, it is known that yields of many crops under field conditions sometimes are much lower than those demonstrated to be possible under ideal conditions. For example, yields of a certain variety of potato under ideal conditions are known to be at least twice those realized commercially. Achievement of maximum yields requires understanding the relationship of water conditions in the soil and plant to growth as well as similar information about other growth factors.

The author presently is introducing the psychrometer technique into the IAEA laboratory at Seibersdorf and into other programs of the Joint FAO/IAEA Division of Atomic Energy in Food and Agriculture, as a companion technique to the much used radiation methods for measuring water content of soils.