METER
ENVIRONMENT

WATER POTENTIAL—A LITTLE HISTORY

Contributors

UNDERSTANDING UNSATURATED WATER FLOW IN SOILS

At the turn of the last century, the USDA Bureau of Soils (BOS) recruited several pure physicists to tackle perplexing problems in agriculture. One of these was Edgar Buckingham. When Buckingham came to the Bureau of Soils in 1902, he had already authored a text on thermodynamics. His first experiments at the BOS involved gas transport in soils, but ultimately he came to consider the problem of unsaturated water flow in soil, and this is where he made his greatest contribution to soil physics.

As a classical physicist, Buckingham used mathematics to examine the mysteries and confusion surrounding how water flows in soil. Realizing that water content did not drive flow in unsaturated soil, Buckingham's challenge was to describe the forces that did. He was naturally familiar with electrical and thermal force fields and the flux they created. These concepts were comfortable analogs for the driving force created in soil by gradients in what he called "capillary conductivity." Buckingham used Ohm's and Fourier's laws to describe this flux.

MEASURING WATER POTENTIAL IN THE LAB

Although Edgar Buckingham described and demonstrated "capillary conductivity" in 1907, he was a long way from being able to measure it effectively. The first instrument to do that was the pressure plate created by L.A. Richards in the 1930s. A pressure plate doesn't measure the water potential of a sample. Instead, it brings a sample to a specific water potential. The instrument applies pressure to force water out of the sample and into a porous ceramic plate. When the sample comes to equilibrium, its water potential will theoretically be equivalent to the pressure applied.

Once the soil samples reach a specific water potential under pressure, the researcher can measure the correlated water content. A soil moisture characteristic can be made by making these measurements at different pressures.

VAPOR METHODS

Over a decade after the introduction of the pressure plate, L. A. Richards in the U.S. and John Monteith in Britain published papers describing how a thermocouple psychrometer could be used to measure the water potential of soil samples by equilibrating the sample with vapor in a closed chamber and measuring the relative humidity of the vapor. At equilibrium, the relative humidity of the vapor is directly related to the water potential of the sample.

The term psychrometer, coined in 1818 by the German inventor Ernst Ferdinand August (1795-1870), means “cold measurer” in Greek. A psychrometer is made of two identical thermometers. One (the dry bulb) is kept dry while the other (the wet bulb) is kept saturated. The difference in temperature between the wet and the dry bulb temperatures can be used to calculate the relative humidity of the air.

THERMOCOUPLE PSYCHROMETERS

The first psychrometers used to measure relative humidity above a soil sample were of necessity quite small. The two thermometers were made of tiny, fragile thermocouples. A thermocouple is a temperature sensor made from two dissimilar conductors joined at one spot. The thermocouple converts a temperature gradient into electricity, which can be measured to determine temperature changes.

Thermocouple psychrometers were first successfully used to measure water potential by D.C. Spanner before 1951, but it was a difficult measurement to make. To get the results he wanted, Spanner had to make his own wire out of bismuth antimony—according to John Monteith, a

1902: Edgar Buckingham comes to work for the Bureau of Soils. His experience in thermodynamics helped form the beginning of our understanding of unsaturated water flow in soils.

1930s: L.A. Richards develops the pressure plate, one of the first instruments capable of effectively measuring “capillary conductivity”.

1940s: L.A. Richards and John Monteith publish papers describing how thermocouple psychrometers could be used to measure the water potential of soil samples.

1951: D.C. Spanner is the first to successfully demonstrate the use of a thermocouple psychrometer to measure water potential in soil.

1983: METER introduces the first commercially available thermocouple psychrometer (the SC-10 later known as the TruPsi).

fume hood at Rothamsted bore the marks of these experiments for many years.

Others struggled to repeat his measurements. Samples took up to a week to equilibrate, and then the fragile thermocouples would often read just one sample before they were broken. Still, by 1961 Richards clearly saw vapor methods as the future of water potential measurements (Richards and Ogata, 1961).

Decagon (now METER) introduced its first commercial thermocouple psychrometer (the SC-10 Thermocouple Psychrometer Sample Changer, later TruPsi) in 1983. This instrument used a delicate thermocouple but protected it inside a sealed enclosure. Nine samples were equilibrated simultaneously and rotated under the thermocouple to be measured.

Prior to each measurement, the wet bulb thermocouple was dipped in a tiny reservoir of water. The electrical output of the thermocouple was sent to a nanovoltmeter, which had to be monitored to determine when the temperatures stopped changing.

DEW POINT WATER POTENTIAL METERS

In the late 1990s, Decagon (now METER) started producing the WP4C Dew Point Potentiameter, an improved method for measuring water potential using vapor pressure. Like the psychrometer, it measures the vapor pressure above a sample sealed inside a chamber. Both instruments are primary methods based on thermodynamic principles.

Unlike the psychrometer, the dew point potentiameter uses a chilled-mirror dew point sensor. A small mirror in the chamber is chilled until dew just starts to form on it. At the dew point, the WP4C measures both mirror and sample temperatures with 0.001 °C accuracy to determine the relative humidity of the vapor above the sample. The water potential of the sample is linearly related to the difference between the sample temperature and the dew point temperature.

The dew point sensor has several advantages. It is faster and gives accurate measurements even when the operator is relatively unskilled. Also, the chilled mirror sensor doesn't require added water and therefore doesn't increase the water content of the vapor above the sample.

This measurement has the advantage of being a primary method for determining water potential based solidly on thermodynamic principles rather than on calibration.

The most recent version of this instrument can resolve temperatures to a thousandth of a degree, making it possible to measure samples as wet as -0.5 MPa with excellent accuracy.

Download the “Researcher’s complete guide to water potential”.

MASTER THE BASICS

In this webinar, Dr. Doug Cobos differentiates water potential from water content, discusses the theory, application, and key components of water potential.

Return to main water potential page.

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