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Soil&Plant

WATER POTENTIAL NEWSLETTER

Water Potential No-man's Land

There's a no-man's land in the middle of the water potential chart—a Bermuda triangle where accurate measurements have historically just disappeared. It's a spot that's too dry for tensiometers and too wet for vapor pressure methods like psychrometers and dew point hygrometers. Pressure plates are

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Microbial Growth and Water Activity

Have you noticed the salami on our home page? The picture up in the right hand corner is a link to our foods division, AquaLab by Decagon. Scientists have discovered a need to measure water in foods much as they do in soils. Nearly all major food companies use water activity to monitor quality in their processed foods.

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INSIDE

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An Interview with Dr. Doug Cobos

Water Potential No-man's Land

▼ *continued from cover*

not great in this range either as samples can sit for weeks or even months without ever coming to equilibrium.

In November 2010, Doug Cobos presented a poster at the ASA, CSSA, and SSSA meetings that showed how dramatic improvements to the WP4 dewpoint hygrometer may at last make it possible to accurately measure water potential in this range. I talked to him about his experiments with the upgraded instrument, called the WP4C.

Tell me about the old WP4 and why it got an upgrade.

The WP4 was by far the best dry end instrument around. Nothing else could even approach it. But it had problems pushing up into the wet range. It crashed at the wet end before tensiometers started to pick up. There was that area that fell between the cracks, and lots of people needed that information. The old WP4 couldn't provide it.

So people were frustrated with the instrument?

Well, the specs we wrote said that the WP4 could read from 0 to -300 MPa with ±0.1 MPa accuracy. It seemed obvious that if I got a measurement of 0.1 MPa with ±0.1 MPa accuracy, I had plus or minus 100% error. But not everybody made that jump. They'd put wet samples in there and the instrument wouldn't do what they expected. They'd get frustrated and put it on the shelf.

I've heard you say some people had *ninja* WP4 skills.

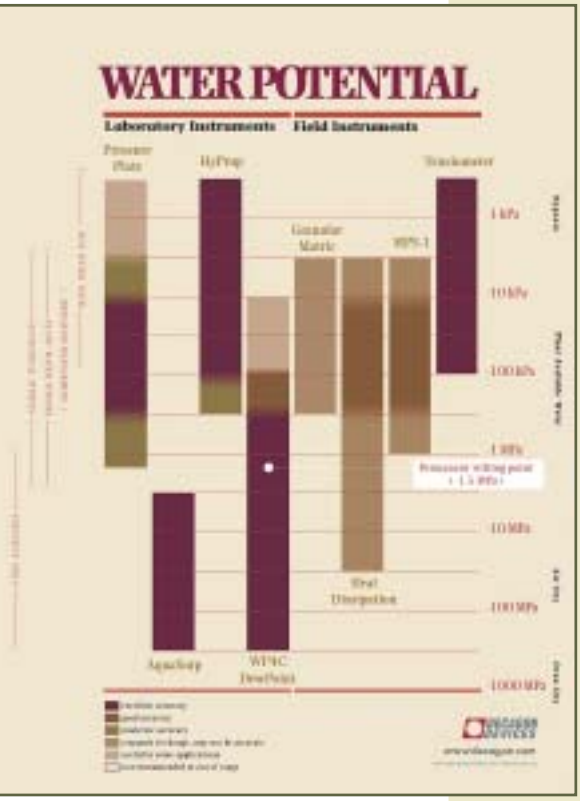
There were techniques that helped some users get better accuracy. If you just plunked a wet-ish sample in the WP4 and took a single reading, that reading was not going to be very good. If you put it in continuous mode and watched the values get logged on your computer screen for a while, you could get much better accuracy. When I showed that method to people, they were amazed at how much better the accuracy was. But we didn't promote *continuous mode* as well as we could have.

The instrument itself had some limitations too, didn't it?

The old WP4 made great temperature measurements for the time when it was developed. But technology has come a long way. We have much higher temperature resolution now, and much better precision at the wet end. I can get plus or minus 0.05 MPa with the new WP4C. With special techniques, we can even do better than that.

From ± 0.1 MPa to ± 0.05 MPa? That's 100% accuracy improvement.

It's exciting. And the instrument is also much better in other ways. It has a *precise* mode that checks for sample equilibrium. That makes sure people aren't just throwing something in there and measuring



For a printable electronic version of the poster, visit: www.decagon.com/posters.

For an electronic copy of Dr. Cobos's poster *"Can a Dewpoint Hygrometer Measure Water Potential at Field Capacity,"* visit www.decagon.com/posters.

too soon. Also, the new sample chamber has a hydrophobic coating. It doesn't absorb and desorb water, which speeds up equilibrium.

How about the calibration on the new instruments?
We started out fresh with the calibration routine—crunched equations to really dial in the instrument. I also worked on the standard salt solutions to figure out what the density should be at low concentrations. That took me days, but it really improved calibration.

Is the new instrument available without temperature control?
That's an interesting question. We used to sell the WP4 and the WP4T. The WP4 had no temperature control. But as I worked on these experiments, I was running the instrument with temperature control in a temperature controlled box. Still, on samples in the very wet range, I can tell from the output data when the AC in my office kicks on. You'd be hard pressed to get good numbers without temperature control.

Any other changes worth mentioning?
The new instrument offers three modes—fast, precise, and continuous.

Fast mode minimizes moisture loss in extremely dry samples, but most users should be using either precise or continuous mode.

Precise mode is new. It makes measurements until two consecutive measurements are very, very close to each other. This mode will improve accuracy for most users. It's good up to -0.5 MPa.

Users measuring samples wetter than -0.5 MPa should use continuous mode. If you can hold the temperature constant, you can see reading stability in the hundredths place, even on very wet samples. Accuracy comes at the expense of speed—it might take 15–20 minutes or longer to get a really good measurement in continuous mode. But continuous mode will dramatically improve accuracy in the wet end. These are the strategies I used in collecting data for the ASA poster.

So what do your results look like?
The results are just phenomenal. If you calibrate the WP4C correctly and use continuous mode in a temperature stable environment you can get better than ±0.025 MPa (0.25 bar) accuracy. You can even see changes at field capacity. A novice user will be able to push it up further into the wet end. They can get better accuracy from precise mode, and quicker measurements thanks to the new block coating. An expert user—someone with a lot of experience—can get some pretty phenomenal data. I'd be glad to share my poster with anyone who'd like to see the details. ■

The WP4C only takes 5 to 10 minutes for a measurement.

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HYPROP: Complete Moisture Rele Curves in Days, Not Wee

As a student, Leo Rivera made plenty of soil moisture release curves using pressure plates. He doesn't remember the experience fondly.

"Let's say you want just three points on the wet end of the curve," he says. "It could take you a month."

Like a lot of other people, Leo always felt there was a better way. So when he came to Decagon, he was interested to discover the HYPROP (the name is short for Hydraulic Properties), a tensiometer-based lab instrument that automatically generates moisture release curves.

I thought, "Wow, that's impressive. This thing generates the whole soil automatically. I'd never seen anything like it. I had to learn how to use it."

Chris Chambers (a scientist on Decagon's support staff) gave Leo a brief introduction to the instrument. He said, "This thing's kind of hard to use, but here you go, figure it out."

The instrument works by holding two T5 mini-tensiometers upright inside a soil sample contained by a 250 ml sampling ring. The ring and sensor head sit on a precision balance. Both the sensor head and

Pressure Plates

In order to make an accurate moisture release curve with a pressure plate, you have to ensure that the sample has fully come to equilibrium at the designated pressure. Several reviewers, including Gee et. al (2002), Cresswell et. al (2008), and Bittelli and Flury (2009) have noted problems with this assumption.

Errors, particularly at low water potentials, may be caused by clogged pores in the ceramic of the pressure plate, flow restriction within the sample, loss of hydraulic contact due to soil shrinkage, and reuptake of water when the pressure on the plate is released. At low water potentials, low hydraulic conductivities can cause equilibrium to take weeks or even months.

Gee et. al (2002) measured the water potentials of samples equilibrated for 9 days on 15 bar pressure plates and found them to be at -0.5 MPa instead of the expected -1.5 MPa. Especially when constructing a moisture release curve to estimate hydraulic conductivity and determine plant available water, pressure plate measurements at potentials less than -0.1 MPa (-1 bar) can cause significant error (Bittelli and Flury, 2009).

Additionally, Baker and Frydman (2009) establish theoretically that the soil matrix would drain differently under a positive pressure than it does under suction. They postulate that equilibrium water contents achieved using

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HYPROP by UMS.

the balance are connected to a computer running the TensioView software.

At the beginning of the test, the soil in the ring is saturated. Because the top of the sampling ring is open to the air, the sample dries naturally over the sampling period. At user-defined intervals, the computer logs the change in sample weight along with the change in water potential at the two different depths.

Most of the time, the user doesn't even touch the instrument. Leo soon discovered that the *art* of the HYPROP is all in filling the tensiometers. According to Leo, it's possible for anyone to learn how to do it.

"I would start by watching the tensiometer refill video," Leo says. "It's a great introduction. But then you just have to practice. It took me a couple of days just to get decent at filling them. I'd fill them and let them cavitate, then fill them and try again. I just kept filling them until they were cavitating above 150 kPa, close to 200. When you get really good, that's when you get over 200."

Once he could consistently fill the tensiometers well, Leo moved on to creating beautiful moisture release curves.

"The cool thing is, not only are you getting a soil moisture release curve, you're getting van Geneuchten parameters from actual data." ■

The HYPROP uses natural soil drying to generate moisture release curves.

pressure will be significantly different than those that occur under natural conditions. Anecdotal evidence seems to support this idea, though further testing is necessary.

Ultimately pressure plates may be relatively accurate in the wet range, (0 to -0.5 MPa), but beyond that water potential errors can be large. ■

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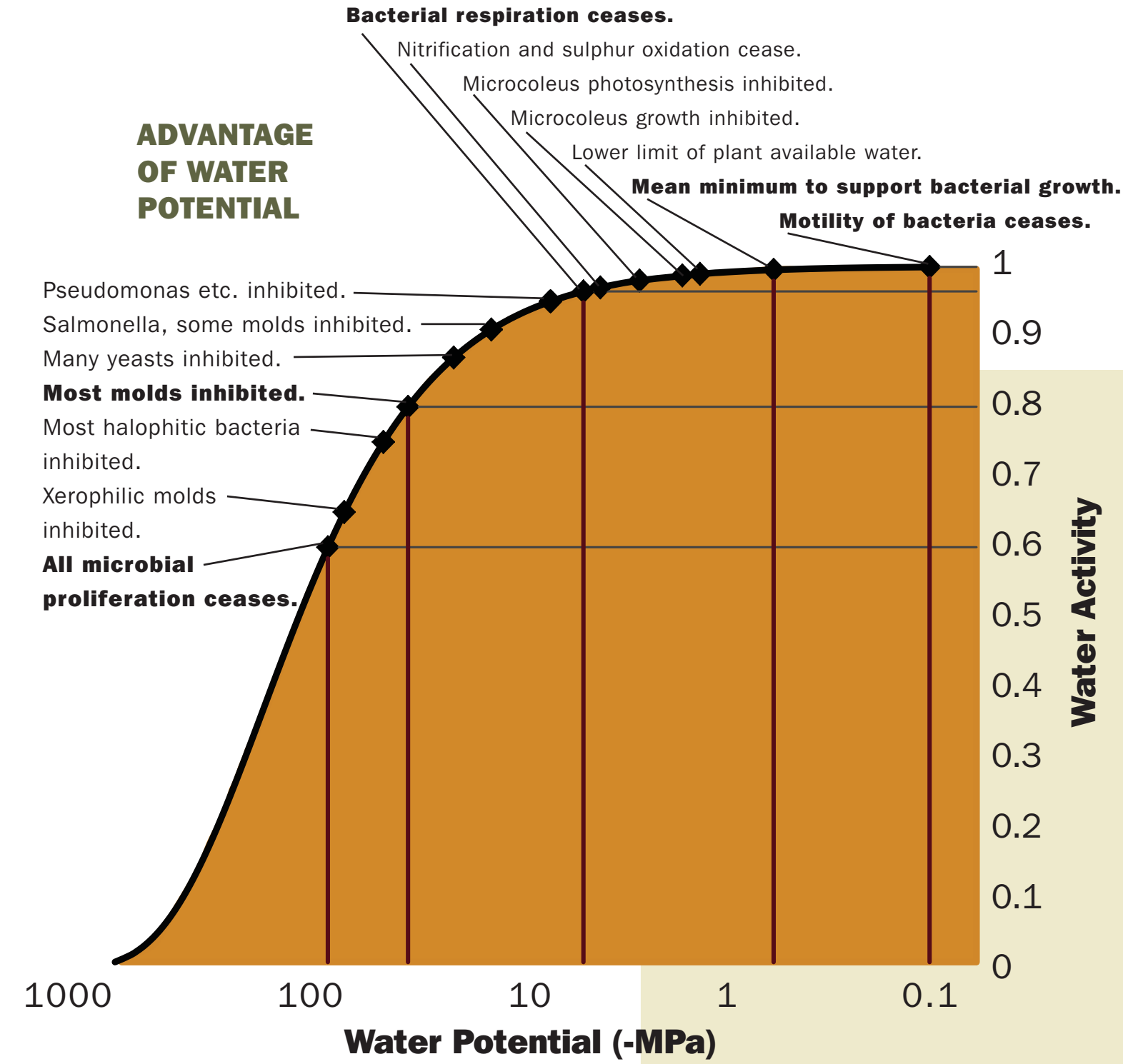

▲ **Figure 1**
Relationship between water potential (log scale) and water activity showing some limits for biological processes.
The line is computed from $a_w = \exp(y/137)$. The biological limits are taken from *L. R. Beuchat, Cereal Foods World, 26:345 (1981) and M. Potts, Microbiological Reviews, 58:768 (1994)*. Though both water activity and water potential measure the energy state of water, **water potential has clear advantages, especially in the wet range where very small changes in energy state result in large changes in biological response.** For example, the entire range of water availability for plants is between water activity values of 1.00 and 0.99.

Water potential is best because small wet range changes cause the largest biological response.

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In 1953, William James Scott showed that microbial growth in food is governed not by water content, as most people thought, but by water activity. Four years later, he established the concept of a minimum water activity for microbial growth. Water activity is now routinely used by food manufacturers to determine whether or not a product is susceptible to microbial proliferation.

In soils, microbial growth is also related to the energy of water, though that energy is typically expressed as water potential rather than water activity. Figure 1 shows the relationship between water potential (plotted on a log scale) and water activity, with microbial growth limits established by L.R. Beuchat (1981) and M. Potts (1994).

Same Measurement, Different Scales

Water activity and water potential use different scales to describe essentially the same measurement. Some people think of them as two different measurements, but they both describe the energy state of water and one measurement can easily be converted into the other. However, water potential is plotted on a log scale, which has clear advantages for biological scientists. In the range where soil microbiologists make most of their measurements, very small changes in energy state result in large changes in biological response. In fact, the entire range of water availability for plants is between water activity values of 0.99 and 1.00. Figure 1 shows how a change of scale spreads out the measurements of interest.

More ►

Water Potential Gives Insight into Microbial Activity

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"Low Hanging Fruit"

Water potential is a key concept in understanding microbial proliferation wherever it occurs. It's not the only factor, but it's an important and frequently neglected element. Dr. Gaylon Campbell refers to water potential's role in microbial proliferation as *low hanging fruit*. He explains, "The furthest most people go is to try to control water content. By expending just a little bit of effort to understand the water potential, there's a lot they could gain."

Factors in Microbial Proliferation

Microbial growth depends on the microbe's ability to move, on whether or not nutrients are able to diffuse to the microbe and wastes are able to diffuse away, and on whether or not the microbe is able to take up water from its environment.

Moving in Water Films

Microbial motility is determined both by the thickness of water films on soil particles and by particle size and packing in the soil. For example, in 1958, Wallace showed that the movement of *H. schachtii* larvae in soil was optimal at matric potentials of -0.025 to -0.004 MPa where the particle size was 150 to 250 µm. These conditions provided the maximum number of ideally sized, water-filled pores for this particular organism. Small soil pores can restrict an organism's mobility, but the thickness of water films within and between the pores is also critical. Even in soil with ideally sized pores, the air-water interface can hold the organism down like a rubber membrane (Papendick and Campbell, 1981).

Diffusion Rates

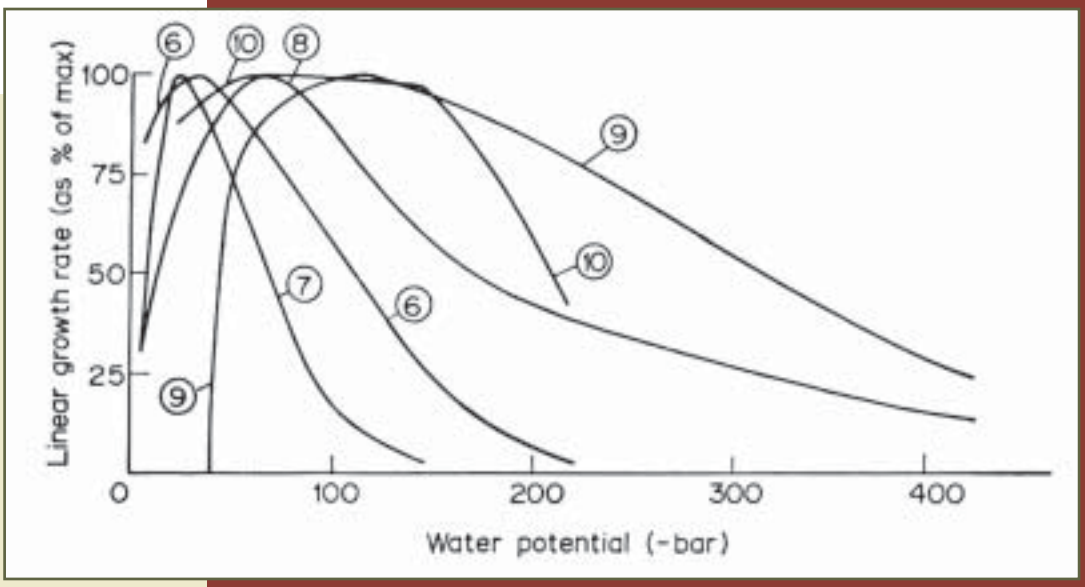
Access to nutrients is affected by motility, but it also depends on diffusion rates. Microbes that cannot move rely on diffusion of gasses and solutes to supply nutrients and eliminate wastes. This is one effect better measured by water content than by water potential. Diffusion rates change as water potential changes but they are probably more closely related to the amount of water in the soil.

Desiccation

Finally, nearly all microbes actively take up water from their surroundings. Their internal water potential is typically higher than the water potential of the surrounding environment, but there finally comes a point when it becomes too dry for the cell to function. That lower limit is best expressed in terms of the energy (potential) and not the amount of water in the soil.

Restricted Function with Lower Water Potential

As water potential is lowered, microbes lose motility first. Then they stop growing. Lower water potential impacts cell growth because growth requires turgor pressure. Without the turgor, cells can't grow, though metabolism can continue. Metabolism ceases at different water potentials, starting with various strains of bacteria. Yeasts and fungi continue to



▲ **Figure 2**
Effect of water potential on the rate of linear extension of eleven fungi.
Curve 6. Aspergillus niger *(Heintzeler, 1939)*
Curve 7. Aspergillus flavus *(Ritchie, 1959; Pitt and Christian, 1968)*
Curve 8. Aspergillus amstelodami *(Scott, 1957)*
Curve 9. Xeromyces bisporus *(Scott, 1957)*
Curve 10. Stereum frustulosum *(Bavendamm and Reichelt, 1938)*

function at lower potentials. Because bacteria tend to be able to out-compete fungi for nutrients and water, fungi actually have lower growth rates at high water potentials. In fact, each specific strain of bacteria, yeast, and fungi has a water potential zone of optimum growth, as shown in Figure 2.

An Important Factor

The vadose zone is home to an incredibly diverse spectrum of fungi and microbes. Curtis et. al (2002) estimate that one ton of soil contains more genomic diversity than is found in all of the oceans. These microbes need an optimum moisture environment for growth. That moisture environment is often best characterized by measuring soil water potential. While water potential isn't the only factor in microbial proliferation in soils, it's an important factor and one that deserves more attention. ■

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How is Water Potential Different from Soil Moisture?

A couple of months ago, we rolled out a new water potential education section on our website. It is now one of the most frequently visited sections on the site. The goal of the webpages is to teach what water potential is, how it differs from soil moisture, and how to measure it in the field and in the lab.

People seem to intuitively understand soil moisture, but sometimes it presents a paradox.

For example, a soil with low water content can have plenty of plant-available water and a soil with high water content can have almost none.

Also, two adjacent patches of soil at equilibrium can have significantly different water content.

In these and many other cases, water content data can be confusing because water doesn't necessarily move from *wet* to *dry*. It moves from high energy to low energy. Water potential is the measure of water's energy state. It's a crucial measurement.

In fact, water potential is one of the most fundamental and essential measurements in soil physics. But it can be difficult to make the measurement and to explain the concept.

We've spent the past year gathering the educational material for the water potential education pages. It covers history and theory and goes into detail about the different instruments available for measuring water potential.

You'll find out:

- Why no single instrument can accurately read the entire range of soil water potentials.
- How to identify the best instrument for measuring water potential in your applications.
- How to convert easily between different water potential units.

Please feel free to use our water potential theory pages *www.decagon.com/education/water-potential/* or link to them from your own website. ■

Can Water Potential Help Predict a Plague?

A single locust is no big deal. It can eat food equal to its body weight in a single day, but it doesn't weigh much. Under certain environmental conditions, however, this locust becomes *gregarious* and bands together with other locusts to create a fearsome and devastating swarm.

Swarms of plague locusts can cover 1200 square kilometers with up to 80 million locusts packed into a single square kilometer. The swarm can eat almost 200 million kg of plant matter per day, with a devastating effect on agriculture.

Dr. Martin Steinbauer, an Australian entomologist, recently used water potential measurements to investigate how efficiently locust eggs were able to extract water from a variety of different soils. His research may ultimately help the Australian Plague Locust Commission better predict plague conditions and reduce damage from these insects. Read more about this research at:
www.ictinternational.com.au/brochures/locust_egg_survival.pdf ■

Redesigned WP4C Extends Your Water Potential Measurement Range

Learn more about the WP4C—watch a new video online at: www.decagon.com/wp4c

▲ Measure the water potential of soil, soilless substrate, plant tissue, or any porous material in 5 to 10 minutes. Effective range: -0.1 to -300 MPa.

The WP4C measures water potential by determining the relative humidity of the air above a sample in a closed chamber (an AOAC-approved method, conforms to ASTM 6836).

NEW WP4C FEATURES

- **Precise Mode**—verifies full equilibrium before displaying a final reading.
- **Speedy Equilibration**—new hydrophobic teflon impregnated nickel alloy sample chamber coating reduces equilibration time.
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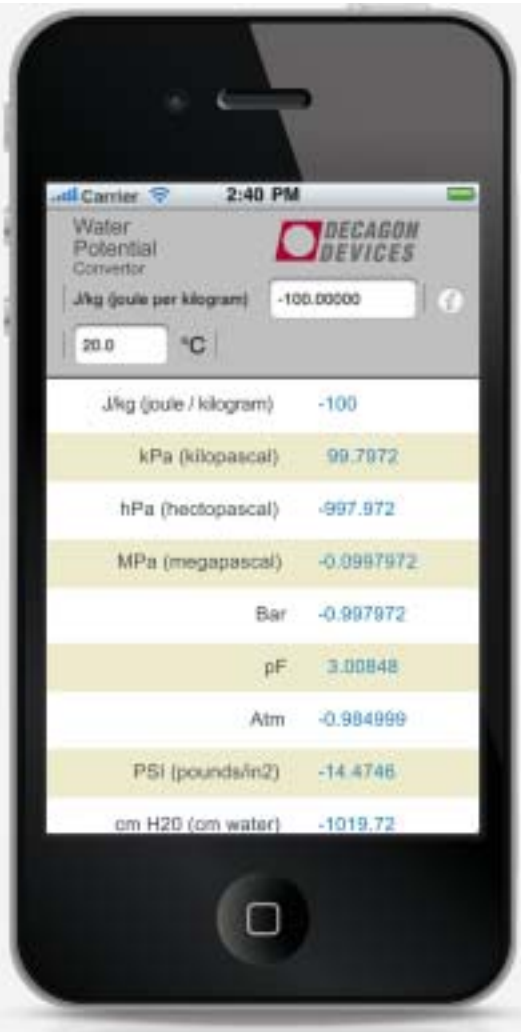
Saturated to Air Dry

Measure water potential over the complete range—with WP4C and HYPROP.

See page 4 to read about the HYPROP.



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