DECAGON
2006

Canopy News

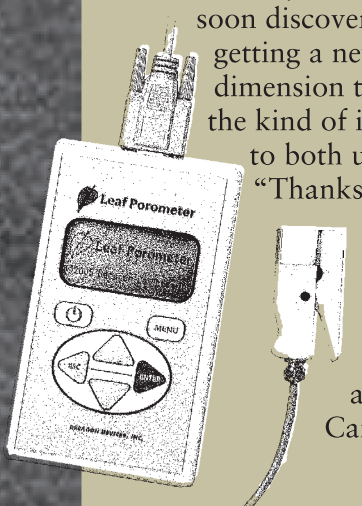
▸ **Marsh Mallow**
Althaea officinalis
Marsh mallow is native to Europe; it was brought to America as a medicinal plant and cough suppressant. Marshmallow is also a spongy confection made of corn syrup and gelatin. The traditional recipe used the root of the Marsh Mallow, instead of gelatin.

First Look at the Steady-State Porometer

I'M LOOKING at a desk full of scientific equipment, an array of commercially available porometers. It looks like a setup for the game "One of these Things is Not Like the Others," and Decagon's new offering is the odd one out. Among larger instruments sprouting hoses and cables, the sleek little unit, about the size of a pocket dictionary, looks remarkably simple. Just one cable connects to a sturdy sensor head. Research Products Manager Bryan Wacker worries that it might be a little too much of a good thing. "I can just hear people saying, 'No air tubes, no dessicant, no motor, no fan? How can this be a porometer?'" he explains.

Like a New Pair of Glasses

I'm trying to listen, but I already have the instrument in my hand and I've clamped it onto his office plant, which is giving me a very low reading. He waves me off. "It's been a while since I've watered. Here, come try Kristy's plants. She's one of those daily waterers." I soon discover the fascination of this porometer—it's like getting a new pair of glasses. Suddenly I'm seeing a new dimension to the world. I want to test every leaf in sight. It's the kind of instrument even a kid could love—intuitively easy to both use and understand. In fact, a beta tester wrote, "Thanks for sending the instructions. I don't need them."



▴ Decagon's new leaf porometer uses a steady-state technique to measure stomatal conductance.

No More Pumping Air

It's clearly a very cool thing, but does it work? Is it really possible to measure stomatal conductance without drying and blowing any air? For the answer, I go talk to Dr. Gaylon Campbell, the brains behind this new technology.

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Measuring Chi Value for the LP80 Ceptometer

LEAF AREA INDEX is the one-sided green leaf area of a canopy or plant community per unit ground area. To *directly* measure LAI, you would have to measure the area of each leaf in the canopy above a unit of ground area. Because this method is both destructive and incredibly time consuming, it is rarely used. All other measurements of leaf area index, from hemispherical photos to optical sensors, attempt to approximate this value. The LP-80 finds LAI by measuring photosynthetically active radiation above and below the canopy. The LP-80 uses those PAR values to calculate leaf area index.

Describing the Orientation of Leaves

The LP80 uses several variables to compute leaf area index (see *How the LP80 Measures Leaf Area Index* in the 2005 issue of *Canopy News* for mathematical details). One of these variables— chi (χ) —describes the orientation of leaves in the canopy.

What is χ?

χ is the "canopy angle distribution parameter." It describes

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DECAGON DEVICES

First Look at Decagon's New Porometer

Mathematics of the Steady State Porometer

DECAGON'S Steady State porometer measures stomatal conductance using a sensor head with a fixed diffusion path to the leaf. It measures the vapor concentration at two different locations in the diffusion path. It computes vapor flux from the vapor concentration measurements and the known conductance of the diffusion path using the following equation:

$$\frac{C_{vL} - C_{v1}}{R_{vs} + R_1} = \frac{C_{v1} - C_{v2}}{R_2}$$

Where C_{vL} is the vapor concentration at the leaf, C_{v1} and C_{v2} are the concentrations at the two sensor locations, R_{vs} is the stomatal resistance, and R_1 and R_2 are the resistances at the two sensors. If the temperatures of the two sensors are the same, conductance can be replaced with relative humidity, giving

$$R_{vs} = \frac{1 - h_1}{h_2 - h_1} R_2 - R$$

Conductance is the reciprocal of resistance, so $g_{vs} = 1/R_{vs}$. ■

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He explains that up until now, porometry has pretty much been about pumping air into and around leaves.

Rudimentary Porometers

Early "Mass Flow" porometers used a blood pressure bulb and valve in combination with a medical clamp and hose to force air through a leaf. By pressurizing air on one side of the leaf and timing pressure drop, researchers hoped to measure flow through the stomates. These porometers could indicate whether stomates were open or closed, but did little else. Forcing air through the leaf was physiologically unsound—it forced stomates to open and the readings taken were not very useful.

Progressive Experimentation

Crude "Null Balance" porometers were built and used by researchers in the 70's. Using equipment ranging from an air mattress pump to a weed sprayer, they pumped just enough desiccated air around a leaf surface to maintain a constant humidity in an enclosed chamber. By measuring the leaf area, air flow rate, and humidity in the chamber, researchers could calculate the stomatal resistance. Later, this concept was used to design sophisticated and effective commercial porometers.

Dynamic Method

"Dynamic" porometers work by sealing a small chamber containing a fast response humidity sensor to the leaf. After pumping dry air through the chamber to achieve some preset humidity, the researcher determines stomatal conductance by measuring the time required for the chamber humidity to rise to some other preset value.

Clunky Instruments

All this air pumping and desiccating makes for a clunky, complicated instrument—the fans, motors, and hoses everyone expects from a porometer. They work well, they measure what they're supposed to, but they aren't very elegant, and worse, they're expensive.

Technical Breakthrough

Inspired by the ideas of Scandinavian researchers measuring skin conductance in burn patients, Dr. Campbell started thinking about a completely different way to measure stomatal conductance—a way that doesn't require moving any air. It relies on a set of equations (shown in the side bar) that allow vapor concentration to be determined from relative humidity measurements in combination with other known values. The sensor head for the porometer is a clamp holding two relative humidity sensors mounted along a fixed diffusion path. By measuring the vapor concentration at two different points along this path, it's possible to compute stomatal conductance, as shown in the sidebar. It was no doubt a complex problem, but

now that it has been solved, it looks simple—a small sensor head, a few electronics, and voila: a porometer about a quarter of the size and price of previous instruments.

Smaller Size Smaller Price

Porometers have been a big money investment—something you had to plan a serious study around. Stomatal conductance data have more general interest, though. They can add significant insight—detailing water use, water balance, and uptake rates of herbicides, ozone, and pollutants as well as indicating water stress. The size and price of this new porometer should make it a tool many canopy researchers routinely use.

Discovery and Understanding

To Dr. Campbell, it's all that—solid science, accurate readings, reliable instrument—and a bit more. You could call it educational possibilities. Or you could just call it the magic of discovery. "Give this to someone with only a passing interest in research, a ten-year-old boy, for example, and he'll go around the garden and come back with some really interesting observations. We gave an instrument to some staff at an in-house demonstration, and they came back having examined variegated leaves. They compared the white to green and discovered that the white areas didn't transpire. Do flower petals transpire? There are lots of questions about what loses water and what doesn't that you can answer with this instrument." ■

About Other Porometers

Doing the Math: Dynamic and Null Balance Porometers

A dynamic porometer measures how long it takes for the humidity to rise from one specified value to another in an enclosed chamber clamped to a leaf. The resistance R is then determined from the following equation:

$$\Delta t = \frac{(R + A) l \Delta h}{1 - h}$$

where Δt is the time required for the cup humidity to change by Δh, h is the cup humidity, l is the cup "length," and A is an offset constant.

Null balance porometers maintain a constant humidity in an enclosed chamber by regulating the flow of dry air through the chamber and find stomatal resistance from the following equation:

$$R_{vs} = \frac{A}{f}\left(\frac{1}{h} - 1\right) - R_{va}$$

where R_{vs} is the stomatal resistance, R_{va} is the boundary layer resistance, A is the leaf area, f is the flow rate of dry air, and h is the chamber humidity.

The resistance values found by these equations are typically converted to conductance values. ■

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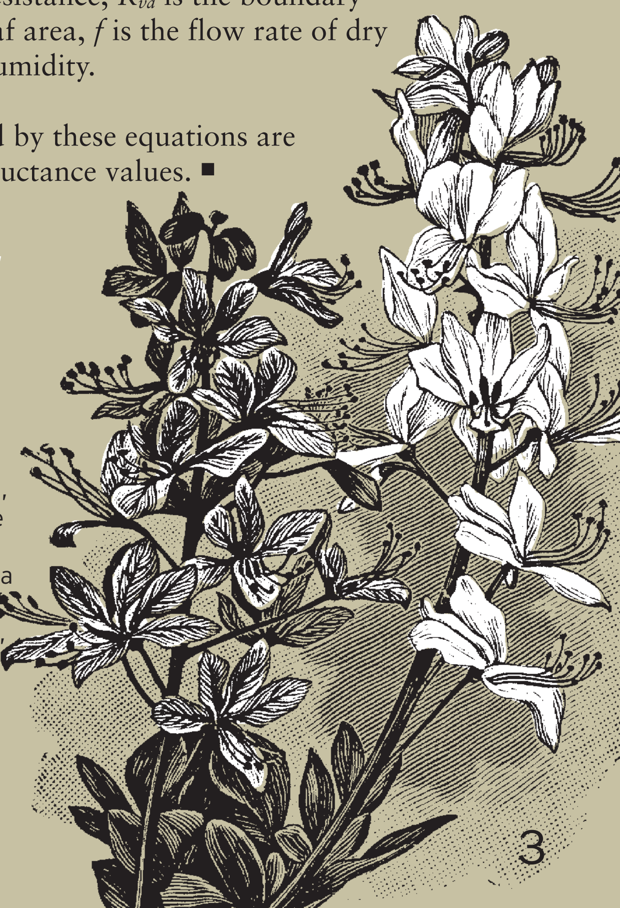

► Gas Plant
Dictamnus albus

The Burning Bush, or Gas Plant, earned its name because of the phenomena that the leaves, flowers and seed pods give off a strong lemon scented vapor which, on a calm summer night, can be ignited with a match.

Tradeshows and Exhibits 2006

American Society for Enology & Viticulture
June 28–30, 2006
Sacramento, California

18th World Congress of Soil Science
July 9–15, 2006
Philadelphia, Pennsylvania

American Society for Horticultural Science
July 27–30, 2006
New Orleans, Louisiana

Ecological Society of America
August 6–11, 2006
Memphis, Tennessee

American Society of Agronomy
November 11–16, 2006
Indianapolis, Indiana

American Geophysical Union
December 12–15, 2006
San Francisco, California

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Decagon Offers Two Workshops

This year Decagon is offering two short courses at the following tradeshows:

18th World Congress of Soil Science, July 8-15, 2006, Philadelphia, PA

Water Content, Water Potential, and Water Flow in Soils—A Short Course for Soil Scientists. Participants will learn about various measurement techniques for a given soil moisture measurement application, to select the appropriate method, and how to install, calibrate, read and maintain a variety of soil moisture sensors.

ASA-CSSA-SSSA, November 11-16, 2006, Indianapolis, IN

Measurement Methods for Plants and Canopies: Water, Light, and Carbon. This workshop focuses on measurements at both plant and canopy scales. The presentation will include information on measurement methods for water balance, plant water relations, light interception, evapotranspiration, and atmospheric transport. Extensive practicum sessions will allow participants to use instruments and analyze sample data to maximize understanding of the methods presented. ■

For more information, please visit:
www.decagon.com/instruments/shortcourse.html

Applications

- Disease forecasting and modeling
- Ecological and agricultural research
- Modeling for blight
- Canopy treatment scheduling

Now Available

New Dielectric Leaf Wetness Sensor

▲ **Monkshood (or Wolfsbane)**
Aconitum uncinatum
Monkshood, an ornamental "buttercup" garden flower, contains large quantities of the alkaloid pseudaconitine—a motor depressant and deadly internal poison that causes suffocation. It is used on poison spears, arrowheads and trap baits. Monkshood applied externally gives an anesthetic action (folk medicine painkiller).

FOR MORE than two years, Decagon has worked to develop a dielectric Leaf Wetness Sensor. By approximating the thermodynamic properties of real leaves, the sensor mimics other leaves in a canopy and accurately measures leaf wetness duration.

How the Leaf Wetness Sensor Works

The Leaf Wetness Sensor approximates the thermal mass and radiative properties of leaves to closely mimic the wetness state of a real leaf. The way it works is simple: if the canopy is wet, the sensor is wet; if the canopy is dry, the sensor is dry. The Leaf Wetness Sensor measures the dielectric constant of the top of the sensor. Water (80) and ice (5) have higher dielectric constants than air (1), so the sensor can determine the presence or absence of wetness from this measurement. Measurements can be logged at user-defined intervals to determine the duration of wetness on the canopy.

Key Challenges

Early designs of the Leaf Wetness Sensor met several key challenges. The original sensor was too thick, giving it too high of a heat capacity. Heat capacity affects the sensors ability to hold water for the same duration as a real leaf. To address this, Decagon's engineers used a fiberglass construction with a thickness of 0.65mm. This gives the instrument a heat capacity which closely matches that of a leaf.

Design Innovation

The Leaf Wetness Sensor's surface treatment also affected its ability to mimic the wetness state of a real leaf. Originally, the sensor surface was green. Although the green coating made the sensor look more like a leaf, it absorbed too much radiation, causing it to dry too quickly. By using a white surface coating, the sensor achieved a radiation balance that closely matches that of a real leaf. The surface coating is also hydrophobic, similar to a leaf with a waxy cuticle. The hydrophobic surface means the sensor will only detect moisture when moisture is present; it will not give a false positive reading during periods of high relative humidity.

Despite these early setbacks, the Leaf Wetness Sensor closely mimics the wetness state of a real leaf, resulting in a convenient, accurate solution to monitoring leaf wetness. ■

The LP80 makes fast, direct measurements of photosynthetically active radiation in canopies. You get instant PAR measurements when you turn it on. You also get a measurement of leaf area index–LAI. But where does this LAI measurement come from, and how accurate is it?

▶ continued from page 1

the architecture of a canopy—how its leaves are oriented in space. Leaves that are distributed randomly in space are said to have a spherical distribution, meaning that if each leaf in the canopy were carefully moved without changing its orientation, the leaves could be used to cover the surface of a sphere. A canopy with spherically distributed leaves has a χ value of 1.

Species-to-species Variation in Canopy Architecture

Many canopy architectures tend to be more horizontal ($\chi > 1$) or vertical ($\chi < 1$). Some canopy types have published χ values—a list of some of these appears in the LP80 manual. But because this value can vary from species to species, it's important to be able to approximate the value for yourself.

Improving LAI Approximation

It's tempting to want an exact number for χ, accurate to at least a couple of decimal places. But because of the incredible variation in canopies, this kind of accuracy is impossible to attain. Leaf area index numbers, though valuable, are always just approximations. A good χ value improves the accuracy of this LAI approximation. But even with a less accurate χ value, LAI approximations will probably be fairly accurate depending on other conditions (see sidebar on opposite page.)

Gap Fraction: Depth and Width Ratio

To approximate a χ value for a canopy, find a representative clump of canopy of equal depth and width. Then determine vertical gap fraction ($\chi 0$)—the percentage of light to shade you see vertically through the clump—and the horizontal gap fraction ($\chi 90$)—the percentage of light you see horizontally through the clump. In a canopy of perfectly vertical leaves, for example, you might see about 10% light to 90% shade horizontally—($\chi 90$) = 0.1—and 100% light vertically—($\chi 0$) = 1. χ is found from the following simple equation:

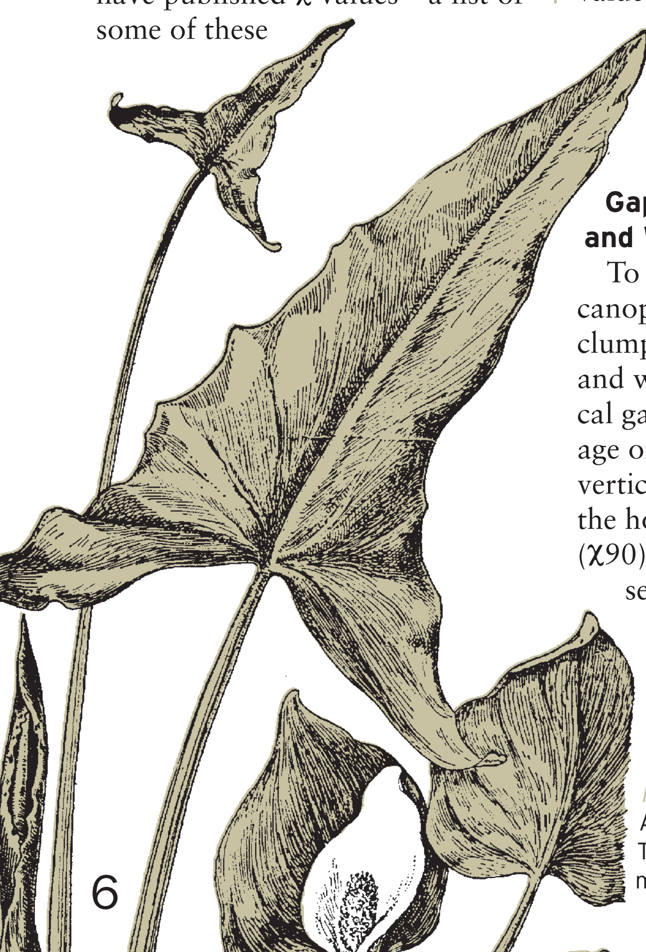
$$\chi = \frac{\ln \tau_0}{\ln \tau_{90}}$$

EQUATION 1

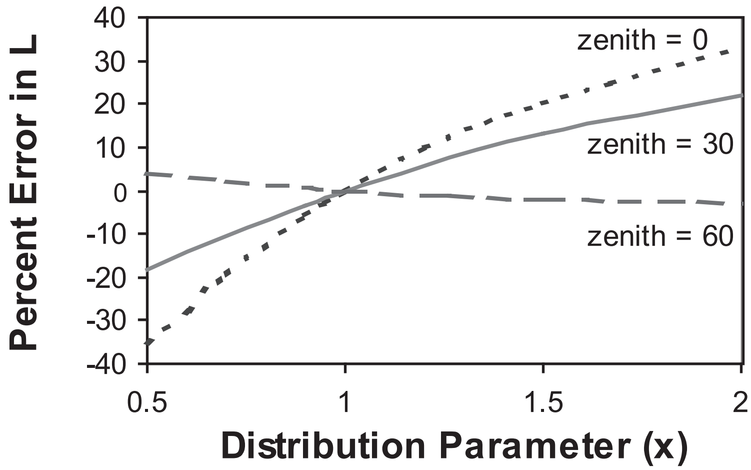
Using this equation, $\chi = 0$ for a perfectly vertical canopy. If the leaves were spherically distributed, with about 10% light visible both vertically and horizontally, ($\chi 90$) = ($\chi 0$) = 0.1. Then, using this equation, $\chi = 1$. (This is, incidentally, the LP80's default χ setting.)

Estimating Gap with an Imaginary Cube

For practical purposes, it can be difficult to estimate the amount of light visible through a "representative clump" of the canopy. You may find it easier to make a backdrop and use it to help you analyze the canopy (we used a one meter by one meter square of colored posterboard.) Find a clump reasonably typical of the canopy you are studying. The clump should include all the typical elements of the canopy—if you are studying row crops, for example, the clump should go from the center of one row to the center of the next to include the



◀ **Arrow Arum**
Peltandra virginica
Arrow Arum is a freshwater wetland plant also known as "duck corn". The seeds contain calcium oxalate crystal (kidney stone producing), so most marsh birds (other than wood ducks) don't like them.



characteristic gap in the canopy that occurs between rows. Imagine dissecting the clump into a cube. To estimate χ90, use the backdrop to form the back side of the cube and position yourself at the front side to make your estimate of the percent of light that is transmitted horizontally through that cubic section of canopy. To estimate χ0, use the backdrop to form either the top or bottom of the cube and position yourself at the opposite end to estimate the percent of light transmitted vertically. Then find χ from equation 1 on the opposite page.

Check the reasonableness of your estimation by remembering that the χ values for more horizontal canopies are greater than one while those of more vertical canopies are less than one. You can specify the χ value for the canopy in the Setup: Set x menu of the LP80.

Using this method, you should be able to estimate a χ value that will minimize uncertainty in the final leaf area index value. ■

▲ This figure above shows the percent error in the LP80 calculation of L if the LP80 is set to x = 1 and the actual distribution parameter of the canopy is the value shown in the figure. It assumes full sun (f_b = 0.8). Note that the error depends on the zenith angle of the sun. Most measurements will occur with zenith angles greater than 30 degrees, so the error in full sun, with no canopy distribution parameter information, is at worst 20%. This error decreases with decreasing values of f_b, and becomes zero when f_b is zero. If the canopy distribution parameter can be estimated with an accuracy of 10% or better, the error in LAI will be 5% or better even at zenith angle of zero. Uncertainty in the distribution parameter is therefore not likely to contribute significantly to uncertainty in LAI.

LAI OR PAR— WHO'S ON FIRST?

Getting a value for leaf area index is often just a point along the way. If you plan to use LAI to model environmental interactions of the canopy, measuring photosynthetically active radiation (PAR) may be a more direct route. That's because many of these mathematical models use LAI to predict PAR in their internal equations. Sometimes researchers use PAR to predict LAI, then unwittingly put the LAI number in a model that goes back the other way. You may want to evaluate whether LAI is the most useful parameter in your particular application. It is sometimes more straightforward, and usually more accurate, to simply measure intercepted PAR and use that data directly in an appropriate model.

CanopyNews

■ Sharp prongs make soil insertion easy.

▲ **New ECH$_2$O-TE sensor measures water content, electrical conductivity, and temperature—all in one.**

FEATURES

- Get 3 readings per Em50 port.
- The higher frequency reduces texture and electrical conductivity effects.
- Digital measurement of soil moisture provides high accuracy readings.
- Serial communication.
- Fewer cables.

APPLICATIONS

- Moisture and salinity monitoring in engineered media or artificial soil.
- Closely monitor fertigation and its results over time.
- Monitor temperature and water use over time.
- Measure temperature, water content and electrical conductivity.

Dielectric Leaf Wetness Sensor Now Available

INNOVATIVE and easy-to-use, the new Dielectric Leaf Wetness Sensor enables accurate and affordable leaf wetness monitoring. Many fungal and bacterial diseases affect plants only when moisture is present on the leaf surface. The Leaf Wetness Sensor determines the presence and duration of wetness on a leaf's surface, enabling researchers and producers to forecast disease and protect plant canopies.

Long-term Leaf Wetness Monitoring

Because the Leaf Wetness Sensor measures the dielectric constant, moisture does not need to bridge electrical traces for the sensor to detect moisture; the presence of water or ice anywhere on the sensor surface will be detected. Unlike common resistance-based sensors, it requires no painting or user calibration, and it can detect ice presence. The low power requirement and long battery life (2+ years with Em50 Datalogger) enable effective long-term leaf wetness monitoring. ■

Benefits

- Imitates characteristics of a real leaf.
- Requires no painting or user calibration.
- Not a resistance method.
- Can detect ice on the "leaf" surface.
- Low power requirements enable long-term leaf wetness monitoring.
- High resolution detects trace amounts of water or ice on the sensor surface.

◄ **Mate** *Ilex paraguarensis* Yerba mate is a holly shrub. When brewed, it makes a tea-like beverage consumed in Argentina, Uruguay, Paraguay and southern Brazil. 300,000 tons of Mate are produced each year.

Visit www.decagon.com/canopy
or call now for more information.
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