How the LP80 Measures Leaf Area Index

Leaf area index (LAI) is just a single number—a statistical snapshot of a canopy taken at one particular time. But that one number can lead to significant insight, because it can be used to model and understand key canopy processes, including radiation interception, energy conversion, momentum, gas exchange, precipitation interception, and evapotranspiration.

Leaf area index is defined as the one-sided green leaf area of a canopy or plant community per unit ground area. It can therefore be found by harvesting and measuring the area of every leaf in a canopy covering one unit area of ground. In 1971, Anderson developed a less destructive method for finding LAI. Using hemispherical photographs looking upwards, he estimated the fraction of light that penetrated the canopy and applied a predictive mathematical model to approximate leaf area index.

Evaluating "fish eye" canopy pictures was tedious work. An assistant would usually lay a grid over each picture and count what fraction of the squares were light. One lab tech recalls, "After too many hours looking at those pictures, I used to dream in checkers." The "checkers" evaluation allowed investigators to find the probability that a random beam of light would penetrate that particular section of canopy.

The mathematical model that converts this fraction of light into an estimate of leaf area index is relatively simple. To understand how it works, picture holding a leaf with an area of ten square centimeters horizontally over a large white square. It would cast a shadow of ten square centimeters. Then, randomly place an identically sized leaf over the square. In all probability, the shadow cast would now be twenty square centimeters, although there is a small chance that the leaves might overlap. When a third leaf is added, the probability of overlap increases, and as more and more leaves are randomly placed, eventually the white square will be completely shaded, and though leaf area will increase as leaves are added, the shaded area will remain constant because all light has been intercepted.

LAI Conversion
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 models are using LAI to predict PAR in the first place. It's possible to go back the other way—to use PAR to estimate LAI. But why do that if PAR is the number you really want? 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.

The equation describing this phenomenon (see Solving the Equation below for its mathematical derivation) is

$$\tau = \exp(-KL)$$

t is the probability that a ray will penetrate the canopy, L is the leaf area index of the canopy, and K is the extinction coefficient of the canopy. If you measure photosynthetically active radiation both above and below a canopy on a bright sunny day, the ratio of the two (PAR below to PAR above) is approximately equal to t. If you know K, you can find leaf area index (L), by inverting the equation:

$$L = -\ln \tau / K$$

The LP80 basically solves this equation to find leaf area index. But there are a couple of complicating factors. In constructing the model, we assumed that the leaves in our artificial canopy were horizontal and black, and that all radiation came directly from the sun. In reality, the angle of the sun changes over the course of the day, and real canopies have quite complex architecture. Also, some radiation is scattered both from leaves in the canopy and from the sky. A full model for finding the leaf area index from a measure of photosynthetically active radiation includes corrections for all of these factors.

$$L = \frac{\left[(1-\frac{1}{2K})f_b - 1\right]\ln\tau}{A(1-0.47f_b)}$$

This equation, which is the one actually used by the LP80, adjusts for the amount of light absorbed (and not scattered) by the leaves in the term A and for the fraction light which enters the canopy as a beam (as opposed to diffuse light from the sky or clouds) in the term f_b. K, the extinction coefficient of the canopy, includes variables for the zenith angle of the sun and for leaf distribution. If you specify your location and set the internal clock to local time, the LP80 calculates the zenith angle of the sun at the time of each measurement. Leaf angle distribution is assumed to be spherical unless you indicate otherwise.

Solving the Equation

If we divide a canopy of randomly distributed horizontal black leaves into so many layers that each layer contains an infinitesimally small fraction of leaf area (dL), the change in radiation from the top to the bottom of that layer is

$$dS_b = S_b dL$$

In other words, the change in the average quantity of sunlight passing through this fraction of the canopy (dSb) is equal to negative (because the amount of light decreases as leaf area increases) the average amount of radiant power per unit area (S_b) times the change in leaf area index (dL). This is a variables separable differential equation. Dividing both sides by S_b and integrating from the top of the canopy downward, we obtain

$$\int_{S_b}^{S_{bo}} \frac{dS_b}{S_b} = -\int_o^L dL$$

Performing the integration gives

$$\ln\left[\frac{S_b}{S_{bo}}\right] = -L$$

Taking the exponential of both sides gives

$$\tau = \frac{S_b}{S_{bo}} = \exp(-L)$$

S_{bo} is the radiation on a horizontal surface above the canopy; t is the probability that a ray will penetrate the canopy, which is the same as the ratio of the beam radiation at the bottom of the canopy to the beam radiation at the top (since we assume no scattering of radiation in the canopy). For canopies with non-horizontal leaves the result is the same except L is replaced by KL, where K is the extinction coefficient of the canopy.

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