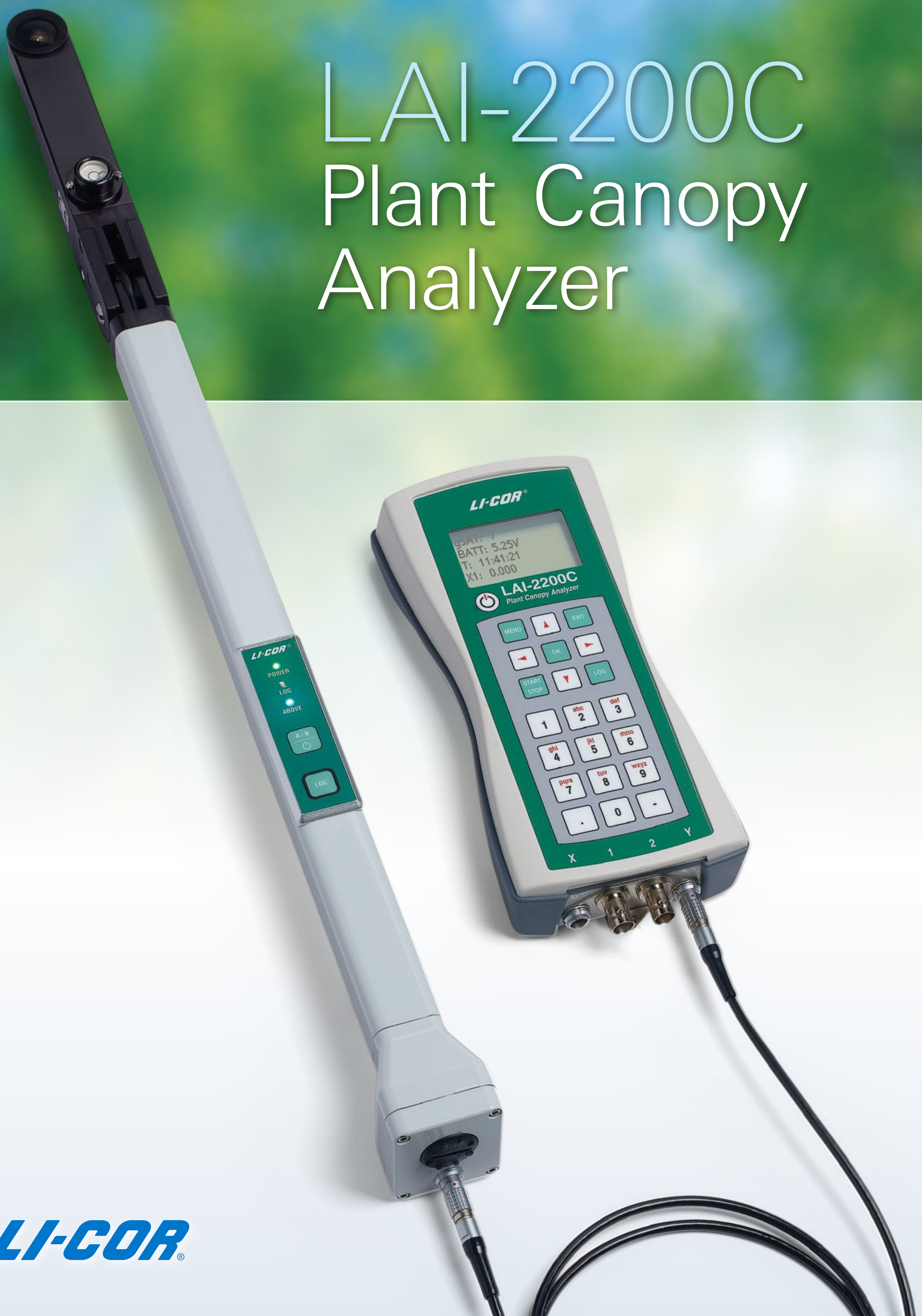
LAI-2200C
Plant Canopy Analyzer



LI-COR

World Standard for Indirect LAI Measurements

The LAI-2200C Plant Canopy Analyzer calculates Leaf Area Index (LAI) and other canopy structure attributes from radiation measurements made with a fisheye optical sensor (148˚ field of view). Measurements made above and below the canopy are used to determine canopy light interception at five angles, from which LAI is computed using a model of radiative transfer in vegetative canopies.

The LAI-2200C consistently outperforms other methods in terms of flexibility, advanced features, accuracy, and ease of use.

Canopy Variety

Computes LAI even in row crops and isolated trees that other methods cannot measure.

Any Sky

Accurate in most daylight conditions, unlike other methods that require specific sun angles or cloud cover.

GPS Integration and Mapping

Internal Global Positioning System (GPS) module integrates location data into the LAI file for easy mapping in Google Earth.

Proven Results

Designed by scientists and engineers to provide quick and accurate results, as well as advanced processing options.

Applications

Ideal for studies of canopy growth, canopy productivity, forest vigor, canopy fuel load, air pollution deposition modeling, insect defoliation, remote sensing, and the global carbon cycle.

The LI-COR Advantage

Short canopies

The low-profile sensor head in the LAI-2200C allows Leaf Area Index (LAI) measurements in short canopies such as grasslands.

Tall canopies

In forests, automated logging can collect above-canopy readings in a clearing while a second LAI-2250 Optical Sensor is used for below-canopy readings. When ceptometry methods are used in tall canopies, it is not possible to use the sun-fleck or gap-fraction mode because shadows are blurred due to the penumbra effect.

Row crops and non-uniform canopies

The LAI-2200C measures the LAI of small plots, gapped, and non-uniform canopies simply and easily by restricting the view in terms of both azimuth (with view restricting caps) and zenith angles (by excluding one or more of the view rings). With ceptometry methods, it is not possible to restrict either the azimuth or the zenith view angles.

Isolated Trees

Foliage density (m^2 foliage area per m^3 canopy volume) is the result when measuring an isolated tree with the LAI-2200C. The File Viewer 2200 software package calculates canopy volume from simple measurements describing the average shape of the tree's crown, and then calculates foliage density. Isolated trees cannot be measured with ceptometry methods because sun-flecks are not distinct for trees taller than a few meters and it may be impractical to wait for the sun angle to change to get measurements at multiple angles.

The LAI-2200C Plant Canopy Analyzer works well for a wide variety of canopy types, including:

- Grasslands
- Forests
- Row crops
- Hedges
- Small plots
- Isolated trees

Optical Sensor

Fisheye lens with hemispheric field-of-view

Ensures that Leaf Area Index (LAI) calculations are based on a large sample of the foliage canopy.

Five silicon detectors arranged in concentric rings

Saves time — no need to wait for the sun's position to change. Measures light from five different zenith angles with one reading.

Filter reduces errors from transmitted and reflected light

Sensor receives radiation below 490 nm only, where leaf reflectance and transmittance are minimal.

Automatic logging and autonomous modes

An unattended optical sensor can record readings at specified intervals without being attached to the console. When measuring tall canopies using two optical sensors, for instance, an unattended optical sensor can be used to make above-canopy readings in a clearing.

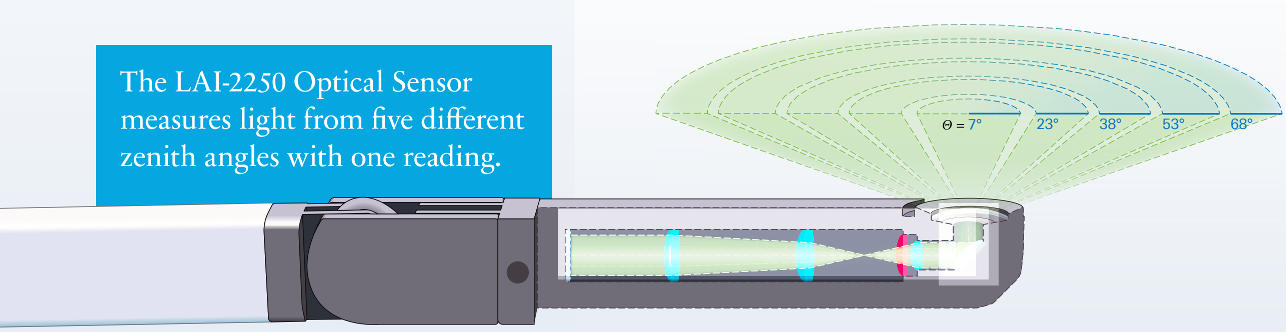
View restricting caps

Allow for LAI measurements of small plots and hedges by blocking undesired objects from the sensor's view, such as the operator or a neighboring plot.

Correction for light scattering

Measurements can now be done throughout the daylight hours, even under clear skies (see page 8, Light Scattering Correction).

The LAI-2250 Optical Sensor measures light from five different zenith angles with one reading.



Console

Menu-driven interface

View GPS coordinates, Leaf Area Index (LAI), standard error LAI, apparent clumping factor, mean tilt angle (MTA), standard error MTA, sample size, and more. Basic data processing is available directly on the console.

Integrated GPS

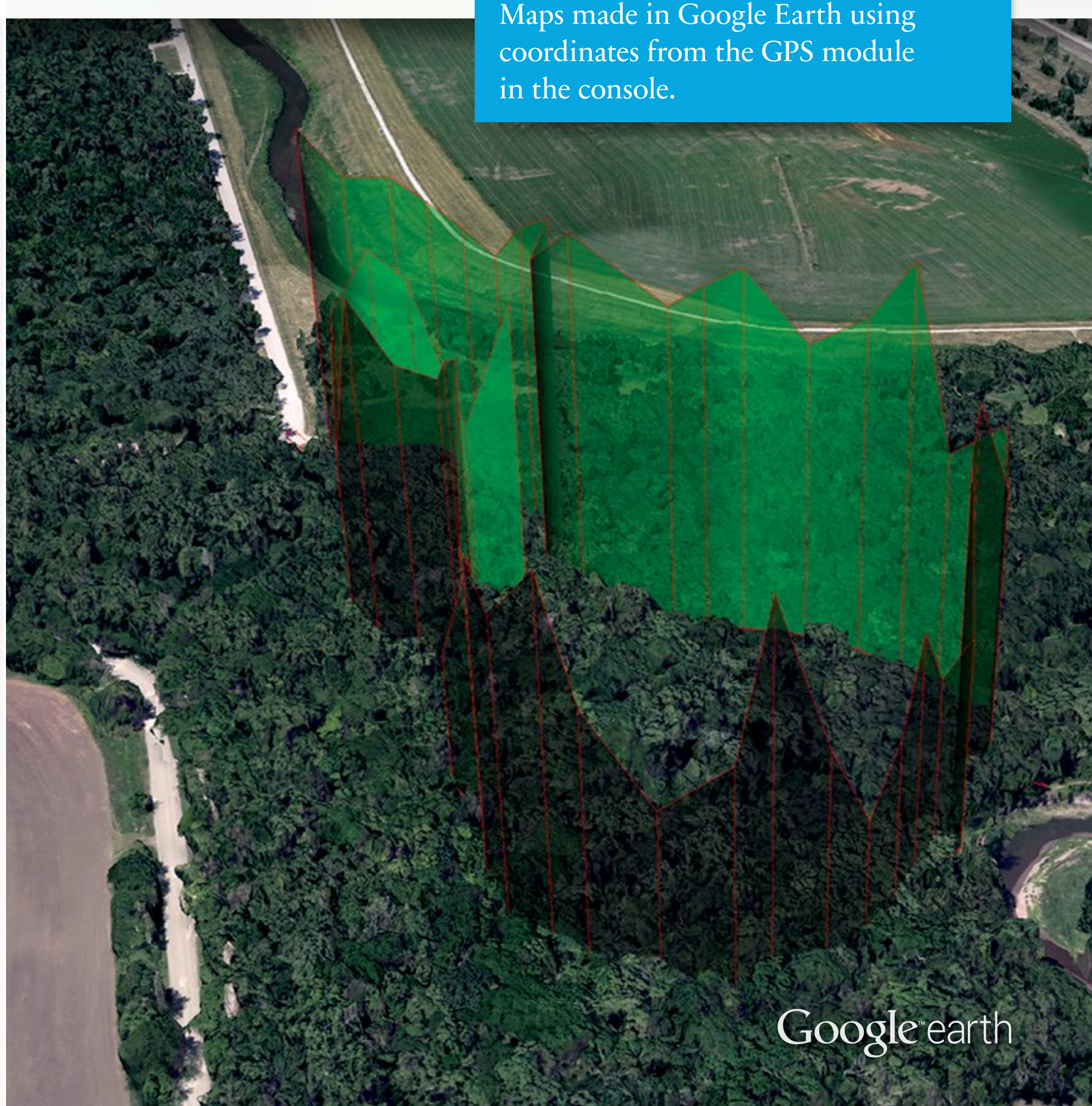
Add location information with each reading or log GPS data independently with GPS tagging.

Light sensor logging

Use the two BNC connectors for attaching LI-COR quantum, pyranometer, or photometric sensors.

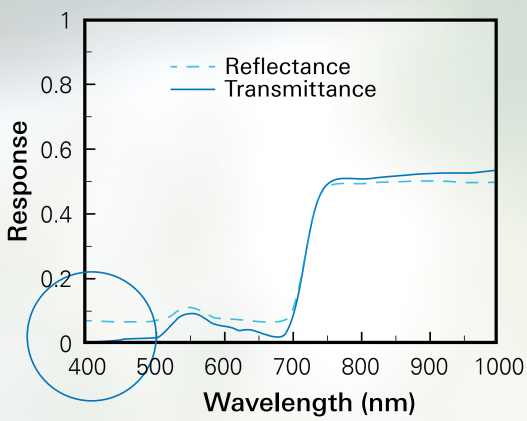
User-friendly features

Take advantage of automatic logging, USB data transfer, and a memory capacity of 1.5 million readings.



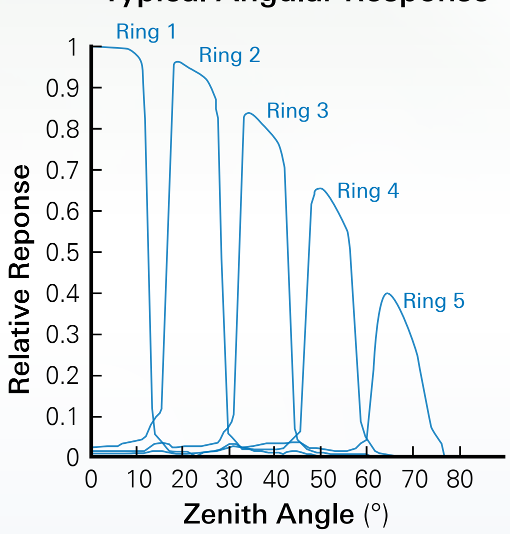
Maps made in Google Earth using coordinates from the GPS module in the console.

Typical Foliage Reflectance & Transmittance



The 490 nm filter minimizes the contribution of radiation scattered by the foliage, which is very low below 490 nm. The detector in the optical sensor responds from approximately 320-490 nm (circled region).

Typical Angular Response



Each detector ring responds over a different range of zenith angles.

Theory of Operation

The LAI-2200C Plant Canopy Analyzer uses the gap fraction technique — the most powerful and practical tool available for indirect sensing of canopy structure. The gap fraction of a canopy is the fraction of view in some direction from beneath a canopy that is not blocked by foliage.

Calculating Leaf Area Index (LAI) with the LAI-2200C requires certain assumptions about the plant canopy. This allows accurate measurements without the need to destructively sample the canopy. The LAI-2200C relies upon these four assumptions:

1. The foliage absorbs all light that is incident upon it. Foliage has low transmittance and reflectance in the waveband detected by the optical sensor (below 490 nm). With scattering correction (see page 8), it is now possible to correct for errors caused by any transmittance or reflectance that does affect readings.
2. The foliage elements are small compared to the area of view of each ring. This is ensured when the distance from the optical sensor to the nearest foliage element, such as a leaf, is at least four times the element width.
3. The foliage is randomly distributed within certain foliage containing envelopes. These envelopes might be parallel tubes (a row crop), a single ellipsoid (an isolated bush), an infinite box (turf grass), or a finite box with holes (deciduous forest with gaps).
4. Foliage is azimuthally randomly oriented. It does not matter how the foliage is inclined, but the leaves should be facing all compass directions.

No real canopy conforms exactly to these assumptions. Offsetting errors are common, such as when leaves are grouped along stems (increasing light transmittance), but arranged to minimize overlap (decreasing transmittance). Most violations of the assumptions can be overcome with the proper measurement techniques, and the model has been proven to work well even if all the assumptions are not met exactly. The LAI-2200C is designed to take these factors into account and quickly deliver accurate results.

Calculating Leaf Area Index

Leaf Area Index (LAI) is the ratio of foliage area to ground area. The LAI-2200C Plant Canopy Analyzer computes LAI from measurements made above and below the canopy, which are used to determine canopy light interception at five angles. These data are fit to a well-established model of radiative transfer inside vegetative canopies to compute LAI, mean tilt angle, and canopy gap fraction.

The approximate field-of-view of each ring is simulated by the fisheye photo (above), where concentric circles represent the five view angles.

The optical sensor of the LAI-2200C consists of a fisheye lens and an optical system. The fisheye lens takes in a hemispherical image, which the optical system focuses onto the five-ring photodiode optical sensor.

Each detector ring views a different portion of the canopy or sky centered on one of the five view angles. The fraction of diffuse incident radiation that passes through a plant canopy, for each view angle, can be expressed as

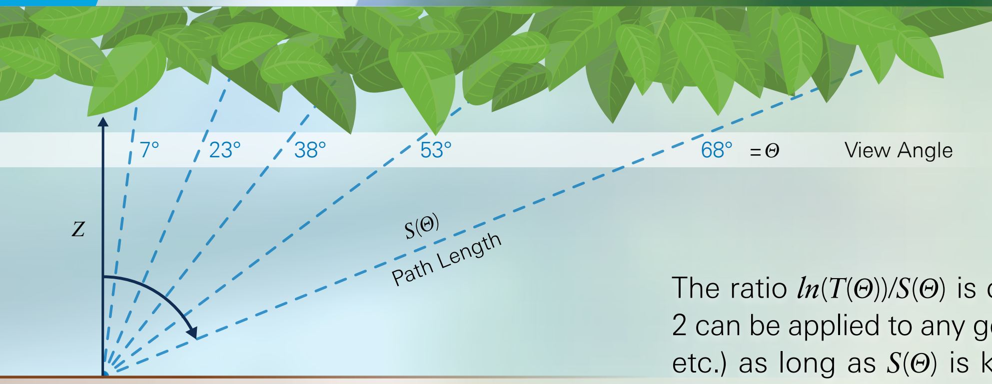
$$\frac{\text{Diffuse intensity below the canopy at view angle } \Theta}{\text{Diffuse intensity above the canopy at view angle } \Theta} = T(\Theta)$$

$T(\Theta)$ is the probability of diffuse non-interceptance for a given view angle (ring) called the gap fraction; it is analogous to a transmittance. $T(\Theta)$ depends on foliage orientation, foliage density, and path length through the canopy in the same way that light transmittance through a solution depends upon the extinction coefficient, absorber concentration and path length, i.e., according to the Beer-Lambert Law.

$$T(\Theta) = \exp(-G(\Theta)\,\mu\, S(\Theta)) \quad \text{— or —} \quad -\ln T(\Theta) = G(\Theta)\,\mu\, S(\Theta) \tag{1}$$

where $G(\Theta)$ is the fraction of foliage projected toward view angle Θ (view ring), μ is the foliage density (m^2 foliage per m^3 canopy; analogous to concentration), and $S(\Theta)$ is the path length through the canopy for each view angle, Θ. Miller (1983) gives an exact solution for foliage density, μ;

$$\mu = -2\int_0^{\pi/2} \frac{\ln(T(\Theta))}{S(\Theta)} \sin\Theta \, d\Theta \tag{2}$$



The path length of the optical sensor's view through a full cover canopy varies by view angle.

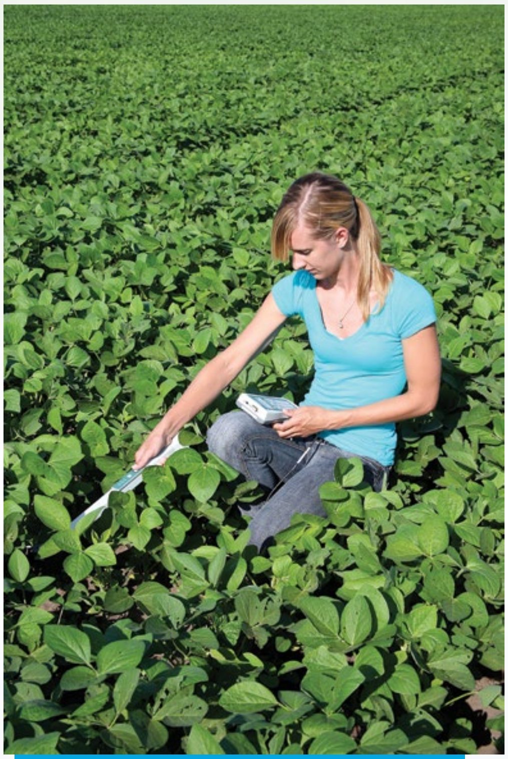
The ratio $ln(T(\Theta))/S(\Theta)$ is called the contact number (m^{-1}). Equation 2 can be applied to any general canopy shape (rows, isolated plants, etc.) as long as $S(\Theta)$ is known. For full cover canopy of height z, $S(\Theta)=z/cos\Theta$; and $LAI = \mu^* z$, so Equation 2 may be rewritten

$$LAI = -2\int_0^{\pi/2} ln(T(\Theta))\, cos\,\Theta\, sin\,\Theta\, d\Theta \qquad (3)$$

The LAI-2200C implements this equation by numerical integration using the five measured view angles. The detector geometry fixes the value of $sin\Theta d\Theta$ for each ring, allowing computation of a constant weighting factor $w(\Theta_i)$ for each ring. The numerical integration then becomes quite simple:

$$LAI = -2\sum_{i=1}^{5} ln(T(\Theta_i))\, cos\,\Theta_i\, w(\Theta_i) \qquad (4)$$

where the subscript i refers to each of the detector rings with view angle centered at Θ_i.



The LAI-2200C accounts for clumping in non-uniform canopies when computing LAI.

Clumping

Multiple canopy transmittance measurements are normally taken for computing LAI. The individual transmittances can either be averaged before computing LAI, or more appropriately, the logs of the individual transmittances should be averaged before computing canopy LAI, as this accounts for clumping on spatial scales that are larger than the field of view of the sensor. The LAI-2200C computes LAI in both ways but reports the values based on the latter method. The ratio of the LAI values calculated using the two methods is used to estimate an Apparent Clumping Factor (Ryu et al., 2010; Leblanc et al., 2005; Van Gardingen et al., 1999; Nilson, 1999; and Nilson and Kuusk, 2004).

Foliage Orientation

The LAI-2200C calculates mean tilt angle (MTA) after Lang (1986). Alternative orientation information, such as gap fraction in various angle classes can be calculated using the included FV2200 software (Windows®, Mac® OSX®, and Linux versions).

Light Scattering Correction

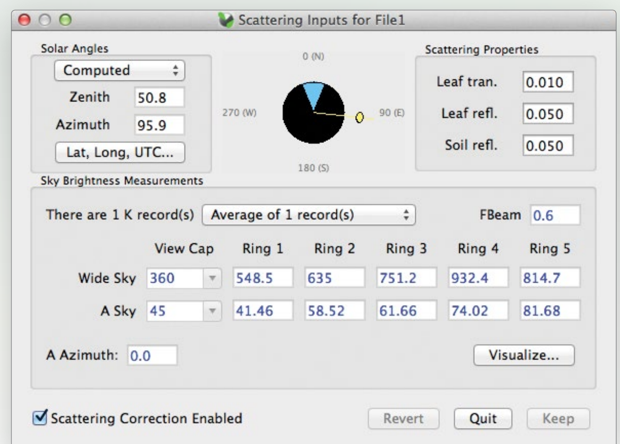
One of the traditional assumptions of the predecessors to the LAI-2200C Plant Canopy Analyzer (the LAI-2000 and LAI-2200) has been that foliage absorbs all the radiation in the blue waveband seen by the sensor (320-490 nm). This is a good assumption under diffuse light conditions such as uniform overcast, just before sunrise, or just after sunset. In direct sunlight, however, reflectance off foliage causes a much greater overestimation of the gap fraction and underestimation of Leaf Area Index (LAI). Therefore these previous versions required the user to perform measurements under overcast skies, just before sunrise, or just after sunset.

With the release of version 2.0, the FV2200 software package now provides a mechanism for correcting measurements for the radiation reflected and transmitted by the foliage (following the model presented in Kobayashi et al., 2013), allowing users to perform measurements under almost any sky condition. We recommend this correction for data be taken in direct sun, but you can also correct data taken when the sun is obscured, adjusting for the actual foliage scattering properties in your plots rather than assuming reflectance and transmittance are both zero.

Scattering correction is a significant improvement, especially where many below-canopy readings are needed, such as heterogeneous forest canopies. Measurements can now be done throughout the daylight hours, even under clear skies. Partly cloudy skies are still challenging, especially when fast-moving clouds are present, but can be accommodated with the proper sampling technique. Full details on how to perform these measurements are included in the instruction manual.

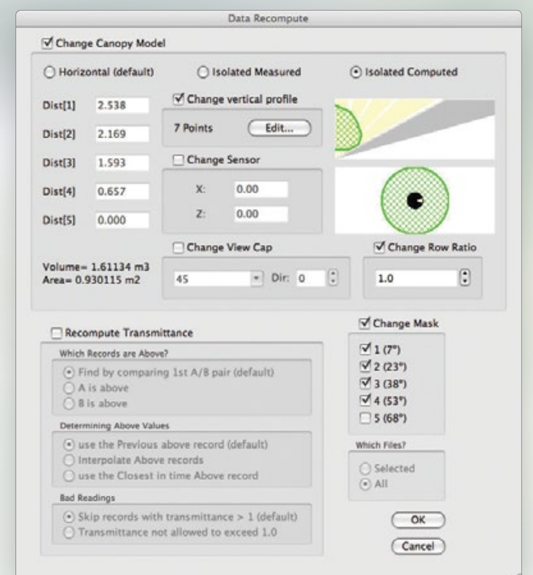
For more information on the light scattering correction, visit: www.licor.com/light-scattering.

Using an optical sensor with diffuser cap to measure sky radiation properties for light scattering correction.



The FV2200 light scattering correction interface.

File Viewer Software (FV2200)



The FV2200 recompute interface, showing a masked outer view ring.

File Viewer 2200 Software is a powerful tool that emulates the functions available on the console, provides a wide range of processing options, and offers many additional functions:

Applies scattering corrections

Accounts for foliage reflectance and transmission.

Maps Leaf Area Index (LAI)

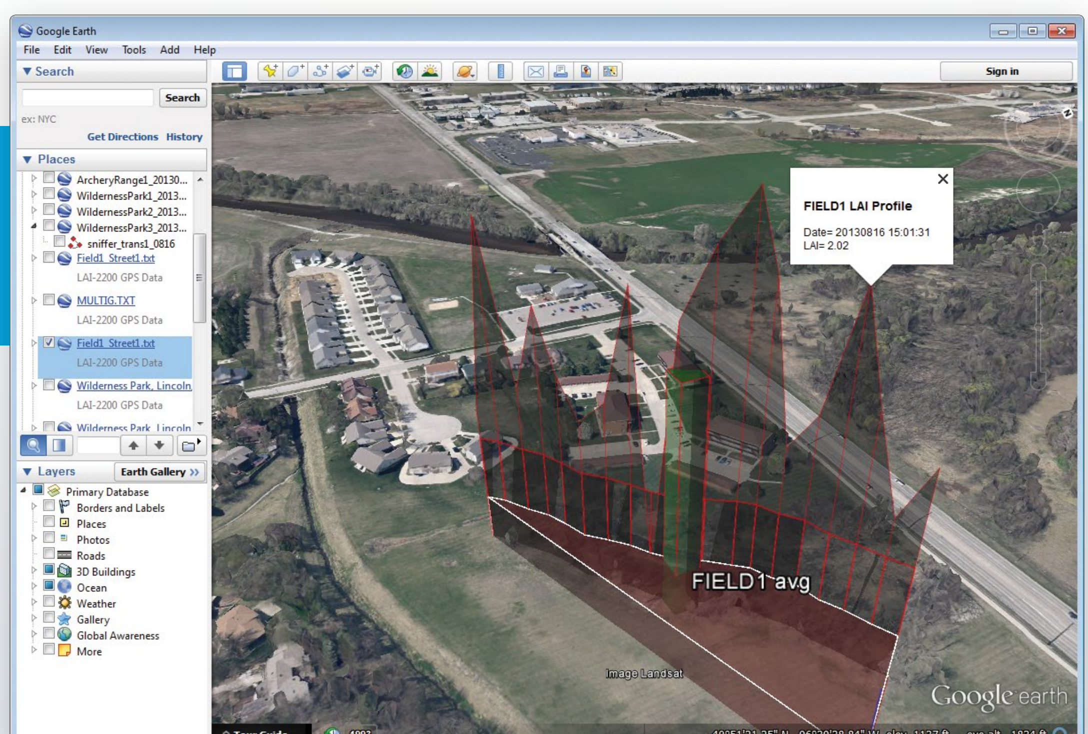
Uses data from the integrated GPS module. Creates KML files for viewing in Google Earth. Options include an LAI profile (3-D path), average LAI, polygons (delineating a study site), or a path for “above” or “below” readings.

Recomputes LAI with alternative settings

Applies different transmittance models and view angles (rings). Masking one or more rings can be useful for small plots.

Recomputes LAI for complex canopies

Makes it possible to evaluate row crops, grape vines, and hedges with irregular profiles, as well as asymmetric individual plants.



Mapping options include an LAI profile – graphically illustrating differences in LAI along a path.

Resources

Kobayashi, H., Y. Ryu, D. D. Baldocchi, J. M. Welles, and J. M. Norman. 2013. On the correct estimation of gap fraction: How to remove scattered radiation in gap fraction measurements? Agric. and For. Meteor. 174-175: 170-183.

Lang, A. R. G. 1986. Leaf area and average leaf angle from transmittance of direct sunlight. Aust. J. Bot. 34: 349-355.

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Miller, J. B. 1963. An integral equation from phytology. J. Aust. Mat. Soc. 4: 397-402.

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Ryu, Y., T. Nilson, H. Kobayashi, O. Sonnentag, B. E. Law, and D. D. Baldocchi. 2010. On the correct estimation of effective leaf area index: Does it reveal information on clumping effects? Agric. and For. Meteor. 150, 463-472.

Van Gardingen, P. R., G. E. Jackson, S. Hernandez-Daumas, G. Russell, and L. Sharp. 1999. Leaf area index estimates obtained for clumped canopies using hemispherical photography. Agric. and For. Meteor. 94 (3–4), 243–257.

LAI-2200C Ordering Information

LAI-2200C Plant Canopy Analyzer
Includes one LAI-2250 Optical Sensor with data cable, LAI-2270C Control Unit, carrying case, USB cable, view-restrictors, diffuser cap, 6 “AA” batteries, belt clip, and FV2200 software.

LAI-2250 Optical Sensor
For use with the LAI-2270C in Autonomous mode. Additional sensor can take above readings independently of the control unit. Includes 2 “AA” batteries, view restrictors, diffuser cap and data cable.

LAI-2270C Control Unit
For use with the LAI-2250 Optical Sensor(s). Includes carrying case, USB cable, 4 “AA” batteries, belt clip, and FV2200 software.

LAI-2200TC Plant Canopy Analyzer - Tall Canopy Package
Two LAI-2250 Optical Sensors with data cables, one LAI-2270C Control Unit, carrying case, USB cable, view-restrictors, diffuser cap, 8 “AA” batteries, belt clip, and FV2200 software.

2200CLEAR Clear Sky Kit with GPS Upgrade
For upgrading the LAI-2200 for GPS integration and clear sky measurements. Includes GPS board, flex cable, anti-static wrist strap, 2 light diffuser caps and instructions.

LAI-2200C Specifications

LAI-2270C Control Unit

Sensor Inputs: Two 6-pin connectors for LAI-2250 Optical Sensors; Two BNC connectors for LI-COR Light Sensors.

Data Storage Capacity: 128 MB of FAT16 memory.

Keypad: 22 button tactile response keypad.

Display: 128x64 graphics display.

Communications: USB (as mass storage device).

Global Positioning System (GPS RADIONOVA® RF Antenna Module):

Horizontal position accuracy: 2.5 m CEP (50% Circular Error Probability, Open-Sky, 24hr Static, good view of the sky).

Maximum position update rate: 1 Hz.

GPS receiver sensitivity, autonomous acquisition: -148dBm.

Time to first fix (TTFF), hot start: 1 second; warm start: 6s (typical); cold start (with good view of the sky): 37 seconds at 90% probability.

Clock: Year, Month, Day, Hour, Minute. Accuracy of ±3 minutes per month.

Power Requirements: 4 “AA” (alkaline, NiMH, lithium) batteries.

Battery Life: 90 hours based on 4 “AA” alkaline batteries without optical sensor attached and without GPS enabled.

Low Battery Warning: Display indicates when battery power is <15%.

Size: 20.9 x 9.8 x 3.5 cm (8.2” x 3.9” x 1.4”).

Weight: 0.454 kg (1.0 lb) with batteries.

LAI-2250 Optical Sensor

Sensor Inputs: One 6-pin bulkhead connector for control unit interface.

Memory: 1 MB flash memory for record storage.

Keypad: 2 button, tactile response keypad.

Clock: Year, Month, Day, Hour, Minute. Accuracy of ± 3 minutes per month.

Power Requirements: 2 “AA” (alkaline, NiMH, lithium) Batteries.

Battery Life: 180 hours of typical operation (based on 2 “AA” alkaline batteries).

Optics: 1.00° maximum decentering error as measured from center of mass of ring 4. 0.50° maximum magnification error as measured from the center of mass of ring 4.

Radiation Rejection: > 99% from 490-650 nm; > 99.9% above 650 nm.

Wavelength Range: 320-490 nm.

Nominal Angular Coverage: Ring 1: 0.0-12.3°; Ring 2: 16.7-28.6°; Ring 3: 32.4-43.4°; Ring 4: 47.3-58.1° Ring 5: 62.3-74.1°.

Lens Coating: MgF_2 for improved transmission at oblique angles (external and internal lenses).

View Caps: Provide azimuthal masking of view into quadrants of 10°, 45°, 90°, 180°, and 270°.

Diffuser Cap: Used to cover the lens when measuring sky radiation properties for scattering corrections.

Size: 63.8 L x 2.9 W x 2.9 D cm (25.1” x 1.125” x 1.125”) (Endcap: 4.4 W x 5.1 D cm; 1.75” x 2.0”).

Weight: 0.845 kg (1.86 lbs) with batteries.

Environmental Conditions

Operating Temperature Range: -20 to 50° C.

Humidity Range: 0 to 95% RH (non-condensing conditions).

Storage: -40 to 65 °C.

LI-COR Biosciences

Environmental

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The LI-COR board of directors would like to take this opportunity to return thanks to God for His merciful providence in allowing LI-COR to develop and commercialize products, through the collective effort of dedicated employees, that enable the examination of the wonders of His works.

“Trust in the LORD with all your heart and do not lean on your own understanding. In all your ways acknowledge Him, and He will make your paths straight.”
— Proverbs 3:5,6

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