

**IPAR-LAI Protocol for PINEMAP sampling.
Version 1.4, Revision Date: Oct. 16, 2012**

1.0 Requirements for all Tier 2 and Tier 3 sites.

In order for the IPAR-LAI measurements to be scaled with remote sensing to the broader landscape, center coordinates are required for every plot, and should be included in the metadata files in latitude/longitude.

1.1 Instrumentation

There are two required instruments for standardized measurements of LAI and IPAR across the Tier 2 and Tier 3 PINEMAP sites. These are the LI-COR LAI 2000 Plant Canopy Analyzer (LI-COR Biosciences, Lincoln, Nebraska, USA) and either the Ceptometer (Decogn, Inc.) or the SunScan Canopy Analysis System (Delta-T Devices Ltd., Cambridge, UK). For optimum results, 2 LI-COR LAI 2000 instruments should be used in synchronization, to capture concurrent above- and below-canopy sunlight. However, single sensor mode can be utilized if only one instrument is available. We assume the 2-sensor mode will be utilized for the LAI 2000 – any deviations from this must be clearly identified in the metadata.

A GPS with differential correction capacity will also be required to determine the plot centers.

1.2 Data files, processing, and metadata

To facilitate standardization and to allow for re-processing of original data, both raw and processed data must be stored. Ceptometer data will be processed to determine intercepted photosynthetically active radiation (IPAR), and the LAI 2000 data will be processed for leaf area index (LAI). Metadata should be recorded and saved as a text file, describing the date, lat/long, time, sun conditions, and any deviations from the measurement protocol. To facilitate sharing, the following naming convention should be followed:

Raw Cepometer Data:	site_ddmmyyyy_raw_ceptometer.xxx
Processed Ceptometer Data:	site_ddmmyyyy_IPAR_ceptometer.xxx
Metadata for Ceptometer:	site_ddmmyyyy_metadata_ceptometer.txt

Raw LI-COR LAI 2000 Data:	site_ddmmyyyy_raw_LAI2000.xxx
Processed LI-COR LAI 2000 Data:	site_ddmmyyyy_IPAR_LAI2000.xxx
Metadata for LI-COR LAI 2000:	site_ddmmyyyy_metadata_LAI2000.txt

2.0 Field Protocols and Data Processing for each instrument

2.1 Ceptometer:

The goal of these measurements is to determine what fraction of incoming radiation is captured by the canopy (intercepted photosynthetically active radiation; IPAR). These measurements are an index since intercepted radiation varies with sun angle (which changes annually and diurnally), sky conditions (direct sun vs. clouds), and leaf area development and abscission. To truly estimate the total amount of intercepted radiation, these sources of variation would need to be integrated throughout a full growing season. Given the sources of variability, it is critical that IPAR measurements be standardized to allow them to serve as a comparison across sites (Will et al. 2005).

2.1 1 Conditions and Considerations

- 1) *Measurements should be made in full sun conditions. Measurements can be made on partly cloudy days during the time periods when direct solar radiation is hitting the canopy*¹. Below canopy measurements are compared to measurements of incident radiation conducted in a clearing at a minimum distance from the sunward stand of at least 3.5 times the canopy height. Therefore, constant sun conditions are necessary. Incident radiation under cloudless conditions changes with sun angle, but is constant enough over periods of 15-30 minutes to measure several plots.² Even on days with 'uniformly' overcast conditions, radiation changes too much over short periods. Using full sun conditions biases estimate of IPAR towards the direct radiation component. However, this is acceptable since the majority of total incoming radiation comes from the direct component.

- 2) *Sun angle is critical to consider.* Measurements must be made when the zenith angle is less than $\sim 30^\circ$ (Figure 1). Time of peak leaf area is ideal. However, the sun angle in September becomes too low to conduct measurements in the northern part of the range. A measurement window of between mid-August and mid-September is optimal. This is because the path length through the canopy increases as a function of cosine of the angle of incident radiation. For instance, 30° from zenith results in 15% greater path length through the canopy than 0° . An angle of 45° results in a path length 41% longer. The minimum angle around June 21 in the Southeast is $\sim 10^\circ$, so realistically shoot for a sun angle between 10° and 30° . Around the solstice, that gives 5-6 hours for measurements, but the time window is much smaller in September. For instance, on

¹ Partly cloudy will work with a couple of caveats. The whole point is to have constant conditions between the reference and the below canopy measurements. Even with external references, under cloudy conditions light is variable in space at such a small scale that accurate real time linkage to an external reference is not possible.

² Clock needs to be accurate to synchronize measurements. It should record time as well as sun angle automatically.

August 22, sun zenith angle is $<30^\circ$ between 11:00am and 1:15pm in Richmond, VA (about the furthest north of our research sites) and reaches a minimum of 25° around 12:15. By September 2nd in Richmond, the minimum zenith angle is 30° . You can use web sites such as <http://www.srrb.noaa.gov/highlights/sunrise/azel.html> to calculate sun angles for sites and days you intend to measure. It is possible to develop empirically derived equations to correct sun angle to a common angle (Will et al. 2005). We recommend doing this on Tier III sites. Generic equations developed from similar stands might be acceptable for corrections on Tier II sites.

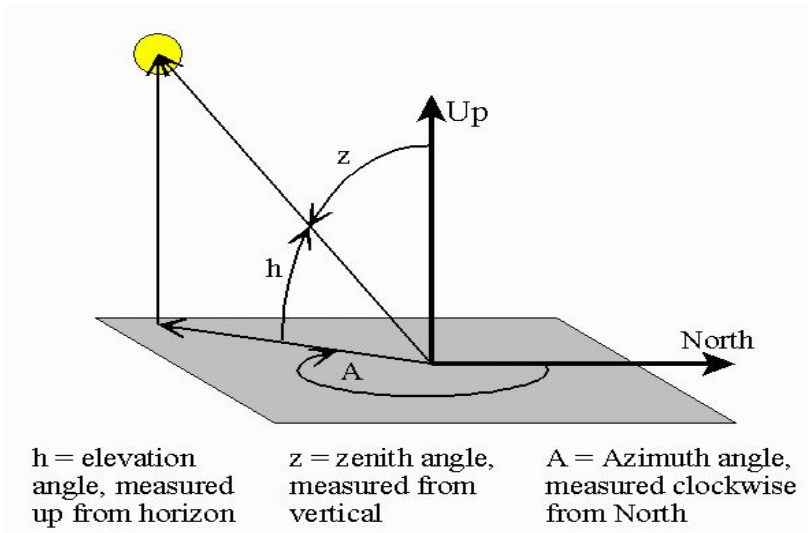


Figure 1. Relationship between solar zenith angle and elevation angle. From: <http://www.srrb.noaa.gov/highlights/sunrise/azelzen.gif>.

2.1.2 Measurement Protocol (Tier II)

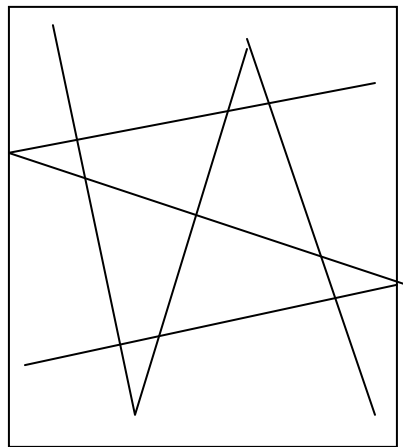
IPAR will be measured in the Tier II sites concurrent with carbon sampling. This will be the time of year near peak LAI. Sun angle may become problematic in September depending on latitude. Measure incident radiation in an adjacent opening with a diameter that is > 3.5 times the height of adjacent trees. Take four readings, one in each cardinal direction with ceptometer level. When processing data, the average of these four will be used to establish incident radiation. Redo the incident radiation measurement every 15-20 minutes. Depending on the site, it may be possible to do several plots before redoing incident readings. Under cloudless skies, incoming radiation is fairly stable and changes slowly in relation to sun angle. For increased accuracy, incident radiation measurements at the beginning and end of sampling period can be interpolated during the measurement period.

Measure radiation beneath the canopy at least 60-70 times (i.e., 60 or 70 subsamples) for a $\sim\frac{1}{4}$ acre plot using the same instrument as was used for incident measurements. The advantage of using the same instrument is that there is no concern regarding calibration. Walk transects across the plots at different angles both lengthwise and crosswise to ensure good coverage of subsamples. Take care not to cast your own shadow over the instrument. Take a reading every

couple of steps ensuring not to bias samples by have too many readings either between or within rows. Keep the ceptometer level. It should take less than 10 minutes per plot to measure.

An alternative to taking sequential incident and under-canopy measurements with the same instrument is to use a separate ceptometer or PAR sensor to log concurrent measurements in an area near the measurement plot. Care needs to be taken to ensure calibration between the instruments as any differences will create a systematic error in IPAR calculation. In addition, cloud/sunny conditions can vary over short distances. Care needs to be taken to ensure that conditions for the remote PAR sensor are the same as for those at the point canopy sampling.

Example of possible transect pathway within measurement plot of Tier II sites



2.1.3 Measurement Protocol (Tier III)

Permanent sample points will be established at Tier III sites due to the rainfall excluders and to increase the precision of repeated samples. Within each measurement plot, three or four points will be located in between each set of adjacent tree rows, i.e., in the middle of the excluders where excluders are present, (minimum of 25 samples per plot). While all points will be in the center of the inter-row space, their placement along the row should be randomly selected. Mark these points for later re-measurement. Measurements will be taken above the excluders and at a similar height in the plots without excluders. IPAR will be measured approximately every 4-6 weeks between late March and September.

The goal at each point is to capture the range of light conditions across the entire inter-row space (tree to tree). Take two non-overlapping measurements towards each adjacent row of trees so that the second reading is further from the point than the first (potential to reach 2 m in each direction). If taken perpendicular to the excluders, this will cover ~13' at each point. If row width > 13', 3 measurements in each direction might be considered. Try to adjust the angle of the measurement so that the two measurements in each direction just reach a line parallel with the planted trees.

2.1.4 Calculations

1. How to calculate IPAR:

$$\text{IPAR} = 1 - (\text{under canopy PAR} / \text{incident PAR})$$

Calculate IPAR for each subsample using this equation and then average subsamples.

2. How to calculate the relationship between IPAR and sun angle (Tier III):

During a day in early summer, measure IPAR hourly from early morning to solar noon or from solar noon to evening. Plot the relationship between sun angle and IPAR and fit a curve.

3. Estimating annual intercepted radiation (Tier III): Adjust all periodic measurements to a sun angle of 30° using the regression between IPAR and sun angle. Interpolate IPAR between sampling dates. Multiply incoming daily PAR by IPAR corrected to 30°. Sum for all days for a given year.

Citation : Will, R. E., N. V. Narahari, B. D. Shiver and R. O. Teskey. 2005. Effects of planting density on canopy dynamics and stem growth for intensively managed loblolly pine stands. *Forest Ecology and Management* 205:29-41.

2.2 LI-COR LAI-2000 Plant Canopy Analyzer:

2.2.1 Environmental Conditions:

For the LAI 2000 measure in diffuse sunlight conditions, within an hour from dawn or dusk with clear skies and within 1.5 hours with uniformly overcast skies. Make sure the sun isn't hitting the tops of trees in view. Ensure there is no fog layer in tops of trees. Ensure there is sufficient light to identify needles (not too dark).

2.2.2 Transect Layout:

See the diagram below from the LAI-2000 manual. Randomly pick a starting tree and walk a diagonal pointing the sensor down the row towards the center of the plot. Space the readings from 0.5m to 1 m depending on row width. Sample one diagonal per row. In the Tier III sites hold the sensor level above the trays at the same set height each time.

2.2.3 Measurements:

If available, use two LI-COR LAI-2000 Plant Canopy Analyzers in two sensor mode. One LAI-2000 instrument should be placed in an open area with a minimum diameter of 3.5 times the adjacent canopy height (with a 90° view cap) to collect measurements at a 15 second interval for use as the above canopy readings. Above- and below-canopy sensors must be calibrated with one another at the beginning of each data collection and also face the same direction. If

samples are collected during uniform overcast conditions, calibration should be done before and after measurements.

Raw data files should be backed up and not modified. Note that any calculations with the FV2000 software will manipulate the input files. Download and backup data every night. Verify that you have the desired view cap size of 90 degrees and that it will fit the sensor before going to the field. Install FV2000 software from link below to laptop before leaving for the field and verify that laptop has necessary ports to connect to data logger and can communicate successfully with the data logger ([http://envsupport.licor.com/index.jsp?m=Current&menu=Area Meters&spec=LAI-2000,Software](http://envsupport.licor.com/index.jsp?m=Current&menu=Area%20Meters&spec=LAI-2000,Software)).

Row Crops. We have found this technique to work well for any row spacing from very wide to full cover canopies. In general, readings should be made along diagonal transects between the rows, as illustrated below. Choose the locations along the transect so that readings are made at even intervals across the row. For example, if making 4 B readings per transect, make the first in the row, the second 1/4 of the way across, the third in the mid-row, and the fourth 3/4 of the way across. The purpose of making a diagonal transect rather than going straight across is to improve the spatial average.

