



Environmental Analysis Program

Pomona College
Biogeochemistry Laboratory

SOP-F605

Leaf Area Index Measurement

Standard Operating Procedure

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1. Purpose

This SOP describes field methods for estimating Leaf Area Index (LAI), the total one-sided area of leaf tissue per unit ground surface area (m^2 leaf / m^2 ground). LAI is a key structural parameter governing light interception, transpiration, and primary productivity (Jonckheere et al., 2004). It is used in the EA Program for characterizing canopy structure at photovoltaic panel sites, restoration areas, and agricultural plots.

Both ceptometer and hemispherical photography methods estimate an “effective” LAI that assumes a random spatial distribution of foliage elements within the canopy. In most real canopies, foliage is clumped rather than random, and the effective LAI underestimates the true LAI by 20–50% depending on species and canopy architecture (Br’eda, 2003; Chen et al., 1997). When reporting LAI values, specify whether a clumping correction has been applied and which correction method was used. Ground-based LAI measurements also serve as critical reference data for validating satellite-derived LAI products (garrigues2008?; zheng2009?).

2. Scope

- **Applies to:** Indirect optical measurement of LAI using hemispherical photography and/or a ceptometer (AccuPAR or equivalent linear PAR sensor) at all EA Program field sites
- **Does not apply to:** Direct destructive leaf area measurement (harvest methods); satellite-derived LAI products (though ground measurements may be used to validate them); root area measurements
- **Location:** All EA Program field sites

3. Definitions

- **Leaf Area Index (LAI):** The total one-sided area of leaf tissue per unit ground area. Dimensionless ($\text{m}^2 \text{ m}^{-2}$). Typical values range from 0 (bare ground) to 1–3 (grasslands and crops) to 5–10 (closed-canopy forests) (Jonckheere et al., 2004).
- **Effective LAI (L_e):** The LAI value obtained from optical methods that assume random foliage distribution. Effective LAI underestimates true LAI in clumped canopies because light passes through gaps between clumps more easily than a random model predicts (Chen et al., 1997).
- **True LAI:** The actual one-sided leaf area per unit ground area, obtained either by destructive harvest or by applying a clumping correction (Ω) to the effective LAI: $\text{LAI}_{\text{true}} = L_e / \Omega$, where $\Omega < 1$ for clumped canopies (Chen et al., 1997).
- **Clumping index (Ω):** A dimensionless parameter (0 to 1) describing the degree to which foliage deviates from a random distribution. Values near 1 indicate nearly random distribution; values of 0.5–0.7 are typical for conifer canopies.
- **PAR:** Photosynthetically Active Radiation (400–700 nm).
- **Ceptometer:** A linear array of PAR sensors used to measure light transmission through a canopy. LAI is estimated from the ratio of below-canopy to above-canopy PAR using the Beer-Lambert extinction model (Norman & Campbell, 1989).
- **Gap fraction:** The proportion of the sky hemisphere visible through the canopy at a given zenith angle. Gap fraction is the primary measurement from hemispherical photography and is inverted to estimate LAI.
- **Extinction coefficient (K):** A parameter in the Beer-Lambert model relating LAI to light transmission; depends on solar zenith angle and leaf angle distribution.
- **Hemispherical photography:** A technique using a fisheye lens pointed upward to photograph the canopy. Gap fraction analysis of the image yields LAI estimates (Frazer et al., 2001).

4. Responsibilities

Role	Responsibility
PI / Field Lead	Approve measurement design, review data
Trained Personnel	Collect field measurements per this SOP
New Students	Complete training before independent use

5. Safety and Hazards

Hazards

- **Physical:** Uneven terrain, tripping hazards from dense vegetation
- **Biological:** Tick and insect exposure in dense canopy understories
- **Heat:** Measurements are often taken in open or partially shaded areas during peak growing season

5.1. Required PPE

- ☐ Closed-toe shoes or field boots
- ☐ Sun protection (hat, sunscreen)
- ☐ Long pants and long sleeves (tick protection in dense vegetation)

5.2. Emergency Procedures

Refer to [SOP-F001 Field Safety](#).

6. Required Materials

Item	Notes
Ceptometer (AccuPAR LP-80 or equivalent)	Linear PAR sensor with datalogger
External PAR sensor (if not built in)	For above-canopy reference
Camera with fisheye lens adapter	For hemispherical photography
Tripod with self-leveling head	For consistent camera positioning
GPS unit or smartphone	For recording measurement locations
Field data sheet	Pre-printed with site/date fields
Compass	For orienting measurements
Measuring tape (50 m)	For locating measurement points

7. Estimated Time

Task	Time
Site setup and orientation	10–15 minutes
Ceptometer measurements (10 points)	20–30 minutes
Hemispherical photographs (10 points)	30–45 minutes
Data download and QC	15 minutes

8. Procedure

8.1. Measurement Timing

LAI measurements should be taken under uniform overcast skies or within one hour of solar noon under clear skies (Weiss et al., 2004). Avoid measurement during patchy cloud conditions, as rapidly changing light causes inconsistent above-canopy reference readings. For hemispherical photography, early morning, late afternoon, or overcast conditions produce the best contrast between sky and foliage (Br'eda, 2003).

8.2. Sampling Design

1. Determine measurement locations using the project sampling design (random, stratified random, or collocated with vegetation transects from [SOP-F603](#))
2. At each location, take a minimum of 5 below-canopy readings (ceptometer) or photographs (hemispherical) to capture spatial variability (Weiss et al., 2004)
3. Record GPS coordinates at each measurement location

8.3. Method A: Ceptometer (AccuPAR)

1. Power on the ceptometer and set the date, time, and site ID
2. Enter the leaf angle distribution parameter (χ). Use 1.0 for a spherical distribution (default for most broadleaf canopies) unless species-specific values are available (Norman & Campbell, 1989).
3. Take an above-canopy PAR reading by holding the sensor bar horizontally in full sunlight (or use the external above-canopy sensor if available)
4. Move to the first below-canopy measurement point. Hold the ceptometer horizontally at approximately 1 m height (or just above the understory layer), perpendicular to the dominant row or canopy orientation.
5. Record the below-canopy PAR reading
6. Rotate the ceptometer 90 degrees and take a second reading at the same point to account for canopy anisotropy
7. Average the two readings for that point
8. Repeat at each of the remaining measurement points (minimum 5 per location)
9. Take another above-canopy reading at the end of the measurement sequence to verify that light conditions have not changed substantially (within 10% of the initial reading)

10. The instrument calculates LAI internally using the Beer-Lambert model:

$$\text{LAI} = \frac{-\ln(\tau)}{K}$$

where τ is the ratio of below-canopy to above-canopy PAR and K is the extinction coefficient (a function of solar zenith angle and leaf angle distribution). This value is the effective LAI (L_e) and does not include a clumping correction.

8.4. Method B: Hemispherical Photography

1. Mount the camera with fisheye lens adapter on the tripod at 1 m height (or just above the understory)
2. Level the camera using the tripod's bubble level
3. Orient the top of the image toward magnetic north using a compass
4. Set the camera to manual exposure: use the sky brightness (not the canopy) to set exposure. Bracket exposures if uncertain (one stop above and below). Exposure settings strongly influence the sky/foilage classification threshold and can introduce systematic bias in LAI estimates (Br'eda, 2003).
5. Take the photograph pointing directly upward (zenith)
6. Record the image number, GPS coordinates, and any notes (e.g., understory density, canopy species) on the field data sheet
7. Repeat at each measurement point

8.4.1. Image Analysis

8. Transfer images to the lab computer
9. Analyze using Gap Light Analyzer (GLA) or the **hemiphot** R package (Steege, 2018):
 - a. Threshold the image to classify pixels as sky (gap) or foliage
 - b. Calculate gap fraction at multiple zenith angle rings
 - c. Invert gap fractions to estimate LAI using a canopy model (e.g., Miller's formula or the ellipsoidal leaf angle model)
10. Report the mean LAI and standard error for each site. Specify whether the reported value is effective LAI or clumping-corrected true LAI.

i Ceptometer vs. Hemispherical Photography

The two methods measure slightly different quantities and may not agree at the same site. Ceptometers integrate PAR transmission along a linear transect and are sensitive to solar angle and sky conditions; hemispherical photographs sample the full sky hemisphere and are analyzed offline, allowing more flexible post-processing. Agreement between methods is typically within 0.5–1.0 LAI units, but systematic offsets can occur, especially in heterogeneous canopies (Jonckheere et al., 2004; **thimonier1996?**). Using both methods at a subset of sites allows cross-validation and helps quantify method-specific bias.

9. Quality Control

- Take at least 5 below-canopy readings per measurement location to quantify within-site variability
- Report the coefficient of variation (CV) across readings; if CV exceeds 30%, increase the number of readings
- For ceptometer measurements, verify that above-canopy PAR did not change by more than 10% between the start and end of the measurement sequence
- For hemispherical photography, visually inspect thresholded images to ensure correct sky/foilage classification; manually adjust the threshold if needed
- Cross-validate: where possible, compare ceptometer and hemispherical photography estimates at the same points (Br'eda, 2003)
- When LAI data will be used to validate remote sensing products, document the spatial footprint (measurement spacing and extent) and the timing relative to the satellite overpass (garrigues2008?)

10. Data Management

1. Download ceptometer data to the lab computer within 48 hours
2. Organize hemispherical images by site and date: LAI_SiteID_YYYYMMDD/
3. Archive raw data and images on the lab shared drive
4. Version-control analysis scripts per [SOP-L801](#)

11. References

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12. Training Record

Before measuring LAI independently, personnel must:

1. Read this SOP and [SOP-F001 Field Safety](#)
2. Demonstrate correct ceptometer operation (power on, set parameters, above/below readings, data download)
3. Demonstrate correct hemispherical photography technique (leveling, orientation, exposure settings)
4. Process one set of images through gap fraction analysis under supervision
5. Be signed off by the PI or field lead