# LAI-2200

## Plant Canopy Analyzer


Instruction Manual

LI-COR®

Biosciences

# LAI-2200

## Plant Canopy Analyzer

### Instruction Manual

LI-COR, Inc.
4647 Superior Street
Lincoln, NE 68504-0425
Phone: (402) 467-3576
Fax: (402) 467-2819
Toll Free: 1-800-447-3576 (U.S. & Canada)
envsupport@licor.com
envsales@licor.com
www.licor.com

LI-COR® Biosciences

Measuring Change in a Changing World®

This manual contains basic operating instructions for the LAI-2200 Plant Canopy Analyzer and associated computer software.

**Notice**


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LI-COR®
Biosciences

LI-COR, inc.
4647 Superior Street
P.O. Box 4425
Lincoln, Nebraska 68504 USA

Phone: 402-467-3576
FAX: 402-467-2819
Toll-free: 1-800-447-3576 (U.S. & Canada)
E-mail: envsales@licor.com

# Declaration of Conformity

**Manufacturer's Name:** LI-COR Inc.

**Manufacturer's Address:** 4647 Superior Street
Lincoln, Nebraska USA 68504

**declares that the product**

**Product Name:** Plant Canopy Analyzer

**Model Number(s):** LAI-2200

**Product Options:** LAI-2250 Plant Canopy Sensor
LAI-2270 Plant Canopy Console

**conforms to the following Product Specifications:**

EMC: FCC 47 CFR Part 15.109 Radiated Emissions, Class A
EN 55011 Radiated Emissions, Class A
IEC 61000-4-2 ESD, 4KV/8KV Contact/Air
IEC 61000-4-3 Radiated RF Immunity, 3/3/1 V/m

**Supplementary Information:**

The product herewith complies with the requirements of the EMC Directive 2004/108/EC.

John Rada
Engineering Manager

Document #53-11229
December 1, 2009

# Table of Contents

## 4 Measurement Guidelines .......... 4-1

## 7 Tutorials and Examples.............7-1



## 8 Instrument Software Reference 8-1

## 9 Theory ........................................ 9-1



## 10 Appendices ............................... 10-1



## Index

# Menu-Level Contents

The menu-level contents follow the LAI-2200 console menu structure. Instrument software is described in Chapters 3 and 8. Chapter 3 is a tutorial guide, which includes numerous step-by-step examples. Chapter 8 is a reference guide that provides brief explanations of each menu item.

# Welcome…

…and thank you for your purchase of the LAI-2200 Plant Canopy Analyzer. The LAI-2200 is the follow-up to the LAI-2000, which LI-COR Biosciences produced and sold for over 20 years. At LI-COR Biosciences, it is our passion to provide scientific instruments of exceptional quality, and we hope that the LAI-2200 performs exceptionally for you. We welcome your comments and suggestions - feel free to contact us at any time.

## About this Manual:

This manual should serve as a guide to understanding the proper operation, abilities, and limitations of this instrument. Operators who are new to the instrument and its principles are encouraged to read all the theory sections and to become acquainted with the body of published literature that cites data collected with the LAI-2000. Operators who are familiar with the LAI-2000 could skip over the theory, measurement guidelines, and canopy type sections and jump right into Chapters 3 and 8. The menu-level contents can help you find explanations of the various functions provided by the LAI-2200 instrument. Chapter 6 is a guide for the FV2200 software, which provides a higher level of post processing functionality.

**Familiar with the LAI-2000? See Appendix F for a brief comparison.**

# 1 Getting Started

## About the LAI-2200

The LAI-2200 calculates Leaf Area Index (LAI) and other canopy attributes from light measurements made with a "fish-eye" optical sensor (148° field-of-view). Measurements made above and below the canopy are used to calculate canopy light interception at five zenith angles, from which LAI is computed using a model of radiative transfer in vegetative canopies.

### What's what

If you have just taken delivery of your LAI-2200 check the packaging list and verify the contents of the shipment. The following components should be included:

#### LAI-2270 Control Unit

The LAI-2270 Control Unit (console) is used to configure instrument settings, store recorded data, and compute results. The LAI-2270 is shipped with 4 "AA" alkaline batteries, which can provide up to 140 hours of operation. An internal lithium backup battery maintains the clock when the main batteries are removed. Refer to page 2-1 for a complete description.

## LAI-2250 Optical Sensor

The LAI-2250 Optical Sensor (wand) is the data collection component of the LAI-2200. It is shipped with two "AA" alkaline batteries, which can provide over 8 hours of continuous use in "autonomous mode". A protective cap is provided to cover the bulkhead connector. Refer to page 2-5 for a complete description.

The optical sensor contains high precision optical components, including lenses, optical filters, and light sensors. It should be treated like an expensive camera lens and protected from impacts and intense vibration. See the section on "Maintenance" (page 2-7) for complete care instructions.

## View Caps

Five view restricting caps (p/n 9920-005) are provided with the LAI-2200. The solid cap (p/n 6520-020) should be used to protect the lens when it is not in use. The five view restricting caps serve to limit the azimuthal field of view of the optical sensor in circumstances in which it is necessary or desirable to block part of the view.

## Data Cables

A USB A to Mini USB cable (p/n 392-07872) and a 9-pin female to female RS-232 cable (p/n 9975-016) are provided to transfer data between the LAI-2200 and a computer.

## Optical Sensor Cables

One 6-pin cable (p/n 392-11542) with bulkhead connectors is provided with each optical sensor. It is to connect the optical sensor to the control unit.

## Bubble Levels

Two bubble levels are provided with each optical sensor. One is a bottom level (p/n 610-03047) that attaches to the underside of the optical sensor for use in situations in which the sensor is held over the operator's head. The top level (p/n 610-03048) attaches to the top of the optical sensor.

Both levels look very similar, however, the top level has the manufacturer's name printed on the bottom, whereas the bottom level does not. They can also be distinguished from one another because it is nearly impossible to stabilize the bubble inside the ring when the level is inverted.

## Lens Cleaning Kit

The Lens Cleaning Kit (p/n 610-03100) includes cleaning solution and lens cleaning cloth.

## Carrying Carabiner

A carabiner (p/n 610-10456) is included to allow hands-free transportation of the control unit. The clip attaches to the base of the control unit with a ring. It can be attached to the user's belt loop.

## Calibration Sheet

The calibration sheet indicates the angular response of your LAI-2250 and its response in an isotropic environment. It is a good idea to store the calibration sheet in a safe location. If it is lost, contact LI-COR Biosciences for the calibration information for your instrument.

## Software CD

The Software CD (p/n 618-10669) contains the LAI-2200 software (FV2200), which is compatible with computers running Windows XP, Vista, or 7; Mac OS X; or Linux operating systems. The latest versions are available from www.licor.com.


## Instruction Manual

The Instruction Manual (p/n 984-10633) contains basic operating and maintenance information for the LAI-2200.

## Accessory Kits

Two accessory kits are provided, one for the control unit (p/n 9922-107), and one for each optical sensor (p/n 9922-108). They include frequently replaced components, such as bulkhead connector end caps.

# Theory of Operation

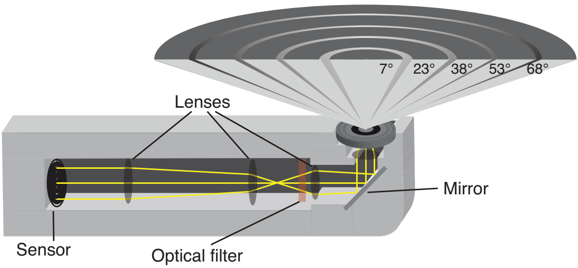
Leaf Area Index is one-sided leaf surface area per ground surface area. Because the LAI-2200 is sensitive to all light-blocking objects in its view, the term foliage area index is more appropriate. In scientific literature, the terms effective Plant Area Index ($PAI_{eff}$) (Garrigues et al. 2008), Vegetation Area Index (VAI) (Fassnacht et al. 1994), and others have been used to refer to indirect LAI measurements that may include non-leafy vegetation. We use the term LAI throughout this manual, except when discussing measurements of isolated plants, in which case we use the term Foliage Density. For more on this, see Computing LAI on page 6-34.

## Basic Theory

The amount of foliage in a vegetative canopy can be deduced from measurements of how quickly radiation is attenuated as it passes through the canopy. By measuring this attenuation at several angles from the zenith, foliage orientation information can also be obtained. The LAI-2200 measures the attenuation of diffuse sky radiation at five zenith angles simultaneously. The LAI-2250 Optical Sensor projects the image of its nearly hemispheric view onto five detectors arranged in concentric rings.

Thus if the sensor is level and viewing the sky, detector 1 will measure the brightness straight overhead, while detector 5 will measure the brightness of a ring centered at the 68° zenith angle (22° above the horizon), subtending 13°.

A normal measurement with the LAI-2200 consists of a minimum of ten numbers: five of the numbers are the signals from the five detectors when the optical sensor was above the vegetation, and the remaining five are the readings made with the sensor below the vegetation. For both readings, the sensor is looking up at the sky. Five values of canopy transmittance are calculated from these readings by dividing corresponding pairs. For example, if detector 1 reads 50 (units not important) above the canopy and 5 below, then the transmittance at that angle (centered at 7°) is 5/50 = 0.10. From transmittances at all five zenith angles, the LAI-2200 calculates foliage amount (leaf area index, LAI) and foliage orientation (mean foliage tilt angle, MTA). In practice, a number of below-canopy readings are usually made to improve the spatial average.




## Assumptions

There are some basic assumptions that must be met in order to make accurate calculations of foliage density and orientation. The extent to which these assumptions are violated will affect the accuracy of measurements and subsequent calculations. The four major assumptions, in approximate order of importance, are:

1. The foliage is black. It is assumed that below-canopy readings do not include any light that is reflected or transmitted by foliage. An optical filter in the LAI-2250 Optical Sensor rejects any radiation >490 nm. Foliage typically reflects and transmits little radiation in this portion of the

spectrum, which helps minimize violations of this assumption.

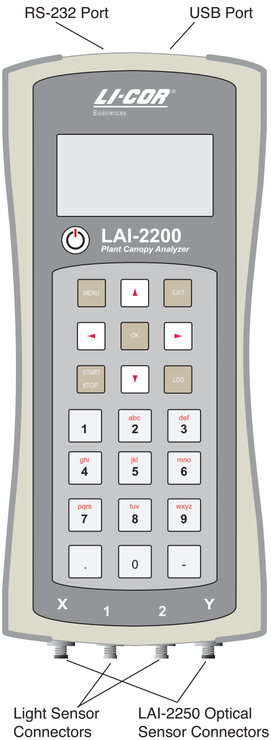
2. The foliage is randomly distributed within certain foliage-containing envelopes. These envelopes might be parallel tubes (as in row crops), a single ellipsoid (an isolated bush), an infinite box (turf grass), or an infinite box with holes (deciduous forest with gaps).
3. The foliage elements are small compared to the area of view of each ring. The approximate guideline is this: the distance between the sensor and the nearest leaf above it should be at least four times the width of the leaf. This relationship is described in more detail later in the manual.
4. The foliage has random azimuthally orientations. That is, it does not matter how the foliage is inclined, as long as all the leaves are not facing in the same compass direction. The importance of this assumption is reduced when measurements are made in a wide range of compass directions or without a view-restricting cap.

No real plant canopy conforms exactly to these assumptions. Foliage is never random, but is often clumped along stems and branches, and certainly is not black. Many species exhibit heliotropism, which violates the azimuthal randomness assumption. The practical compromises that must be made are often not serious, however. Many canopies can be considered random, and living foliage does have relatively low transmittance and reflectance of light below 490 nm. Offsetting errors may be common, such as when leaves are grouped along stems (increasing light transmittance), but arranged to minimize overlap (decreasing transmittance).

Some canopies violate these assumptions to an extent that requires consideration. Measurements of conifer canopies, with their high degree of organization, or senescent crops, with thin reflective leaves, might have large absolute errors. The LAI-2200 is very sensitive to small relative differences. In some cases, it might be necessary to calibrate the instrument with direct measurements in order to achieve high absolute accuracy.

# 2 Introduction to the Instrument

The purpose of this section is to describe the physical characteristics of the instrument and to introduce the keypad interface, basic software navigation, initial setup, and instrument care.




## Control Unit

The control unit (console) housing is constructed from durable ABS plastic with a rubber seal between the two halves. The rubber seal also serves as a shock cushion to protect the instrument from impacts.

### Display

The display is a 128x64 LCD graphics display. It displays alphanumeric characters. To adjust the display contrast hold the minus(-) key and press the up or down arrow keys.

### Keypad

The LAI-2200 features a 22-button tactile response keypad. The upper block of 9 keys are used to navigate through menus, select menu options, and log data. Basic functions of the upper 9 keys are described below. The lower block of 12 keys are used to enter alphanumeric characters. Each key is used to enter the letters and numbers indicated by the label on the key.

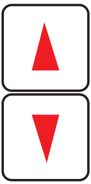

Press the **Menu** button to go to the Main Menu; or when in Logging Mode, to go to the Log Adjust menu.


The **Exit** button returns to the main screen unless an input or toggle field is active. In these cases it returns to the previous screen.

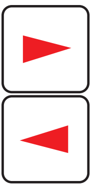

The **OK** button selects the highlighted menu field or implements a setting after changes have been made.


The **Start/Stop** button is used to initiate or terminate a logging sequence.


When in Log mode, the **Log** button records a reading (or two if two wands are attached).



The **Up** arrow and **Down** arrow buttons are used to navigate through menu options and increment or decrement values in some fields.



The **Right** arrow and **Left** arrow buttons advance to the next or previous menu sub-level when on a menu screen. If a toggle field is active they toggle the setting. They also are space and backspace keys in alphanumeric fields.

When entering alphanumeric characters with the keypad, each button cycles through a loop of characters and stops looping when a different button is pressed or after 1 second has passed without a button press. Some fields can only accept numeric or alphabetic characters. The right arrow key is used to enter spaces and the left arrow key functions as a backspace key in alphanumeric fields.



## Cable Connections

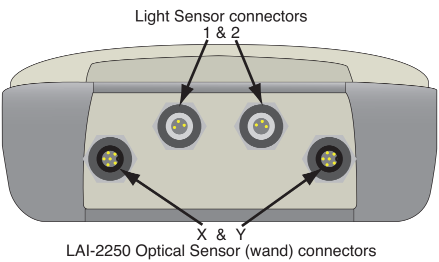
Cable connections are on the top and bottom of the LAI-2200 console. Protective caps (p/n 620-10306) for each bulkhead terminal should be kept in place when the connectors are not in use.

### Optical Sensor Cable Connections

The 6-pin bulkhead connectors (labeled X and Y) are to attach optical sensors (wands). The control unit will automatically detect an attached wand. Wands can be attached or removed while the instrument is powered on.

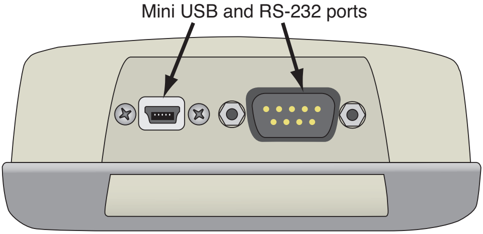
### Light Sensor Cable Connections

Two 3-pin bulkhead connectors are available to attach LI-COR Biosciences Light Sensors. They are labeled “1” and “2” on the front of the control unit and identified as Port 1 and Port 2 by the control unit. Light sensors that terminate with a BNC type connector will require an adapter (p/n 392-10657). Refer to page 3-18 for details.



## Data Cable Connections

An RS-232 port and a Mini USB port are available for communicating with a computer (see page 6-3). When connected with a USB cable, the computer will identify the LAI-2250 as a mass storage device.




## Memory

The control unit is equipped with 128 MB of non-volatile flash memory. The instrument stores data on an internal Secure Digital (SD) card, which should provide sufficient memory for intensive data collection (enough storage for over 1.5 million records).

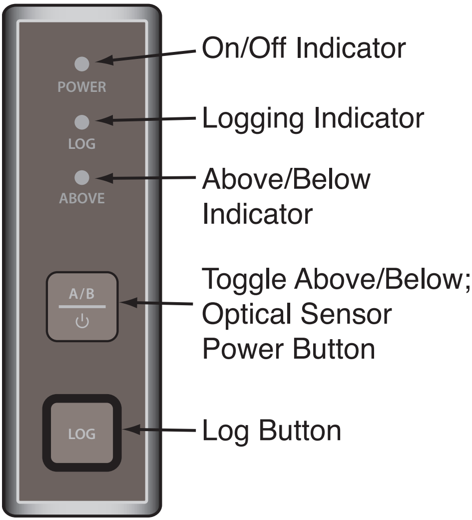
The format for the SD card is FAT16. Do not modify the card in any way when connected to a computer, and never remove or replace the card unless it is with a card purchased from LI-COR Biosciences (p/n 616-10387). If you need to use a user-supplied SD card for any reason, contact LI-COR for formatting instructions.

# Optical Sensor

The optical sensor (wand) is constructed with a durable aluminum enclosure, which protects the electronic and optical components. It can be mounted to a camera tripod or raising pole using one of the ¼"-20 tripod mounting holes. It can be used independently of the control unit for data collection. When the wand is attached to a console, it is powered with the console batteries – it does not require its own batteries. Otherwise, it requires two "AA" batteries.

## Keypad

The optical sensor keypad includes two buttons that are used to log data, switch between **A** and **B** readings, and power on/off the optical sensor. The **LOG** button on the wand is the same as the log button on the console – if the console is in logging mode (see page 3-13), the Log button will log a record to the open file.



Optical sensors will turn on when 1) the control unit is turned on (if the wand and control unit are attached), or 2) the optical sensor cable is connected to a powered-on control unit 3) the optical sensor power button is pressed (when disconnected from the control unit). To turn the optical sensor off, press and hold the A/B|Power button for 2 seconds. To switch between **A** and **B** readings press and release the A/B|Power button.

## Indicator LEDs

Three LEDs indicate the state of the optical sensor. The "Power" LED is illuminated when the sensor is turned on. The "Log" LED illuminates when data is being recorded. When the Log button is pressed the log LED lights up for the duration of the reading and turns off when the log is complete. The optical sensor's Log LED will flash every 2.5 seconds or 1 second as part of automatic, unattached logging (see page 3-16). The LED labeled "Above" indicates whether the next reading from this sensor will be labeled **A** (LED is on) or **B** (LED is off). Pressing the A/B key switches between **A** and **B** readings.

## Features

The optical sensor has 1 MB non-volatile flash memory that is used when operated in unattached mode (for about 25,000 records). The optical sensor will indicate that its memory is full by flashing all three LEDs simultaneously. When the optical sensor batteries are low (2 V), the green power LED will turn red. The optical sensor will shut off automatically when the battery voltage is below 1.8 V.

Optical sensors do not require batteries when it is used in attached mode - they use power from the control unit. Be aware, however, that if a data cable is removed during a data transfer between the wand and console, the files may be damaged or lost. The control unit display indicates when data transfer is taking place with an on-screen indicator (see Logging Mode, page 3-13). Be sure to wait until data transfer is complete before disconnecting the data cable.



# Maintenance

The LAI-2200 is designed for low maintenance, and generally it should require little servicing beyond keeping it clean and taking care of the batteries.

## Replacing the Batteries

### Control Unit

The control unit battery compartment is on the back of the instrument. To open the battery compartment, remove the two screws that secure the battery cover with a #1 Philips screwdriver. The control unit requires 4 "AA" batteries. Be sure to observe proper polarity when changing batteries. Replace the batteries and reattach the cover.

Proper polarity for LAI-2250 Optical Sensor batteries


### Optical Sensor

The optical sensor uses 2 "AA" batteries, which are in the handle of the optical sensor. To remove the optical sensor batteries, use a coin or large flat-tipped screwdriver to turn the battery cap counter clockwise about ¼ turn. When inserting new batteries, insert the negative (-) pole into the battery holder first. The positive (+) pole on the second battery makes contact with the black cap (p/n 345-10735).

If the instrument is to be stored for a long period of time, remove the batteries to prevent damage that may result from battery leakage and corrosion.

## Calibration

There are two parts to the factory calibration. One is done at a range of angles in collimated light, and is used to center the detector and verify the angular response. The other is doen in isotropic conditions (an integrating sphere) and provides calibration factors that are used to match each ring's output to each other, but not to any absolute standard. Ths inter-ring calibration has no effect on LAI determination, but would be important if you were to use the sensor to map angular distributions of diffuse radiation.

Recalibration of the optical sensor is not necessary, as long as the optics within the sensor remain in place. The detectors may have long-term electrical drift, but this will not affect LAI determinations.

Instructions for entering calibration multipliers are on page 3-4. The procedure for matching two sensors is separate from calibration and is described on page 3-10.

## Cleaning the LAI-2250 Optical Sensor Lens

The optical sensor lens should be kept free of dust, dirt, and deposits when collecting data. To help keep the lens clean, leave the opaque lens cap in place when the instrument is not in use.

The front lens of the optical sensor can be cleaned with distilled water or the Lens Cleaning Kit that is included with the instrument. *Note: Be very careful not to scratch the* $MgF_2$ *coating on the lens. Avoid cleaning the lens with paper products, and never wipe the lens while it is dry. Damage to the lens is not covered under the warranty.*



The instrument display and keypads can be cleaned with a moistened non-abrasive cloth when necessary.

## Storage

When storing the LAI-2200 for a long period of time, remove the "AA" batteries, replace the bulkhead connector caps, and put on the lens cap.

# 3 Using the LAI-2200

This section introduces the basics of the LAI-2200, including a description of configuration options, usage considerations, and a guide for making basic measurements. It is recommended that users who are unfamiliar with the LAI-2200 follow the example measurements and become thoroughly acquainted with the practical considerations (in the next two chapters) before attempting real measurements with the LAI-2200.

## Initial Setup

### Power ON and OFF

To power on the LAI-2270 Control Unit press the power button. It is below the left side of the display.

If it is not attached already, attach an optical sensor to the X or Y port using the cable (p/n 392-11542). The optical sensor should turn on when the control unit is turned on (if the cable is attached), when connected to a powered up control unit, or when the optical sensor power button is pressed.

To turn off the control unit, press the power button. To turn off the optical sensor, press and hold the power button for 2 seconds. The control unit features a user-settable auto off timer that will shut off the instrument automatically. The auto off timer can be set for 5-60 minutes. The optical sensor automatically shuts off in 30 minutes if no button is pressed (unless configured for automatic logging or connected to a control unit).

### Console Auto-off Timer

To set the auto-off timer on the Control Unit (console), press the **Menu** button, select **Console Setup**, then **Auto-off Timer**. Set the timer as desired and press **OK** to save the settings.

## Monitor Mode Navigation

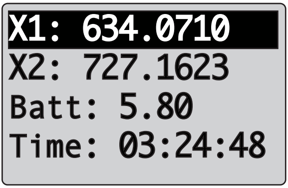
```
X1: 634.0710
X2: 727.1623
Y1: 0.0000
Y2: 0.0000
```

When the LAI-2200 is turned on, Monitor Mode (right) will be displayed. Observe the variables called X1, X2, Y1, and Y2. These are values from rings 1 and 2 from the X and Y sensors. Each row of Monitor Mode can be set to display any one of the values in Table 3-1.

*Table 3-1. Variables that can be displayed in Monitor Mode.*

| | |
|---|---|
| X1,...,X5 | Readings for Wand X, rings 1 - 5 |
| Y1,...,Y5 | Readings for Wand Y, rings 1 - 5 |
| T: | Time (HH:MM), 24 hour notation |
| D: | Date (YYYY/MM/DD) |
| BATT: | Battery voltage |
| 1: | Readings for Light Sensor 1 |
| 2: | Readings for Light Sensor 2 |

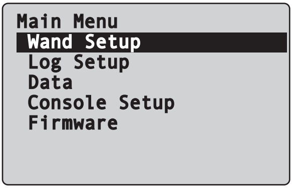
To change variables on the display, press the up or down arrow to select a field. The active field will be highlighted for about 1 second. Press the right or left arrow button to scroll through available variables.






## Basic Menu Navigation

Basic navigation through menus is accomplished with the upper block of 9 keys. When viewing a menu (press the **Menu** button to view the Main Menu, shown below), the selected menu level will be highlighted.




Press **OK** or the **Right Arrow** to select the highlighted menu option, press the **Left Arrow** key to go back a menu level or toggle field settings, and press **EXIT** once to return to the Main Menu or twice to return to Monitor Mode.

## Setting the Clock

Be sure to set the clock on both the console and optical sensor(s).

### Console

The console clock uses 24-hour time notation (1:00 p.m. = 13:00). To set the clock:

1. Press the **Menu** > **Console Setup** > **Set Time** and press **OK** (or the **Right** arrow button).
2. The time field reads HH:MM YYYY/MM/DD. Use the **Up** and **Down** arrow buttons to select the

correct values for each field, and use the **Left** and **Right** arrow buttons to switch between fields.
3. Press **OK** to implement the new time or **EXIT** to abandon changes.

### Optical Sensor

The optical sensor (wand) clock can be set manually or synchronized with the control unit clock.

1. To set the wand clock, connect the wand to the control unit, go to the **Menu** > **Wand Setup > Select wand > Clock** and press **OK** (or the **Right** arrow button).
2. Select **Set Time** to set the clock manually or **Sync Time** to synchronize the optical sensor clock with the control unit clock.
3. The time is implemented after you select "Yes". Verify the time and press **OK**.

*Note: If using two optical sensors, the clocks in both must by synchronized in order to match data in time. Be sure to synchronize the clocks.*

## Calibration and Match Values

Every wand has two sets of 5-number calibration values: The "permanent" set (accessible via **Menu > Wand Setup > Cal Values**) and the "working" set (**Menu > Wand Setup > Match Values**). The match values are the ones that are always used when the wand is making measurements. The only reason the **cal** values (which are printed on each wand's calibration sheet) are there is to serve as built-in reset values, whenever you choose to do that.

Normally, the **match** values aren't important – as long as none of them are 0, which would make the corresponding ring read 0 all the time. When they are important is when two wands are in use, and when both wands will ultimately contribute to the same LAI file. In that case, one of the wands will need to have its **match** values changed so the pair will make the same measurement under the same conditions This simple procedure is described on page 3-10.

# Overview of Configurations

## Basic Setup

The settings described below in "Wand Setup" affect the selected wand and are stored on the wand. Those described in "Log Setup" affect the global template and will be applied to any new file that is created on the control unit. Settings that affect how LAI is computed are stored as part of each file. The procedure for changing the settings of a file (post processing data) is described on page 3-25 (control units) and in Chapter 6 (using FV2200).

### Wand Setup

Certain pieces of information are stored on each optical sensor. You may wish to change or view these settings. They are described below. In order to access these settings, one or more wands must be connected, and you must select a wand.

**Set Name:** You can name each wand (up to 8 alphanumeric characters). The name is stored on the wand and can be viewed when the wand is connected to a console.

**Clock:** Set the wand time by synchronizing with the console clock or entering the time manually.

**Cal Values:** View/Edit the 5 back-up calibration values. These values are shown on the wand's calibration sheet.

**Match Values:** Access the 5 working cal values: **view/set values** to directly edit or reset them, and **calculate values** for matching two wands.

**Auto Log:** The control panel for setting up automatic logging for wand.

## Log Setup

Basic parameters can be set prior to collecting data. For most applications the default settings will work fine, but the preferred settings will vary depending on the application. Most of the following settings can be changed for a file after data has been collected as well. The following items are in the **Main Menu > Log Setup** menu:

**Transcomp:** Defines how transmittance is computed (including which readings (**A** or **B**) are used for above-canopy readings, how they are used, and what the instrument does with transmittances >1.0). These settings are described in detail in the table below. Normally, **A** readings are above canopy, and **B** readings are below. The software can also be set to determine which is above and which is below by comparing the readings (ring by ring) of successive **A/B** pairs or records until it finds a pair for which every ring of one is consistently higher than the corresponding ring of the other. The ID of the higher record, whether **A** or **B**, is assumed to be the above record ID through the rest of the file.

| Transcomp Setting | Description |
|---|---|
| Define Above | |
| A | (Default) A records are Above, B are Below |
| B | B records are Above, A are Below |
| Compare | Find which is Above and which is Below |
| Determine Above | |
| Previous | (Default) Use the previous Above record |
| Interpolate | Interpolate between the nearest (time) Above readings |
| Closest | Use the closest in time Above record |
| Bad Readings (when a Below record has values that exceed those of a corresponding Above record) | |
| Skip | (Default) Skip that record |
| Clip | Force the transmittance (Below/Above) to be 1.0 for that ring |



**Prompts:** Two prompts can be defined, and responses can be entered during data collection (see page 3-11 for details) for each file.

**Obs Remarks:** An observation remark can be entered for each data record. This remark is edited in the log setup menu, and can be changed for individual records by pressing the Menu key while in Logging Mode.

**Angles:** This provides access to the angle values associated with each ring. There is no need to change these values.

**Distances:** The distance vector consists of five values used in calculation of contact numbers for the five rings of the optical sensor. Use the default values unless you are measuring an isolated crown of a plant. Refer to page 5-13 for more information.

**Masks:** The mask determines which rings are used (default = all) to compute LAI. Data from rings that are ignored are still measured and recorded, however, so nothing is lost even if a data file is generated with all rings ignored.

**Controlled Sequence:** A sequence of **A** and **B** readings can be defined, then the instrument will prompt you for the next reading.

**PAR Sensors:** Activate, name, and enter the calibration multipliers for LI-COR Biosciences Light Sensors here.

## Console Setup

The Console Setup menu (**Main Menu > Console Setup**) provides some basic setup options:

**Set Time:** Set the instrument time, as described on page 3-3.

**Auto Off Timer:** Set the duration that the control unit will remain powered on after no buttons have been pressed (5-60 minutes, increments of 5 minutes).

**Beeper:** Turns the console beeper on or off.

# Attached vs. Autonomous Configuration

## Attached Configuration

This is the configuration used when the optical sensor(s) is attached to the control unit. The main advantage of having the sensor attached to the console is real-time display of measured or computed values. When in log mode, pressing the wand or console LOG button adds data to the file on the console, not the wand, and LAI calculations are updated for that file.



## Autonomous Configuration

This is useful for logging above canopy readings well away from the console, for later import to the console. Data can be logged manually (press LOG) or automatically (page 3-16) on an unattached wand, and later transferred to the console and merged with below-canopy readings. Note that you can also use a wand by itself to make complete one-sensor readings of a canopy: Just label above and below readings appropriately using the A/B button, transfer the result to a file, and recompute that file. However, since records stored on a wand accumulate in one big file, this method is not convenient for generating multiple LAI files, unless you keep careful track of starting and stopping times, so you'd know how to parse the file later.

# Operating Modes: One and Two Sensor Modes

## One Sensor Mode

The simplest operating mode is to use one sensor for above and below readings. A sequence of readings can be predefined (see controlled sequence, page 3-15 if attached to a console), or determined "on-the-fly" by using the A/B key on the wand keypad. The basic procedure for using this mode is described on page 3-20.

## Two Sensors Mode

Two-sensor mode simply means that there are two (or more!) sensors involved in collecting above and below canopy readings. Both sensors can be attached to the console during the measurement, but they don't have to be. If both aren't attached you'll have to do some work later to get the files together (page 3-23). Either way, you'll have to do some work up front or after the fact to make sure all sensors involved are matched – so they read the same things under the same conditions. This is described in the next paragraph.

## Matching Sensors

There are two approaches to matching sensors. One method, described here, matches the sensors before data is taken. Thus, you do a little up-front work, and then don't worry about it. The other approach is to not bother about getting the sensors to agree at the start, but rather simply make a reading or two with both sensors having the same view. You might do this before taking data, then again at the end. These readings are then used in post-processing to adjust the data from one of the sensors before LAI is recomputed. See page **Error! Bookmark not defined.** for a detailed description.

Here's how to make two sensors match each other before collecting data. It will adjust the match values of one sensor.

1. Attach the two sensors to be matched to the console, and turn on the control unit.
2. Place the sensors side by side so they both see the exact same diffuse view (no direct sun). View the readings in Monitor Mode (page 3-2).
3. Set match values.
    a. Press **Menu**, select **Wand Setup**, select a wand and press **OK.**
    b. Select **Match Values** and press **OK**.
    c. Select **Calculate** and press **OK**. The wand chosen in step "a" will be set to match the other wand. Press **OK**.
4. View values in Monitor Mode to confirm match.
5. To reset the original calibration values, select **View/Set Values** from the **Match Values** menu (**Menu > Wand Setup > select wand > Match Values**). Press "**Log**" to reset, then **OK**.



Note that when data is logged, each A or B record contains an indicator (e.g. W1, W2, etc) telling what wand took the data. In the header is a "Contributing Sensors" section that relates the wand indicators to actual serial numbers and match values:

```
          :
DISTS     1.008     1.087     1.270     1.662     2.670
GAPS      0.000     0.000     0.000     0.000     0.000
### Contributing Sensors
MATCH     W1        PCH2516   3978      1244      1000      1004      1289
MATCH     W2        PCH2462   3650      1044      900       904       1144
### Data
A         1         20090924 15:23:21   W1        199.228   198.956   202.214   186.611   190.670
B         2         20090924 15:23:55   W2        2.48003   2.33006   2.68008   3.11003   4.21009
B         3         20090924 15:24:02   W2        7.43006   2.60031   2.15000   3.34005   4.14001
          :
```

## Set Prompts

There are two prompts for storing additional information with each data file. Each prompt can be defined so that it requests a specific type of information, such as "What" and "Where". In this case, for the "What" prompt, you could enter a habitat type, and for the "Where" prompt, you could enter the location. After they are defined, you can enter up to 8 alphanumeric characters in each of the prompt fields when you create a new data file. To set prompts:

1. Press the **Menu** button, then go to **Log Setup** and select **Prompts**.
2. Enter the desired prompts in the **Prompt1** and **Prompt2** fields. If you wish, you can enter default responses, or leave the **Resp1** and **Resp2** fields blank. Either way, you will be able to enter responses in the **Resp1** and **Resp2** fields when you create a new data file.

## Creating Data Files

An LAI measurement is made by collecting above and below readings in a file. Follow the steps below to create a new file:

1. With the instrument on, press the START|STOP button.
2. Select "New File" and enter a file name (a maximum of 8 characters or numbers).
3. View/Edit remarks, and/or press **OK**.
4. The LAI-2200 is now in Logging Mode (below). Log **A** and **B** readings.
5. Press **Start|Stop** (or **Exit**) to save the file and quit.

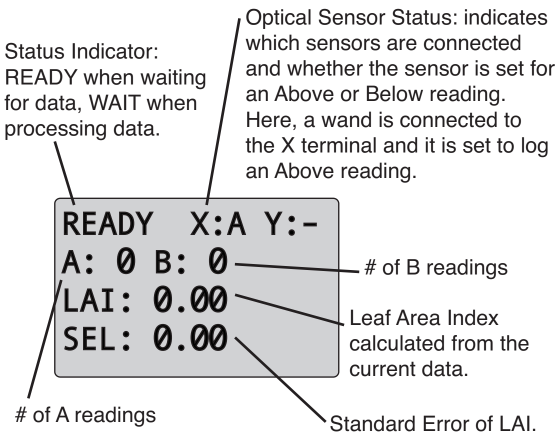
## Logging Mode

After a new file is created (see above), the console will enter Logging Mode, which is used to log data to the open file. In Logging Mode, the display will show four lines of data. The Status indicator line is always displayed, along with three of the following fields:

| | |
|---|---|
| A:# B:# | # A readings, #B readings |
| T: | Time (HH:MM), 24 hour notation |
| D: | Date (YYYY/MM/DD) |
| BATT: | Battery voltage |
| 1 or 2 | Readings for Light Sensor 1 or 2 |
| X1,...,X5 | Readings for Wand X, rings 1 - 5 |
| Y1,...,Y5 | Readings for Wand Y, rings 1 - 5 |
| SEQ: | Off or ...AB...to indicate controlled sequence |
| LAI: | Current Leaf Area Index |
| SEL: | Standard Error LAI |
| MTA: | Mean Tilt Angle |
| SEM: | Standard Error MTA |



Use the arrow keys to change what is displayed in the other fields. These changes are saved automatically.



You can also enter the "Log Setup" menu from the logging menu (press the **Menu** key while in Logging Mode). Any changes made here will only be reflected in the current file, except changes to light sensors, which will be retained even after exiting Logging Mode.

## Computations During Logging

While logging data, the LAI-2200 provides real time updates of some computed quantities, such as LAI. These computations are always done with a TransComp setting of "xPx". That is, the middle setting (Determine Above: Previous, Interpolate, or Closest in time) is always P (Previous), regardless of what you have selected. This is out of necessity, because there is no way to interpolate or choose the closest "Above" reading before all the "Above" readings have been made. When you are done logging and close the file, if the file needs to be recomputed because of this mismatch, (or for other reasons, such as logging to an existing file), you will be prompted with "Recompute?". If you respond with "OK", the file is recomputed and stored. If you decline the recomputation, the file is stored without being recomputed. It can be recomputed at a later time.

## Logging Configurations

### Manual Sequence

This is the simplest way to collect data with the LAI-2200. The optical sensor can be attached (a file must be open to use attached mode) or detached from the control unit. Select "Above" or "Below" with the **A/B|Power** button, position the sensor and press "**Log**" to record data values. Each record will be tagged with an **A** or **B**, depending on settings. To collect data in this mode, go to **Menu > Log Setup > Controlled Sequence > Use = No**, create a new file (page 3-12), enter Logging Mode (page 3-13), and begin recording data. Or, disconnect the wand from the console and simply begin recording data. Manually controlling the sequence is option whether the wand is attached to a console or not.

## Controlled Sequence

If a wand is attached, then a controlled sequence is an option. Specify beforehand what sequence you want, (for example, ABBBB with 3 repetitions), and the console will automatically label logged records accordingly. The Ablove LED on the wand (and the SEQ lines on the console) will indicate the next required reading. The following steps describe how to define a sequence:

1. Connect the optical sensor to the control unit.
2. Go to **Main Menu > Log Setup > Controlled Sequence** and press **OK**.
3. Set the "Use" field to "Yes".
4. Set the number of repetitions (from 1 to 41).
5. Define the sequence. Press the number 2 button to specify an **A** reading and the 8 button to specify a **B** reading (e.g. for the sequence **ABBBB**, press 28888). The sequence can have up to 20 readings.
6. Press **OK**. The controlled sequence will be used for any new file.
7. Create a new file. To view your position in the sequence, in the logging screen, use the left or right arrow key to change a field to indicate "Seq:". This will indicate where you are in the sequence. The wand LEDs indicate which reading is next in the sequence.

The sequence can be interrupted at any time by pressing the **A/B|Power** button. For example, if the upcoming measurement is specified as an **A** reading, press the **A/B|Power** button to change the upcoming reading as a **B** reading. After logging the data point, the sequence will continue with the next specified measurement.

To deactivate the controlled sequence, set the "Use" field to "No".

### Automatic Logging

This configuration option allows you to set up an optical sensor to log data at specified intervals, *whether or not the wand is attached to a console*. Automatic logging can be configured to record data values at intervals from 5 seconds to 3600 seconds (60 minutes) in 5 second intervals. You can also specify the start and end time and date for automatic logging. Automatically logged data can be treated as **A** or **B** readings. Data points can be manually logged during auto-logging by pressing the Log button.

The following procedure describes how to configure automatic logging:

1. From the Main Menu, select **Wand Setup**, select a wand, and press **OK**. Then select **Auto Log** and press **OK**.
2. Select **Start Time**, and enter the desired start time and day (you can only set the start day of the current month). Press **OK**.
3. Select **Stop Time**, and enter the desired stop time and day (current month). Press **OK**.
4. Select **Frequency** and enter a multiple of 5 seconds between 5 and 3600 seconds. Press **OK** after entering the value.
5. Select the On/Off field, highlight "On" and press **OK**. The optical sensor can be disconnected from the control unit. If the wand is powered off, it should power up automatically at the specified start time. If these readings are "Above", be sure

that the blue "Above" LED is illuminated. This will ensure that these readings are tagged with an "**A**" in the file.

When automatic logging is "On", the Log LED on the wand will blink every 2.5 seconds during the run-up to the logging start time. When it begins logging data, the LED will blink every second and the wand will beep at the beginning and end of each log.



## Transferring Wand Data

Data is stored in a wand under these conditions:

- Data logged because of automatic logging (attached or unattached)
- Log button pressed while wand unattached.
- Log button pressed while wand attached, but console not in logging mode.

Wand data can be moved to the console, put in a new file, or appended to an existing file. Here are the steps:

1. Connect the wand to the console. From the **Main Menu**, select **Data**.
2. Select **Wand Data** and then choose **Download**.
3. Select the optical sensor that has the desired data.
4. Choose "New File" to create a new data file or choose "Add to File" to append an existing data file.
5. If you choose "New File" name the file (up to eight-characters) and press **OK**. If you choose "Add to File", select the file from the list and press **OK**.

It may take several seconds for the file to be transferred and for appended files to be modified. When the file is copied, it remains in the memory of the optical sensor. To delete files from the optical sensor memory, select "Purge" from the **Wand Data** menu, and then select the appropriate optical sensor. Press OK to purge, or EXIT to return to the **Wand Data** menu.

## Connecting PAR Sensors

The light sensor connectors (1 and 2) on the LAI-2200 accept LI-COR Biosciences Quantum sensors (LI-190 or LI-191), Pyranometers (LI-200), or Photometric sensors (LI-210). In most applications, Photosynthetically Active Radiation (PAR) is the variable of interest. Light sensors that terminate with a BNC type connector will require an adapter (see below). The light sensor connectors are configured to measure the signal (microamps) normally provided by LI-COR Biosciences light sensors.

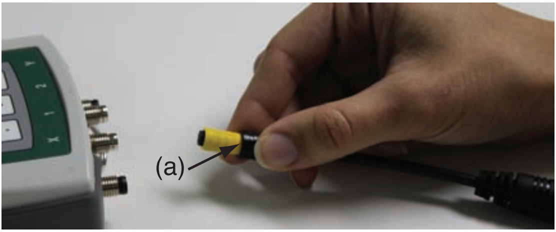
Follow this procedure to enable a light sensor:

1. Attach the light sensor cable to port 1 or 2, then go to **Menu > Log Setup > PAR Sensors**, select Port 1 or Port 2 (which ever has a light sensor attached), and press **OK**.
2. Set the “Enabled” field to “On”.
3. (Optional) Name the sensor. The name is used in the “Contributing Sensors” section of data files (see page 3-28).
4. In the “Cal” field, enter the calibration multiplier for your light sensor. The calibration multiplier is printed on your sensor’s calibration sheet. It also can be found on LI-COR Biosciences’ Technical Resources Library web site.
5. Press **OK** to implement the changes.

Light sensor settings are saved to the global template and will be applied to any data file that is created.

The light sensor adapter (p/n 392-10657) is a 6-inch cable that terminates to a 3-pin female connecter on one end and a BNC connector on the other.

To attach the light sensor adapter, slide the black collar (a) away from the terminal, toward the cable.




Align the pins and the yellow terminal will slip over the port with a small amount of pressure.

Then slide the black collar over the yellow terminal to secure the adapter.

Attach the light sensor terminal to the BNC terminal on the adapter.

# Making Basic Measurements

Making measurements: Now that you've become familiar with the operating principles of the LAI-2200 and the instrument accessories, it is a good idea to make a few sample measurements. Be sure to review the "practical considerations" in Chapters 4 and 5 prior to collecting actual data because the use of improper measurement techniques will result in poor data quality.

## Operation: One Sensor, One Control Unit

This step-by-step section requires one LAI-2270 Control Unit and one LAI-2250 Optical Sensor and view caps. You will be guided through the following procedures:

- Create a data file
- Make a measurement
- View live readings in Logging Mode

1. Place the desired view cap (see chapters 4 and 5) on the sensor with the opening pointing away from the handle. Attach the optical sensor to the control unit (either the X or Y terminal) and turn on the control unit. Verify that the sensor is operating correctly by placing a hand over the lens and observing that the reading drops (in Monitor Mode). Remove your hand and notice that the reading returns to normal.
2. Set prompts, if desired (see page 3-11).
3. Press the **START|STOP** button on the control unit and choose **New File**. Enter a file name.
4. Enter responses to the prompts and press **OK** to save or **Exit** to skip the prompts. Now the LAI-2200 will enter Logging Mode and it is ready to record data.
5. Position the optical sensor above the canopy. Be sure it is level and that no foreign objects are in

view of the sensor. Verify that the **Above** LED is illuminated (press the A/B button on the wand if it is not). Press the **Log** button on the wand or control unit to record an **Above** reading.

6. Press the A/B button (the **Above** LED will turn off). Hold the optical sensor below the canopy (level and oriented in the same direction as the above-canopy reading was) and press the **Log** button to record a **Below** reading.
7. LAI, MTA, SEL, and SEM values will be visible in Logging Mode (use the arrow keys to change what is displayed).
8. Continue making **B** readings, moving the sensor to a new location each time. Typically, the distance between **B** readings is on the order of the canopy height. You can intersperse **A** readings as necessary, if sky conditions or the view direction changes.
9. When you are finished, press the **START|STOP** button to close the file and exit Logging Mode.



## Operation: Two Sensors, One Control Unit

The steps in this section require one control unit and two optical sensors. In this section and the section that follows, you will be guided through the following procedures:

- Match the sensor
- Set up data logging with one sensor in autonomous mode and the other in manual mode
- Create a data file
- Make measurements
- Merge the two datasets on the control unit
- View data on the control unit

1. Synchronize the clocks in both wands (see page 3-3), and purge any data from the wand that will log the **Above** readings (**Menu > Data > Wand Data > Purge**).
2. Place the desired view caps over the lenses of two optical sensors with the openings facing away from the handles (see chapters 4 and 5). Connect the optical sensors to the control unit and turn on the control unit.
3. Match the sensors as described on page 3-10.
4. Set prompts if desired.
5. Match the sensors. Select **Menu > Wand Setup > select wand > Calculate Values**. Choose how to match the wands. Be sure that both wands have the same view cap, are level, and share exactly the same view. Press **OK**. The instrument will compute new match values for one of the sensors.
6. Navigate to **Menu > Wand Setup > select the wand that will record Above readings > Auto Log**.
   a. Set Auto Log to “On” and press **OK**.
   b. Set the Start Time/Date as desired (remember to use 24 hour notation) and press **OK**.
   c. Set the End Time/Date to 30 minutes past the current time/day (or as desired) and press **OK**.
   d. Set the Frequency to 60 seconds and press **OK**.

   The Log LED will blink every 2.5 seconds prior to the start time.
7. Disconnect the sensor that was configured in the previous step. Place it in an area that affords a clear view of the sky. Be sure it is level, stable, and oriented so it views the same sky that the below-canopy sensor will see.
8. Press the **START|STOP** button on the control unit, select **New File**, and name the file.

9. Begin to record the below-canopy readings with the other optical sensor and control unit. Always be sure to orient the sensor so it is viewing the same sky as the above-canopy sensor. Be sure that all readings are tagged with a **B** (the blue "Above" LED should be off when readings are taken).
10. After collecting the below-canopy readings, re-connect the **A** readings wand to the control unit. If autologging is still active on the **A** readings wand, turn it off **(Menu > Wand Setup > select wand > Auto Log > Use = off)**.
11. Navigate to **Main Menu > Data > Wand Data > Download > select wand**. Choose "Create new file" and name the file. The records will be saved. Purge the wand data if desired.
12. Follow the steps below to merge the two files and compute LAI.



## Importing A Readings from Separate Files (Console)

When **A** readings are collected autonomously, they need to be imported by the file that holds the **B** readings before LAI can be computed. This can be done on the control unit (described below) or with the FV2200 software see (page 6-14).

1. If it hasn't been done already, transfer the records from the wand to the console: Navigate to **Menu > Data > Wand Data > Download > select wand**. Choose "Create new file" and name the file.
2. Navigate to **Menu > Data > Console Data** and select the file that is to receive the imported records. Select the file that has the **B** readings.
3. Select **Edit** from the menu, then select **Import Observations**.
4. Choose to import **A** records.

5. Press **OK** and the file will be recomputed using the imported records.
6. LAI values will recompute automatically and can be viewed in **Menu > Data > Console Data > select file > View Header**.

# Data Management on the Console

## Viewing Data on the Console

To view data in a file, navigate to **Menu > Data > Console Data > select data file > View**. The following options are presented:

**View Header:**

File Name – the name of the file
Date and Time – date file was created
Response1 and 2 – responses to prompts 1 and 2
LAI – Leaf Area Index for the file
SEL – Standard Error LAI
ACF – Apparent Clumping Factor
DIFN – Diffuse Non-interceptance
MTA – Mean Tilt Angle
SEM – Standard Error MTA
SMP – Sample Size

**View ANGLES/MASKS:**

Displays angles and masks used for each ring.

**View CNTCT#/STDDEV:**

Displays contact number and Standard Deviation for each ring in the current file.

**View AVGTRANS/GAPS:**

Shows average transmittance and gap fraction for the current file.

**View Observations:**

Shows values for individual readings. Use the left and right arrow keys to navigate through the list.

## Reprocessing Data on the Console

A set of basic data processing features are available on the LAI-2200 Control Unit. Refer to Chapter 6 for advanced data processing with the FV2200 software. To edit data that is stored on the control unit, navigate to **Main Menu > Data > Console Data > select data file > Edit**:

**Edit Angles** to change the angles (normally, the default values should be used).

**Edit Mask** to apply a mask to one or more rings. Masked rings are ignored when LAI is computed. The data for masked rings is retained in the file.

**Edit Distances** to change the default distances. This is useful for measuring isolated canopies (see page 7-3 for an example).

**Edit Transcomp** to change how transmittance is computed. See page 3-6 for a detailed explanation.

**Import Observations** to import **A** records from another file to the current file. This command imports all **A** records or just the ones that are closest in time to the existing **B** records in the target file.

**Strip Observations** to delete all **A** or **B** observations from a file.

## Additional Data Management Features

Three data management options, in addition to those mentioned above, are available under **Menu > Data > Console Data > select data file.** These include:

**Recompute** to recalculate LAI and other variables.
**Delete** to permanently remove the selected file.
**Rename** to rename the file.

# Connecting to a Computer

The LAI-2200 has both an RS-232 port and USB connection that can be used to transfer data to a computer. Use of the USB port is described below. Refer to page 6-3 for instructions on using the RS-232 port using the FV2200 application. *Serial communication with RS-232 should not be done while connected via USB.* To transfer files from the older LAI-2000 using FV2200, see page 6-5.

Plug the USB cable into a USB port on your computer and the LAI-2270 Control Unit. The LAI-2200 is recognized as a USB mass storage device when it is attached to a computer (PC, Mac, Linux platforms are supported). *The LAI-2270 will not be recognized if it is in Logging Mode or a menu, so be sure to enter the Monitor Mode by pressing* EXIT*, or just turn off the control unit.*

When it appears on your desktop, the name of the LAI-2200 will be LAI unless it has been renamed. Inside the LAI directory, you will find a folder named Data, and inside Data you will find your logged data files.

These files can be manipulated in the normal ways: you can rename them, copy them to your computer (drag-and-drop or cut-and-paste), delete them, and open them with an application (FV2200, a spread sheet, etc.). You can also create other directories on LAI, and move any sort of file to them, but only files within the Data folder will be accessible to the console's software.

In the root directory of LAI, you may see some files with .bin and .img extensions. The .bin and .img files hold copies of the firmware for the console and wand. Updating console or wand firmware involves downloading new files from http://download.opensource.licor.com/projects/fv2200, putting them in the root directory of LAI, and then telling the console to do the update (see sections 10-1 and 10-2).

When you are done with LAI, eject it before unplugging it, just as you would with any USB storage device.

# About Data Files

## File Format

Files generated by the LAI-2200 are text based and consist of four basic parts: Header, Statistics, Sensor Information, and Observations. These are described below.

Header

```
LAI_File     SAMPLE2
Version      1.0.0
Date         20090924 15:23:12
Prompt1      Plot
Resp1                   6
Prompt2      Trtmt
Resp2                   2
TransComp             ACP
Model          Horizontal
LAI                  4.21
SEL                  0.12
ACF                 0.964
DIFN                0.028
MTA                    46
SEM                    12
SMP                     8
```

Statistics

```
MASK             1        1        1        1        1
ANGLES           7       23       38       53       68
AVGTRANS     0.286    0.032    0.016    0.021    0.029
ACFS         0.598    0.934     0.99    0.984    0.983
CNTCT#       2.078    3.377    3.296     2.35    1.353
STDDEV       1.433    0.615    0.223    0.192     0.12
DISTS        1.008    1.087     1.27    1.662     2.67
GAPS         0.123    0.025    0.015     0.02    0.027
```

Sensor Information

```
### Contributing Sensors
Sensor   W1      PCH2516              3978    1244    1000    1004    1289
```

Observations

```
### Data
A    1 20090924 15:23:21  W1  199.23  198.96  202.21  186.61  190.67
B    2 20090924 15:23:55  W1   2.483   2.336   2.688   3.113   4.219
B    3 20090924 15:24:02  W1   7.436   2.631    2.15   3.345   4.141
B    4 20090924 15:24:08  W1  128.27   17.03     4.1   3.341   4.031
B    5 20090924 15:24:15  W1   83.73   6.755   3.677   2.986    5.03
A    6 20090924 15:24:26  W1  180.92  207.22  216.94  192.78   190.3
B    7 20090924 15:24:39  W1   32.46   4.261   2.506   8.798   11.12
B    8 20090924 15:24:46  W1  160.44   11.91   5.148   3.233   5.847
B    9 20090924 15:24:55  W1   12.92   3.185   2.461   3.872   5.312
B   10 20090924 15:25:02  W1   6.688   4.448   3.827   3.935   3.988
A   11 20090924 15:25:21  W1  172.05  190.29  216.11  210.73  191.75
```

### Header

The header is a group of fields at the top of the file. It includes the file name, console firmware version, time stamp indicating when the file was created, and user remarks. The remaining part of the header contains the result of LAI calculations: leaf area index (LAI), standard error LAI (SEL), apparent clumping factor (ACF), diffuse non-interceptance (DIFN), mean tilt angle (MTA), standard error MTA (SEM), and the number of pairs of Above and Below observations that were included in the calculations (SMP).

### Statistics

The statistics group contains 8 groups of 5 numbers: MASK indicates which rings were included in calculations (1 indicates the ring is included, 0 indicates omission). ANGLES are the midangles of the field of view for each of the 5 rings. CNTCT# are the mean contact frequencies (the logarithm of the gap fraction divided by the path length), STDEV are the standard errors of the contact frequencies, DISTS are the path lengths, and GAPS are the gap fractions. ACFS is the apparent clumping factor for each ring, and AVGTRANS is the average transmittance for each ring in the file. Chapter 9 discusses how these quantities, as well as those in the header, are computed.

### Sensor Information

This field indicates which sensors were used to record the data and the name of the wand used. The five values to the right are matching values for each ring in the sensor. If light sensors (quantum, pyranometer, or photometric) were connected to port 1 or 2, the light sensor name and calibration information would be in this field too.

### Observations

The Observations each have a label (**A** or **B** indicating above or below the canopy), a sequential number, a time stamp, and the readings from the five rings of the detector. In this example, the first four samples (**B** readings 2 through 5) use **A** reading 1 as a reference. The next four samples (**B** readings 7 through 10) use the **A** reading 6 as a reference. Light sensor observations would be labeled 1 or 2, and would be visible in the rows.

## What do the Results Mean?

**LAI** is the answer to the question "How much foliage?". Although LAI nominally means "leaf area index", please remember that the LAI-2200 is measuring all light-blocking objects, so "foliage area index" is more appropriate. LAI is dimensionless, but it can be thought of as {$m^2$ one-sided foliage area/$m^2$ ground area}. However, if the Model is not Horizontal (that is, if the DISTS values have been changed to reflect measurements of an isolated plant instead of an "infinitely" horizontal canopy), then the LAI value is foliage density (foliage area in $m^2$/canopy volume in $m^3$). See page 6-34.

**MTA** answers "How is the foliage orientied?". If all the foliage were horizontal, then the correct MTA would be 0°; if all were vertical, MTA would be 90°. This information may not be of particular interest to everyone, but it is wise to make sure the numbers seem at least reasonable. Typically, MTA will range from the 30s to the 60s, but an unexpected MTA value can indicate something wrong with the measurement or the DISTS values.

**DIFN** is calculated by integrating gap fraction (GAPS) to yield a value that indicates the fraction of sky that is not blocked by foliage. This value ranges from 0 (no sky visible to the sensor) to 1 (no foliage visible to the sensor). DIFN is in essence a single value representation of canopy structure, as it combines LAI and MTA into one number. However, DIFN does not depend on the same assumptions that go into LAI and MTA, but only depends on the assumption of no scattering by the foliage. Of all the values computed by the LAI-2200, DIFN comes the closest to being an indicator of "canopy light absorption". However, canopy absorption involves not only canopy structure (DIFN), but also the foliage spectral properties in the wavelength range of interest (for example, the photosynthetically active 400 to 700 nm region) for the foliage and the surface beneath the canopy, and the location of the sun. Therefore, in terms of canopy absorptance, DIFN is merely an indicator of the absorption of diffuse, short wave (<490 nm) radiation.

**ACF** is Apparent Clumping Factor, and is equivalent to the apparent clumping index $\Omega_{app}$ defined by Ryu, et al (2010). One of the assumptions the LAI-2200 makes (page 1-6) is that foliage positioning is random - if not for the entire canopy, at least for parts of it. For example, consider a widely spaced row crop: The randomness assumption is clearly wrong when considering the entire field, but is much better when considering just one row. Lang and Xiang (1986) showed that in cases like this, if multiple transmittance measurements are made so that each contains either mostly row or mostly gap in its view, they can be combined by averaging the natural logarithms of the transmittances to give the correct leaf area index. For this reason, the LAI-2200 combines multiple transmittance readings by averaging the natural logarithms of the transmittances when computing LAI (see Chapter 9). The ACF value is

$$ACF = \frac{LAI_{\log(avg(T))}}{LAI_{avg(\log(T))}} \tag{3-1}$$

where $LAI_{\log(avg(T))}$ is the leaf area index computed by taking the log of the averaged transmittances, and $LAI_{avg(\log(T))}$ is that reported by the LAI-2200 (computed by averaging the logs of the transmittances). Note that the simple averaged transmittances for each ring are reported in the statistics block of the file, after the label AVGTRANS, while the log-averaged transmittances are reported after the label GAPS. Ring by ring values of ACF are shown after the labels ACFS.

The purpose of ACF is to provide a way to "undo" the avg(log(T)) protocol used by the LAI-2200 to combine readings. Why would you want to do that? If, for example, you had an independently determined clumping factor $\Omega$ (determined, for example, from a gap size distribution measurement) for a canopy that you wished to apply to the LAI-2200 results, you would need to do this to compute a true LAI (Ftrue)

$$Ftrue = \frac{LAI \times ACF}{\Omega} \tag{3-2}$$

LAI × ACF undoes the clumping factor compensation inherent in how the LAI-2200 works, and allows the independently determined clumping actor $\Omega$ to be applied.

# 4 Measurement Guidelines

This section includes practical considerations for data collection procedures and guidelines for collecting data under a variety of sky conditions.

## Guidelines for Getting Good Data

Collecting reliable data with the LAI-2200 depends on having a protocol that is appropriate for the canopy of interest and suitable for the measurement conditions. For any **A** or **B** readings that are used as a pair, the view cap must be the same size, the optical sensor must view the same part of the sky, and the view cap must cover the same part of the sensor (this only applies if the same sensor is used for both **A** and **B** readings).

When sky conditions are not ideal, adjustments may need to be made in the measurement protocol. For example, multiple **B** readings are generally required to achieve a good spatial average; the view of the sensor may need to be restricted to mask out the operator or the sun; a dense canopy with large gaps may require a narrowed field of view so that gaps and canopy can be correctly integrated. These considerations are discussed below.

### Where to Measure?

#### A readings

In general, **A** readings should be made as closely as possible to **B** readings, both in time and space; however, under certain conditions and with the appropriate protocol, this is not essential to acquiring good data.

In some situations, especially in forest canopies, it may be impossible or impractical to record **A** readings near the **B** readings. In these situations, it is best to use two optical sensors (page 3-21), with one sensor positioned above the canopy or in a clearing, logging data automatically. Additional suggestions are in Chapter 5.

### B readings

It is best to consider a sampling protocol that is designed for the canopy type that is being measured. The best protocol for measuring a short homogeneous canopy (such as a grassland) may not be the best protocol for measuring a row crop (and it certainly will not be the best protocol for measuring a tall heterogeneous canopy). Guidelines for measuring specific canopy types are presented in Chapter 5.

One approach to collecting **B** readings is to make measurements equally spaced along one or more transects under the canopy. Alternatively, measurements can be made at randomly chosen locations in the study area, though practical considerations periodically make this difficult. Predetermined sample locations may violate the guidelines for usage and require adjustments to the sample location in order to collect valid data. For example, avoid making measurements with a leaf immediately above the sensor, because one leaf may block the entire view of the center rings. At the larger zenith angles, when foliage is beside the sensor rather than above it, an individual leaf blocks much less of the view. The section called Foliage Size, beginning on page 4-8, provides detailed guidelines for minimum distances and the theoretical justifications. Refer to

Ross (1981) for guidelines used for fisheye photography.

## How many B Readings?

When determining the proper number of **B** readings, first consider the ground area over which the computed LAI is to be valid: An entire field? Part of a field? A small plot? Second, what fraction of this area does one **B** reading represent? As a rule of thumb, consider each **B** reading to represent a sample of the canopy that is cylindrical (or some fraction of a cylinder if a view cap is used) with a radius roughly equal to the canopy height (the potential view of the sensor is larger than this, but the effective range is reduced by foliage). Thus,



$$A = f\pi H^2 \qquad \textit{4-1}$$

where $A$ is the ground area represented by the sample, $f$ is the view fraction (0.75, 0.5, 0.24, or 0.125 for the 270°, 180°, 90°, and 45° view caps respectively), and $H$ is canopy height. For example, one **B** reading with no view cap ($f$=1) in a canopy 5.0 m on a side and 1.0 m tall is a sampling of approximately 3 m², or 12% of the total ground area. If that same canopy were only 0.2 m tall, then one **B** reading would represent only 0.5% of the ground area. Thus, canopy height is a very important consideration.

Another consideration is the variability of the density of the foliage in the plot. A homogenous canopy would require fewer **B** readings than a heterogeneous one. Table 4-1 provides guidelines for determining the proper number of **B** readings. See page 9-12 for the derivation.

This simple procedure is used to determine the number of **B** readings necessary for 95% confidence that the true LAI mean is within ±10% of the measured LAI.

1. Make an LAI reading based on 6 **B** readings. Be sure to include both the thinnest and densest parts of the canopy.
2. Divide the Standard Error of LAI by LAI (SEL/LAI)
3. Use the table below to determine the number of **B** readings.

*Table 4-1*

| SEL/LAI | # B Readings | SEL/LAI | # B Readings |
|---|---|---|---|
| 0.01 | 2 | 0.06 | 11 |
| 0.02 | 3 | 0.07 | 13 |
| 0.03 | 5 | 0.08 | 16 |
| 0.04 | 6 | 0.09 | 19 |
| 0.05 | 8 | 0.1 | 23 |

## Using View Caps

Use the 270° view cap to hide the operator from the sensor anytime measurements will be made with the operator potentially in the field of view. No view cap would be needed if the operator were very careful to block exactly the same portion of the sensor's field of view for both **A** and **B** measurements, but it is simpler to use the view cap.

In general, any object that is common to both the **A** and **B** readings will not affect the LAI computation. Thus, one could measure the LAI of grass beneath a tree if the **A** and **B** readings are in close proximity so that the tree occupies the same portion of the sensor's view for both **A** and **B** readings.

Here is a summary of reasons to use a view cap:

1. To remove the sun from the sensor's view
2. To remove the operator from the sensor's view
3. When sky brightness is very non-uniform
4. When there are significant gaps or clumps in the canopy
5. To reduce the required plot size
6. To reduce the required clearing size for above-canopy readings in a forest

There are times when it is preferable to use the 180° or 270° field of view instead of a narrow one:

1. To avoid loss of signal near twilight or under very dense canopies
2. If the goal of the measurement $L_e$ (effective LAI), not $L$ (true LAI).

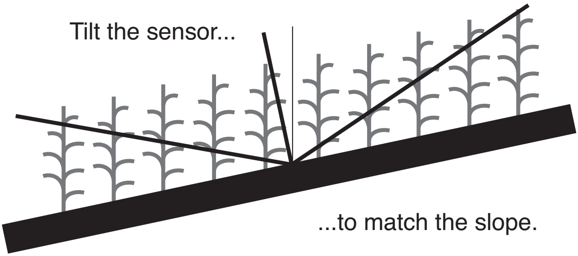


Be very careful that the **A** and **B** sets of readings are made with the sensor(s) viewing the same region of sky <u>without rotating the view cap on the sensor</u>. This is because there are usually slight azimuthal variations in the sensitivity of the optical sensor's detector, especially on the outer ring.

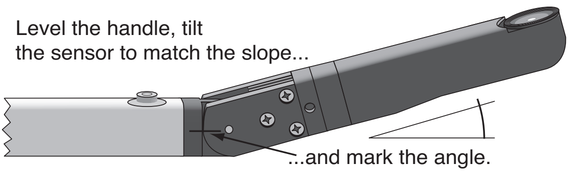
When using the view cap to block the sun, it is good practice to shade the entire lens from the sun, to prevent light reflected from the surrounding view cap structure from influencing the readings. Usually it is only the 5$^{th}$ ring that responds to such reflections.

## Measuring on Slopes

When making measurements on sloping terrain, hold the optical sensor parallel to the ground rather than level. Make sure that all associated **A** and **B** readings are made with the sensor tilted at the same inclination and pointed in the same compass direction.




One way to ensure that the sensor is held at the same inclination for each reading is to mount the bubble level on the handle rather than the sensor. Fix the hinge at an angle that permits the handle to be held level while the sensor is held at the desired inclination. Mark the two pieces at the hinge so that this angle can be reset easily.




If it is impossible to incline the “above” and “below” sensors at the same angle when measuring on a slope, the effects can be minimized by using a 45° view cap, and orienting the sensor for **B** readings along the contour (looking neither uphill nor downhill). The **A** readings need to be taken at the same compass direction as the **B** readings.

## Bad Readings

Theoretically, **B** readings should always have lower values than **A** readings. In very sparse foliage they will be very close, and in large gaps where no foliage is seen by the sensor, they will be identical. But that is only in theory.

As a practical matter, a **B** reading may exceed the value of it's **A** reading for one the following reasons:

1. Changing sky conditions
2. Normal measurement variation
3. Operator error (**A** and **B** out of sequence)
4. Making **B** readings in sunlit foliage (this is also operator error)

A **B** reading is "bad" if one or more of the rings has a value that exceeds its associated **A** reading, so that the transmittance for that ring is greater than 1.0. If this is due to operator error or changing sky conditions, it would be good for the operator to be alerted so that the measurement can be started over. But, if a reading is bad simply because of sparse foliage and normal fluctuations, it would be nice for the console to overlook the slight discrepancy and proceed using a value of 1.0 for the transmittance(s) of the offending ring(s).

To determine this setting, go to the **Main Menu > Log Setup > Transcomp >** and scroll down to **Bad Readings**. Select one of the settings described below (press OK to save the setting).

**Skip:** When a transmittance greater than 1.0 is found, that **B** reading is ignored in the calculation. The offending record is still stored in the file, however. You will know that a bad reading occurred if the number of **B** readings is larger than the sample size in Logging

Mode (see page 3-13). **Skip** should be used in cases where **A** and **B** readings are not expected to be very close.

**Clip:** If a transmittance greater than 1.0 is encountered, it is considered to be simply 1.0. Note that this does not change any stored values. This mode is useful when measuring in canopies where **B** readings are likely to be made under little or no foliage.

## Foliage Size

As a general rule, the distance between the sensor and the nearest leaf above it should be at least four times the width of the leaf. When a view cap is used this distance should be increased, but when more **B** readings are taken the distance can be decreased.

Table 4-2 provides guidelines for determining the minimum distance from the sensor as a function of foliage element size and zenith angle. To determine how close a particular leaf size can be to the sensor, find the column for the view cap being used in Table 4-2. Divide the values by the number of **B** readings to be made and multiply the results by the leaf width (cm).

*Table 4-2*

**Distance Factors**

| | | Sensor Field of View: | | | | |
|---|---|---|---|---|---|---|
| Ring | Angle (°) | 360° | 270° | 180° | 90° | 45° |
| 1 | 7 | 10 | 20 | 30 | 50 | 100 |
| 2 | 22 | 4 | 5 | 8 | 20 | 30 |
| 3 | 38 | 3 | 3 | 5 | 10 | 20 |
| 4 | 52 | 2 | 3 | 4 | 8 | 15 |
| 5 | 68 | 2 | 2 | 3 | 7 | 14 |

The formula for determining whether a leaf is too close to the sensor is:

$$\text{minimum distance} = \left(\frac{d \bullet w}{B}\right) \qquad \textit{4-2}$$

where *d* is the distance factor from Table 4-2, *B* is the number of **B** readings, and *w* is the leaf width (cm).

For example, with no view cap and only one **B** reading, a 5 cm leaf should be 50 cm ((10/1)×5) away at 7°, 20 cm ((4/1)×5) away at 22°, and 10 cm ((2/1)×5) away at 68°.



## Derivation of Eqn. 4-2

One of the LAI-2200 assumptions (Chapter 1) is that the foliage elements are small compared to the sensor field of view. Lang and Xiang (1986) derived a formula for the error as a function of foliage area and sample area: If R is the ratio of sample area (the region over which gap frequency determinations are made) to the area of an individual leaf, then the factor (E) by which the gap frequency is in error is

$$E = -R\ln\left(1-\frac{1}{R}\right) \qquad \textit{4-3}$$

We apply this analysis to an LAI-2250 sensor by considering the sample "area" to be the distance around a particular ring's view at a distance from the sensor that corresponds to the closest foliage. For example, the view of ring #2 is centered at 22°. If the closest foliage at 22° is 50 cm from the sensor, then the sample size for that ring (assuming the full 360° view) is (2π)50(sin(22))=118cm. If the leaf width is 5 cm, then R in equation 4-3 is 118/5 = 24, and the error is 1.02 or 2%.

Table 4-2 above is for an error (E) less than 5%, requiring the ratio of view circumference to leaf width (R in equation 4-3) to be at least 10.6.

## Sky Conditions

Measurements with the LAI-2200 can be made under a variety of sky conditions. Obscured sun is best, but measurements can be made on clear days in the proper settings and with the proper techniques.

### Direct Sun

Try to avoid making measurements under direct sunlight by working at sunrise, sunset, or on a cloudy day. If measurements must be made in direct sunlight, follow these procedures:

a. Make all **A** and **B** readings with your back to the sun, with the view cap blocking the sensor's view of you and the sun.
b. Make sure your head or another object shades the sensor whenever an **A** or **B** reading is made. Even though the view cap prevents the detector from seeing direct sun, shading the optics prevents reflected sunlight from influencing readings.
c. If possible, shade the part of the canopy that is visible to the sensor. *The more sunlit leaves the sensor can see, the larger the underestimate of LAI.* This is especially true in short canopies (which, fortunately, are easier to shade), because leaves in tall, dense canopies tend to be shaded by the top of the canopy.

The amount of sunlit foliage seen by the sensor (and thus, the LAI underestimate) depends on many things, including sun angle, foliage angle distribution, and foliage distribution. If the canopy is not shaded, you will find that LAI measurements seem to be a function of time of day.

Welles and Norman (1991) found that measurements made in direct 11 to 56% lower than corresponding measurements made with the sun obscured.

Canopies that are fairly uniform and don't have large gaps are more accurately measured in direct sun than non-uniform canopies with large gaps. Typically, you could expect underestimates in LAI of 10% in uniform canopies without large gaps. The problem comes with large gaps: if you have below canopy readings in which the sensor is viewing a lot of sunlit foliage (e.g. edge of a forest clearing, looking at the side of a sunlit spruce tree), then much larger underestimates can be expected.

Sometimes, you just have to find a way to deal with direct sun. Suppose you have many transects to measure, and they cannot be done in the relatively brief time afforded near sunrise or near sunset. Further, there is no hope of clouds during the day. Let's make it a forest canopy, so you cannot shade anything, and hardly uniform, so there are lots of gaps so you cannot ignore the sun's effect.

What do you do? Try this: pick out a couple of representative transects that you can measure when the sun is low. During the day, make all of the measurements, following the advice on page 4-11 (i.e. use an appropriate view cap, and always keep the sun in the blocked portion of the view). Then, when the sun is low, repeat the measurements on your representative transects, collecting data at exactly the same points, if possible. Use those transects to compute a "sun effect", by comparing the LAI results with and without direct sun, and apply that correction to the rest of the transects. A variation on this, if you have trouble with the notion of a "representative" transect, is to pick two or three transects that span the range of clumping factors that you have, and compute the direct sun effect as a linear function of ACF, then compute and apply your correction factor on the rest of the transects that way.

## Scattered Clouds

Measurements can be made under scattered clouds if the appropriate sampling technique is used. If possible, wait for the sun to be obscured by a passing cloud before making measurements. If clouds are moving rapidly, minimize the time between **A** and **B** readings (a few seconds is preferable) and/or the distance between **A** and **B** sensors.

## Very Non-Uniform Overcast

If the sky has distinctly bright and dark regions, there is greater potential for error when measuring non-uniform canopies. The part of the canopy that lies in the direction of the brightest part of the sky will contribute the most to measurements. One solution is to narrow the sensor's field of view so that the bright and dark sky are not included in both the same readings.

a. Reduce the field of view with a view cap so that the region of sky viewed at any one time is as large as possible, but still uniform.
b. Make **A** and **B** readings with the sensor viewing the dark part of the sky; then repeat the sequence with the sensor viewing the bright part of the sky. Be sure the sensor is viewing the same region of sky for all associated **A** and **B** readings.
c. Minimize the time between **A** and subsequent **B** readings, especially if low, fast-moving clouds are present.

## Clear Skies

Clear skies are good in that they are uniform. Interpolating over time works well, and large distances between **A** and **B** sites are tolerable. If the sun is at or below the local horizon (no sunlit foliage is visible to the sensor), then blue sky is ideal. However, if the sun is illuminating foliage in the sensor field of view, then LAI will be underestimated. To determine the extent of underestimation, measure LAI in the same locations just before sunrise or after sunset. Compare this measurement to one made during mid-day.

## Rain, Fog, and Dew

Accurate measurements can be made in wet canopies if care is taken to keep water droplets off the lens. Working in rain is also possible, but measurements will have greater uncertainty. Droplets on the lens present a concern because they block light. A few small droplets can reduce the light seen by some rings by 10% or more. Therefore, it is important to keep the lens free of droplets by wiping it with the cloth provided in the Lens Cleaning Kit.

# 5 Canopy Types

This section includes suggested protocols for measuring LAI in various canopy types. It also describes some relevant considerations and suggestions for acquiring the best data in different canopy types.

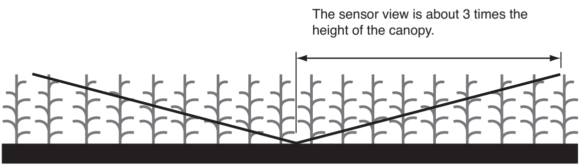
## Measuring Plant Canopies

### Short Homogeneous Canopies

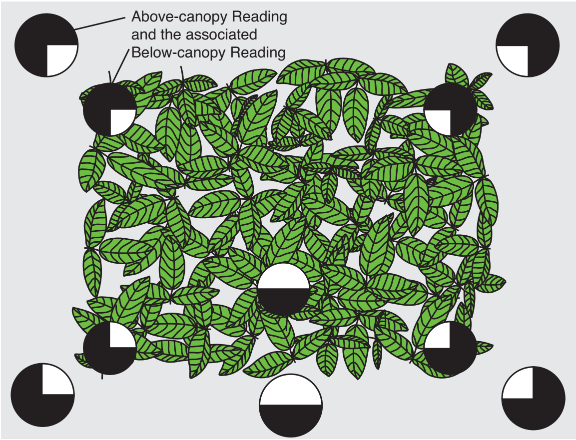
Short homogeneous canopies are the simplest to measure. Under stable sky conditions with a 270° view cap, one **A** reading for four or more **B** readings should be sufficient. To reduce uncertainty of measurements, you can take more **B** readings.

### Small Plots

When measuring small plots, it is important to be sure that objects outside the plot do not influence measurements. From beneath a canopy, the sensor's potential view is conical, with a radius that is about 3 times the canopy height. The sensor has a view of 74° (tan (74)=3.48). However, 3 serves as a working number because of the reduced probability that foliage will be significant at the edge of the sensor's field of view.



In a canopy that is 1 m high, the sensor should be at least 3 m from the edge in any direction that it can "see". In a plot so small that the sensor will "see" outside the plot area if measured from the middle, one could use a 90° view cap and make readings from the corners looking into the plot. Alternatively, a 180° view cap could be used if the measurement were taken near the center of the plot.




In dense canopies, the minimum plot size may be reduced if foliage blocks enough of the sensor's view. This is easily tested by getting down on the ground and looking up at about a 30° elevation angle. If you are unable to see the edge of the plot from this vantage point, then the plot is large enough regardless of its actual dimensions.

An additional method for measuring small plots is to do the LAI computations without the outer ring. Without the outer ring, the minimum plot size decreases to 1.6 times the canopy height. The outer ring can be omitted with the Mask function prior to data collection (beginning on page 3-5), after data collection on the control unit (beginning on page 3-25), or after data collection using the FV2200 software (page 6-29).

## Row Crops

Row crops, with architecture ranging from very wide row spacing to closed canopy, can be measured accurately using the technique described here. In general, readings should be made along diagonal transects between the rows, as shown in Figure 5-1. Choose locations along transects 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 ¼ of the way between the rows, the third at mid-row, and the fourth ¾ of the way across. Measuring with a diagonal transect, rather than a perpendicular transect, improves spatial averaging.

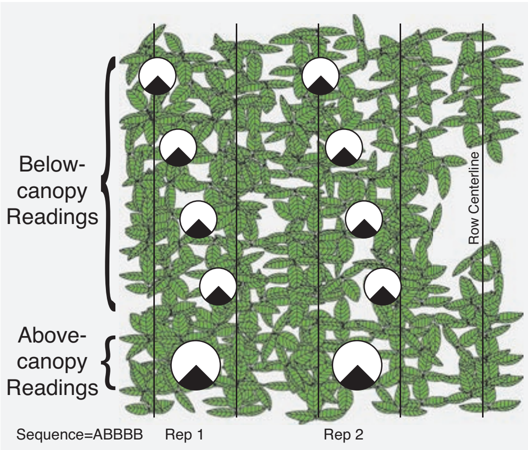



*Figure 5-1. A row crop with a homogeneous canopy (e.g., no gaps between rows) can be measured with a wide view cap.*

Be sure to make all **B** readings at the same height; if furrows and mounds cannot be smoothed, position a board along the transect and rest the sensor on it when taking readings.

If the rows have significant gaps where vegetation is lacking, perform the Canopy Gap Test (page 5-10) to see if these gaps merit special attention. If the Gap Test error is less than 10% (homogeneous canopy), then use as wide a field of view as possible, depending on sky conditions. If the Gap Test error is greater than 10% (heterogeneous canopy), then use the 45° view cap and double (at least) the number of diagonal transects. Measure the transects in pairs: one transect with the sensor looking along the row, and the other with the sensor looking across the row, as shown in Figure 5-2.

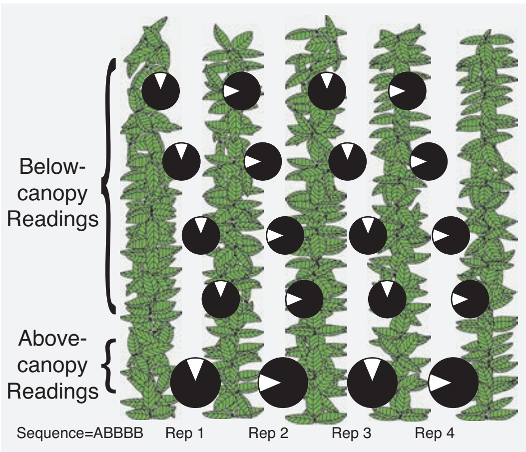



*Figure 5-2. A row crop with a heterogeneous canopy (e.g., gaps between rows) may require a narrow view cap and more repetitions.*

## Tall Canopies and Forests

The primary challenge to measuring very tall canopies is getting the **A** readings. Also, because it is impossible to artificially shade such a canopy, it will be difficult to make reasonable measurements during sunny days, unless the canopy is so full and dense that sunlit leaves are not visible to the sensor, or unless readings are made in early morning or late evening.

Method 1: Two-sensor mode is the obvious solution for obtaining above-canopy readings. Two LAI-2270 Optical Sensors are required, with one located above (or out of) the canopy and automatically recording **A** readings in autonomous mode. The other is used to collect the **B** readings. Data from the two sensors can be merged to calculate the desired variables (see page 3-21 for a step-by-step example).

Method 2: A single sensor can be used effectively. Follow the protocol described on page 3-20, except set Transcomp to “Interpolate” (page 3-6). Record one **A** reading in a clearing or above the canopy. Proceed with recording **B** readings under the forest canopy in accordance with your protocol. After collecting a number of **B** readings, collect a second **A** reading. LAI values will be visible in logging mode. The “Interpolate” setting fits a linear function to the **A** readings for each ring and predicts the appropriate above-canopy values based on the time of each **B** record,

Method 3: This is a combination of Methods 1 and 2. A sensor configured for autonomous logging in two-sensor mode is used to log continuous **A** readings in a clearing. A second sensor, configured to record **A** readings that bracket the **B** readings, as described in Method 2 above, logs its first and last **A** readings next to the sensor that is recording the series of **A** readings.

Using this method, it is no longer necessary to rely totally upon the second optical sensor for **A** readings, nor is it necessary to rely on a linear interpolation of **A** readings from the unit that collected the **B** readings. LAI can be computed for each method and compared. Another advantage is that this method automatically provides the data necessary to calibrate the two sensors to each other, which removes the need to match the sensors beforehand.

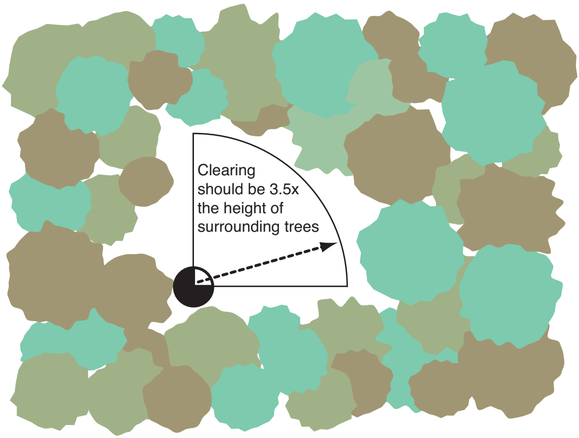
## Making A Readings in Forest Canopy

There are several considerations for getting **A** readings in a forest canopy.

**A** readings should be made as close as possible to the site to be measured. The maximum acceptable distance depends entirely on sky conditions. With blue sky (ignoring the sun for a moment), the two sensors could be kilometers apart and still see the same sky brightness distribution. With an overcast sky, however, the lower the clouds, the greater the probability that two sensors some distance apart will see different skies, especially with the central rings (near the zenith). A low, inhomogeneous overcast sky with quickly moving clouds is the worst case, when even 100 meters could be too great a distance between the sensors.

If making **A** readings in a clearing, be sure that the clearing is big enough. With a 180° or larger view cap, the sensor should be in the middle of a clearing with a diameter at least 7 times the height of the trees above the sensor ($2 \times \tan 74° \approx 7$).


With the 90° or 45° view cap, however, a clearing half that size (diameter only 3.5 times the tree height) can be used, since the sensor can now be positioned on the edge of the clearing (looking in).




This is a common reason for using a narrow view cap in a forest. Neglecting the outer ring may be necessary if an adequately large clearing is not available. In that case, the clearing should be 1.5 times the canopy height if the 45° or 90° view cap is used. Refer to the "Small Plots" discussion earlier in this chapter.

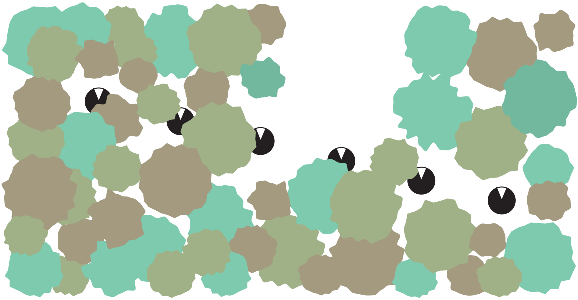
When making **A** readings for forest canopies, clearings can be made "bigger" by raising the sensor. Use the bottom level and hold the sensor over your head. The sensor can be elevated by standing on a stump, the cab of a vehicle, or by raising the sensor with a long pole, etc.

*Don't forget:* The **A** readings should be made with the same view cap (covering the same part of the optical sensor), sensor inclination (if the ground slopes), and direction of view that the **B** readings will have.

## Canopies with Large Gaps

LAI is proportional to the logarithm of the gap fraction, so the proper way to average gap fractions is to average their logarithms (Lang and Xiang, 1986). This in fact is how the LAI-2200 averages multiple **B** readings in a file. However, each **B** reading is a linear average of the light from whatever azimuthal view is visible to the sensor, as determined by the view cap. Problems can arise if the sensor sees dense foliage in one direction and little or no foliage in another direction at the time a **B** reading is recorded, because the gap in the canopy will be "over weighted", and LAI will be underestimated. A way to avoid this problem is to use a view cap to restrict the sensor's field of view, so that dense and sparse regions of the canopy are included in separate **B** readings. The figure below illustrates how a 45° view cap helps isolate a gap near a transect.

If on the other hand, you wish to measure $L_e$ (effective LAI), then you do not want the instrument to log average. In this case, use a wide field of view (270°), and multiply yor resulting LAI by ACF, the apparent clumping factor (3-2).



The Canopy Gap Test (page 5-10) can be used to estimate the error of using a wide field of view in a heterogeneous canopy, when large gaps and foliage are included in the same **B** reading.

## Conifers

It is well known that conifer needles are not arranged in space randomly, and radiation penetration models that make that assumption will underestimate the transmittance of a conifer canopy (for example, Norman and Jarvis, 1975; Oker-Blum and Kellomaki, 1983). Since the LAI-2200 assumes random foliage positioning, it will underestimate LAI in conifer canopies.

Numerous researchers have developed sampling techniques for acquiring accurate LAI measurements in evergreen forests, including Chen (1996), Stenberg (1996), Chen et al. (1997), and Kucharik et al. (1998). A detailed sampling protocol for conifer stands is described in Law et al. (2008).

## The Gap Test

The canopy gap test is a quantitative way to estimate the error of using a wide field of view in a heterogeneous canopy. That is, a canopy with dense foliage in some areas and sparse (or no) foliage in others. The problem is that LAI is proportional to the logarithm of the gap fraction, but for any one reading, the sensor will linearly average gap fraction over its view. If the sensor's view includes both dense and sparse foliage areas, the gap fraction for that **B** record will thus be incorrectly averaged. If the dense and sparse regions are measured in separate **B** records, they will be correctly averaged.

A simple method of estimating the error of using too large a view cap is to do the following:

1. Use a 45° view cap.
2. Set Transcomp to A-P-C (Above, Previous, and Clip).
3. Make a measurement in the canopy consisting of 2 AB pairs. Both of the below readings should be in the same location, but one viewing the densest part of the canopy, and the other viewing the sparsest part. (Because they are viewing different directions, you need separate **A** readings for each **B** reading.)

Look at the value of ACF, apparent clumping factor. For purposes of this test, interpret this as the ratio of the LAI you would get with a wider view cap to the one you would get with the narrower view cap. For example, an ACF of .95 means the wider view cap would produce an LAI that is 5% lower than that found with a narrow view cap. An ACF of 0.8 would be 20% lower, and so on. The lower the ACF, the more you need the narrow view cap.

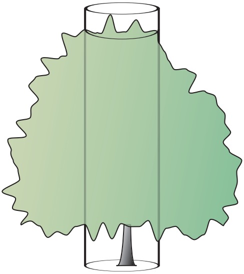
# Measuring Isolated Plants

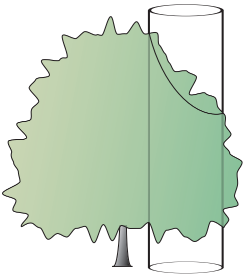
This section describes the measurement of isolated plants, for which a different protocol must be used. We begin with a discussion of LAI and foliage density.

## LAI or Foliage Density?

LAI is one-sided leaf (or foliage) area per unit ground area. In a large, homogeneous plant community, LAI is a reasonable way to express the amount of vegetation. An isolated plant presents difficulties, however, because the amount of foliage over a given area of ground depends on ground position. For example, consider a single tree:

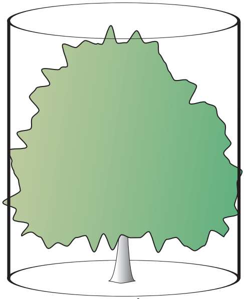
The amount of foliage above a unit ground area at the tree's center…

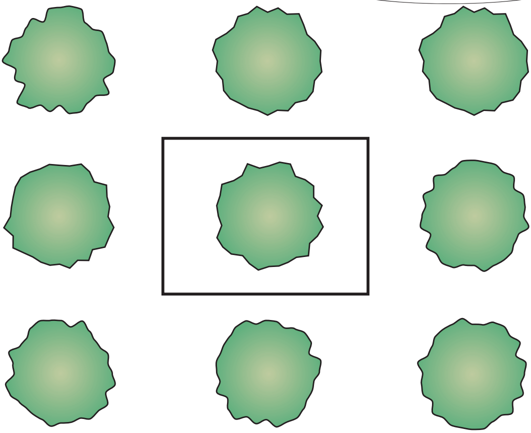




…is probably different than the amount of foliage near the tree's edge.

Also, the ground area affects the LAI measurements. For example, we might wish to express LAI based on the tree's drip line area, or based on the area associated with the tree as a member of a community, as illustrated in the over-head view below.





Thus, LAI for an isolated plant is ambiguous unless the size and position of the ground area is also given.

A more useful measure of foliage amount for individual plants, or clumps of plants, is that of foliage area density (or simply foliage density), which is foliage area divided by canopy volume. Foliage density has units of $m^2$ foliage area per $m^3$ canopy volume, which reduces to units of inverse length, typically $m^{-1}$. If a tree has 2 $m^2$ of foliage in a 5 $m^3$ crown, its foliage density is 0.4 $m^2/m^3$, or 0.4 $m^{-1}$.

## The DISTS Vector

In Chapter 9, which describes the theory of the LAI-2200, it is shown that the only theoretical difference between measuring LAI and measuring foliage density involves something called the DISTS (Distances) Vector.

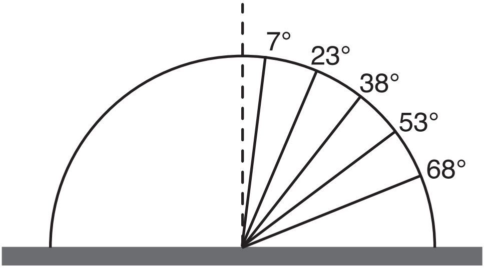
The DISTS Vector is a group of 5 numbers in the control unit that are used in the computations. These numbers indicate the distances sky radiation must travel through the canopy to reach each of the 5 detector rings of the sensor. They can be viewed on the console by navigating to **Menu > Log Setup > Distances**. The default values in this vector are $1/\cos\theta$, where angle is the view associated with each of the five rings (7°, 23°, 38°, 53°, and 68°). When making LAI measurements, there is no need to adjust these values since $1/\cos\theta$ is sufficient regardless of canopy height.

Foliage density measurements, however, require that the DISTS vector indicate the actual mean path lengths that each ring sees through the canopy. When results are computed, the LAI value is now foliage density. The units of foliage density depend on the units used for the DISTS values. If distances are entered in m, then the foliage density is in $m^{-1}$.

To set the DISTS vector for new data, go to **Menu > Log Setup > Distances**. To change the DISTS vector for an existing data file, go to **Menu > Data > Console Data**. Select a data file, then **Edit > Edit Dists**.

## A Simple Example

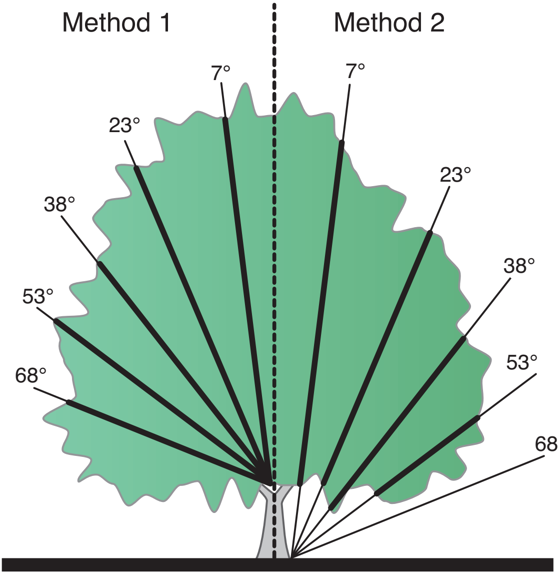
Consider a perfectly hemispherical shrub with a radius of 0.7 m. A hemisphere is the simplest because the path lengths for each ring view are identical.




To measure the foliage density of this shrub, access the Distance vectors (**Menu > Log Setup > Distances**) and set each of the five values to 0.7. The measurement is similar to that for LAI, except that a spatial average under the shrub is now not wanted; we will take only one **B** reading, directly under the center of the plant. This example is discussed further on page 7-1.

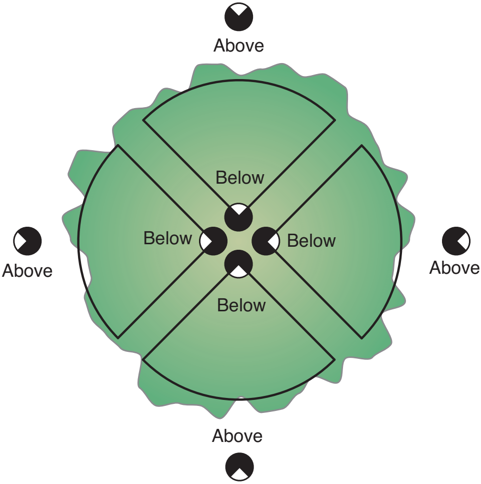
## Isolated Trees

Trees are best measured using the 180° or smaller view cap, and placing the sensor next to the trunk below the crown for **B** readings. The view cap prevents the sensor from seeing the trunk of the tree. Usually, you will put the sensor above or below the largest branches in the crown because it is important to avoid having these branches dominate the sensor's view. Place the sensor just above the low branches (Method 1) or place it well beneath them out of the canopy (Method 2). Both techniques are illustrated below:

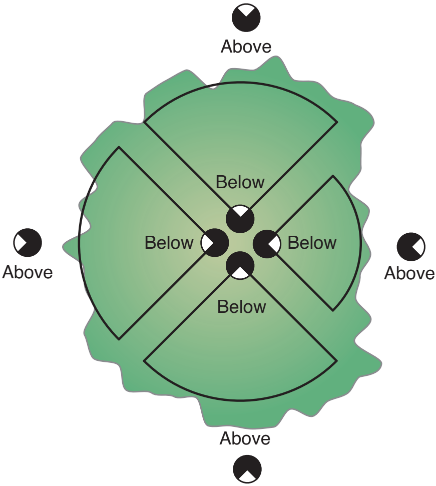



The thick segments of the diagonal lines in this figure indicate the distances each ring sees through the canopy. Note that sometimes a ring will see no foliage, as with the 68° ring in Method 2 above. A ring that sees no foliage should be masked (see page 3-6). A 90° or 45° view cap can be used to further reduce the size of the canopy that is sampled. The view cap and view directions should be chosen to avoid including neighboring trees in the measurement.

If a tree is symmetric and well isolated, several **B** readings can be taken in different directions. The figure below illustrates measuring a tree with 4 **B** readings 90° apart, but a better average could be obtained with 12 **B** readings 30° apart, for example. *Note: all associated above and below readings must be viewing the same portion of the sky.*

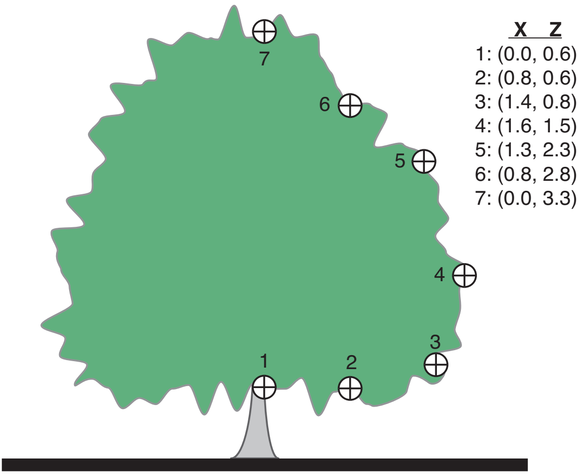


If a tree is asymmetric, then the path lengths through the tree (and thus the distance vector) will depend on azimuthal direction. Since only one distance vector is associated with a file, asymmetric trees should be measured using several files. Average foliage density is then computed by averaging the foliage densities from each of the files.



A simple method for computing path lengths and canopy volumes is provided in the FV2200 software (see page 6-24). Use a coordinate system centered below the tree, and determine the coordinates of a sufficient number of points to describe the shape of the canopy. Alternatively, a photograph of the tree that includes a meter stick for scale can be used to obtain the tree profile.

An example of the measurements needed to describe a tree crown are shown below:




The FV2200 software can use these data to determine path lengths, neglect rings if necessary, and compute canopy volume, foliage density, or dripline LAI.

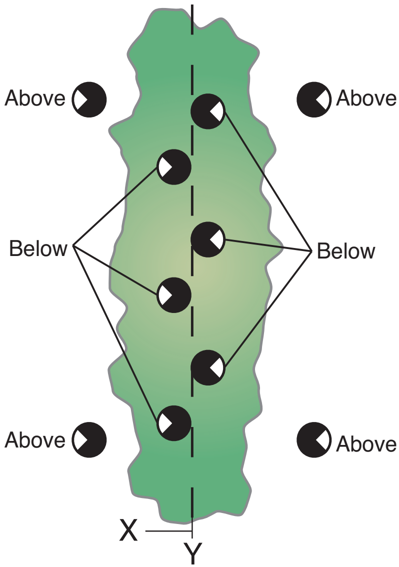
Refer to page 7-3 for detailed examples, including descriptions of the use of FV2200 to compute the variables of interest.

## Isolated Rows and Hedges

The measurement of individual rows (e.g. hedges, grape vines) is possible with the LAI-2200. Again, the data should be treated as foliage density. Here we describe two methods for measuring isolated rows or hedges.

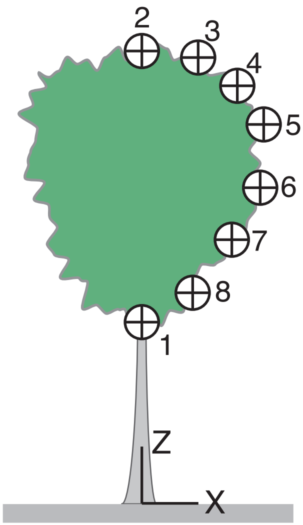
### Method 1

The measurement of isolated rows, such as a hedge or the rows in a vineyard, is similar to measuring isolated trees. With this method, the above and below measurements are taken along the length of the row.




For the below-canopy readings, place the sensor near the row center and orient the view cap so that the sensor looks away from the center. Keep it close to the lowest vegetation, but far enough away from any leaves to ensure that individual leaves do not block the view (see page 4-2).

Next, characterize the canopy shape by measuring a number of X, Z coordinates. The number of coordinates required will vary, depending on the complexity of the canopy shape. If the canopy is asymmetrical, characterize each side with X, Z coordinates. Measure or estimate the row ratio for the hedge (the length Y over width X). These values are used by FV2200 software to compute the foliage density or dripline LAI.

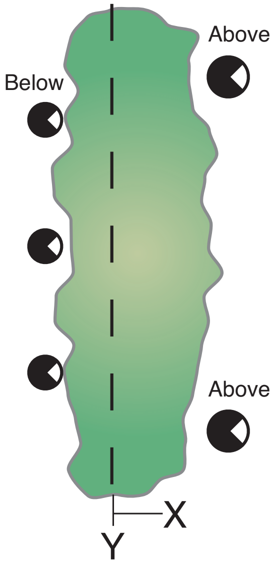



| | X | Z |
|---|---|---|
| 1: | (0.0, | 0.5) |
| 2: | (0.0, | 1.97) |
| 3: | (0.31, | 1.89) |
| 4: | (0.51, | 1.77) |
| 5: | (0.67, | 1.55) |
| 6: | (0.63, | 1.29) |
| 7: | (0.54, | 1.01) |
| 8: | (0.25, | 0.64) |

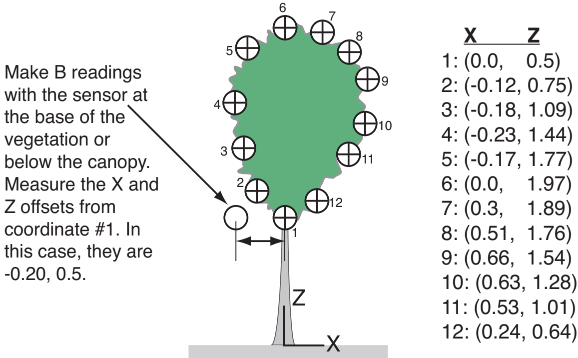
For asymmetrical canopies, LAI would need to be computed for each side of the canopy. LAI for the hedge would be the average of LAI for both sides. A complete example, including sample data, is presented on page 7-6.

### Method 2

A simple way to measure LAI in a hedge is to take an **A** reading viewing the sky. Take a number of **B** readings on one side of the row or the other, being sure that the sensor "sees" through the hedge, as shown below. It is useful for both symmetrical and asymmetrical canopies.




In addition to the above and below-canopy readings, measure X, Z coordinates to characterize the shape of the entire canopy, measure the distance between the sensor and the hedge centerline, (the X offset in meters), and the distance between the sensor and the bottom of the canopy, (the Z offset in meters). Measure or estimate the row ratio for the hedge (the length Y over width X). This information will be used in the FV2200 software to compute distances and LAI for the shrub. In the figure below, the sensor was held at the base of the canopy, resulting in a Z offset of 0.




These data and a complete example are presented on page 7-9.

# 6 Data Analysis with FV2200

## Introduction to FV2200

FV2200 allows easy manipulation of LAI-2200 and LAI-2000 data files (hereafter referred to as LAI files). These files can be read from disk, or imported from either console type (LAI-2200 or LAI-2000). LAI files can be manipulated in any way that they can on the console, and in many other ways besides.

## Installing FV2200

The installation CD will work on Windows and Macintosh (OS X) computers.

### Windows

A splash screen should open automatically when the CD is inserted. To install the FV2200 program, click the "Install FV2200" button.

### Macintosh

To Install FV2200, drag and drop the FV2200.app program to the Applications short cut right next to it.

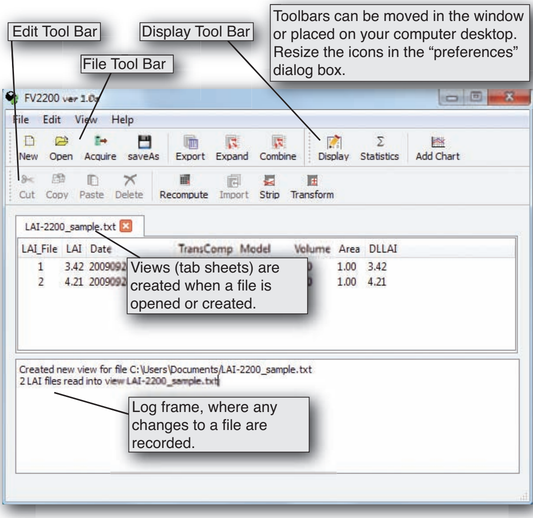
### Linux

There is a folder on the CD named "Src". In that folder is a .tar.gz file. To install FV2200, copy this file to your computer, expand it, and follow the directions in the "readme" file.

# Main Window

When the FV2200 software is launched the main window will open. From this window, you can import LAI files from or open LAI files from a disk.

Three tool bars are visible in the Main Window: File, Display, and Edit. Tool bars can be hidden, moved around or detached by clicking and dragging the tool bar drag handle. Hide and show toolbars using the View menu or by right-clicking on the menu bar. To resize buttons in the tool bars or change display defaults, select **File > Preferences** (PC) or **FV2200 > Preferences** (Mac). Choose between small icons (no boxes checked), large icons, or icons with labels (small or large).



# Transferring Data from the Console to a Computer

There are two ways to transfer data files from the LAI-2200, and one way to transfer files from the LAI-2000. These are described below.

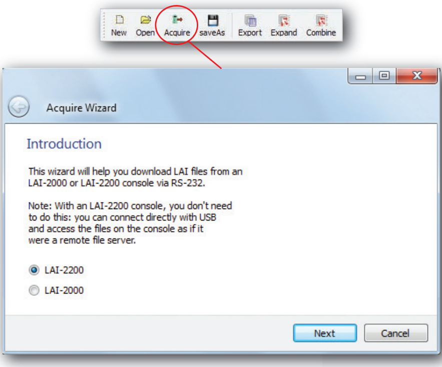
## USB File Transfer

When the LAI-2270 Control Unit is attached to a computer with the USB cable, it will be recognized as a mass storage device (see page 3-25). Do not attempt to use RS-232 and USB simultaneously.

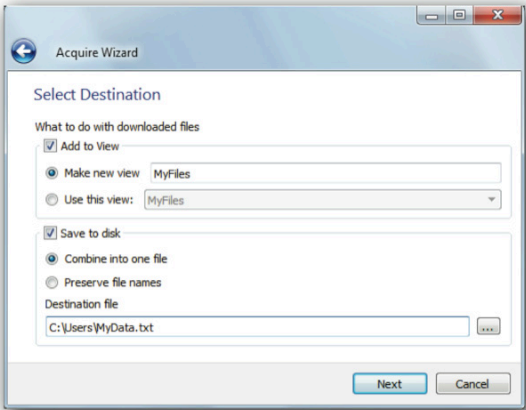
## RS-232 File Transfer – LAI-2200

The Acquire Wizard can be used to transfer files using the RS-232 connection from an LAI-2200 (below) or an LAI-2000 (page 6-5). Be sure the USB port is *not* connected to a computer when using RS-232 transfer.

1. Attach the RS-232 cable to the DB-9 port on top of the LAI-2200 and attach the other end to the 9-pin serial port on your computer.
2. Launch the Acquire Wizard by clicking the **Acquire** button or by clicking **File > Acquire**.



3. Check the LAI-2200 radio button and click "Next".
4. Select the correct serial port. On Windows, the name will be COM1, COM2, etc. On Macs, you will need a ASB-serial converter, and the name will be /dev/cu, followed by some name that depends on what converter you are using (e.g. /dev/cu.usbserial-FTDEIPXP). On Linux, it will be /dev/tty... or dev.usb… Click "Next".
5. Select the files you would like to copy, then click "Next".
6. Choose the destination of the file(s): You can route them to a view (either a new view, or add them to an existing view, if any), and/or save them directly to one file, or multiple files preserving the original file names.




7. After the transfer is compete click Finish. The file(s) will be visible in a tab sheet (view) if that was your choice.

## RS-232 File Transfer – LAI-2000

The steps below describe how to import data from an LAI-2000 using FV2200:

1. Click the "Acquire" button to launch the Acquire Wizard. Check the LAI-2000 radio button and click "Next".
2. Connect the LAI-2000 to the serial port on your computer with a 9-pin RS-232 cable. On the LAI-2000, press FCT 31 and enter the following settings: Baud=4800; Data bits=8; Parity=none; XON/XOFF=NO.
3. Press FCT 33 and enter the following: Format: Standard; Print Obs: YES.
4. Click "Next".
5. Select the serial port that is attached to the LAI-2000 and click "Next".
6. Choose whether you would like to route to a view (check "Add to View"), save the file, or both. You may open the files in any of the current view tabs or a new view tab, and save multiple files as one file.
7. On the LAI-2000, Press FCT 32 and enter the page range. The incoming data will be displayed in the Wizard window, as well as routed to a view and/or saved in a file, depending on what you selected.
8. Click "Finish" and the FV2200 will process the last file that was downloaded. Note that the last file received will not be processed (added to a view, or written to disk) until you press the Finish button.

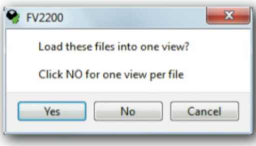


# Viewing Files

To open files that are saved on your computer's hard drive or the LAI-2200 console if it is attached via USB, click the "Open" icon or **File > Open** and navigate to the stored file. Double click the file to open it, or select multiple files and click **OK**.

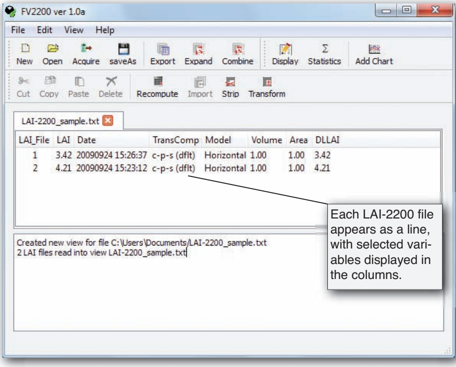
Alternatively, you can *drag the data file(s) onto the main window*: The file(s) will be opened in the current view, or if there are no views, one will be created.

On Mac and Windows operating systems, you can *drag and drop the data file(s) onto the FV2200 icon*: on Mac, if FV2200 is not running, it will launch, create a view, and open the files in that view. If FV2200 is running, this is just like dropping the files onto the main windows On Windows, FV2200 will launch (if it is already running, a second one is launched), a view is created, and the files opened in the view.



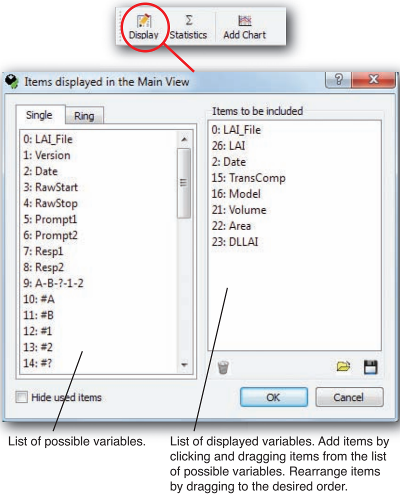

If multiple files were selected, click "Yes" to place them into one tab or "No" to place them in separate tabs. Once files have been opened, a view is created with the tab showing the source files. If you open another file or group of files, these will go into a second view. LAI files (rows of a view) can be cut, copied, and pasted from one view to another.

The bottom section of the Main Window is the Log frame, in which a log of activities is displayed.




## Column Headings

You can choose which column headings are displayed in all views by clicking **View > Display** or the Display icon. Data can be sorted by right-clicking a data file and selecting "Allow Sorting" from the Main Window. Click a column heading to sort the data. Click again to reverse the sort order.



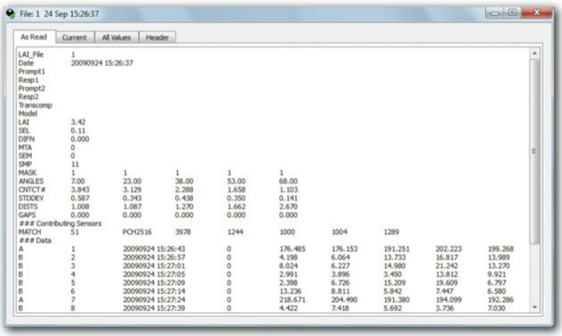

6 Data Analysis with FV2200

## Selecting Files in a View

Most of the FV2000 tasks have options for operating on selected or all LAI files in the currently view. If no files are selected, the task will operate on all files in the view. LAI files in a view can be selected by clicking on them. Multiple files can be selected using ctrl + click (⌘ + click on Macintosh) for non-contiguous entries, or shift + click for an entry range.

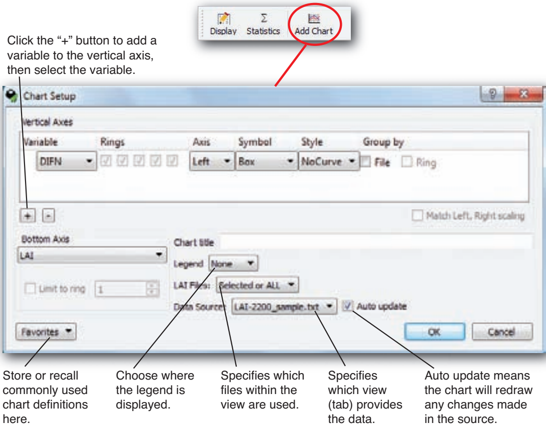
## Viewing File Details

If you double click on an LAI-2200 file in a view, a File Details window will open. This is described in the File Details section (page 6-32).

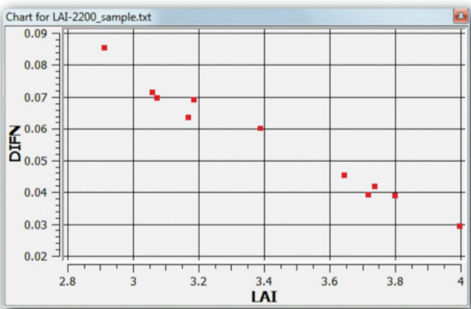



## Adding Charts

You can add one or more charts by clicking the Add Chart button.




Select the variables and settings for the chart and click **OK**. If the "LAI Files:" field was set to "Selected or ALL" or "Selected Only", you can change the file that is displayed simply by selecting one or more files from the Main Window after creating the chart. Right click on the menu bar to recall a list of charts that were created recently.



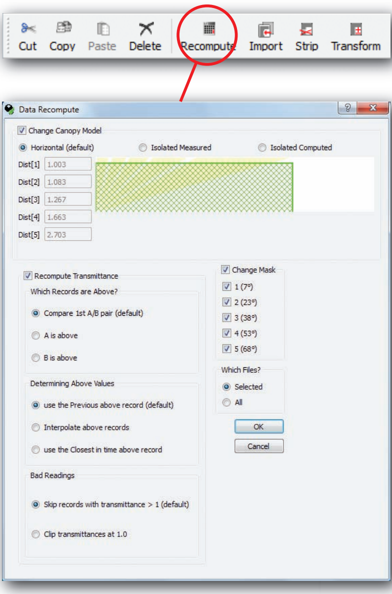

Right click or double click on the chart area to open the Chart Context menu with options for editing the chart, choosing the data source, changing page size for printing, printing, saving the chart as a .pdf file, or removing charts. This is described in more detail on page 6-47.

# Common Tasks

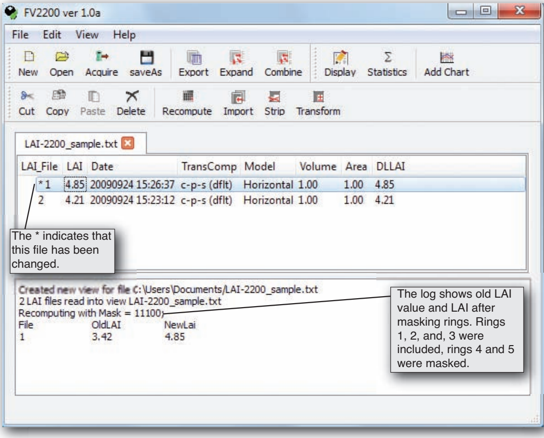
## Excluding Rings from Analysis

Mask attributes can be changed in the FV2200 software. For more information, see Masking Rings on page 6-29.

1. In the Main Window, select the files that you wish to recompute, and click the **Recompute** button (or click **Edit > Recompute**). The Recompute Observations dialog box will appear. Alternatively, double-click a data file to open the File Details window, select the Header tab and click **Change…**
2. Check the **Change Mask** box, then unselect the box beside each ring that is to be omitted.



3. Click **OK**. Changes to calculations will also be displayed in the "Log" section of the Main Window.




## Expand a File

Sometimes it is of interest to expand a single LAI file into multiple files in order to examine the spatial variability of LAI that the file contains. You can create a new file for each **B** reading (and associated **A** reading) found, or a new file each time the above-canopy reading changes.

1. In the Main Window, select the files to be expanded.
2. Click the **Expand** button or **File** then **Expand…**. A "File Expand" dialog box will open.
3. Select "Create a file for each Above/Below pair" or "Create a file for each above-canopy and all associated below-canopy records".
4. If desired, select a new Transmittance Computation method.
5. Click **OK** to create the new files.

The dialog box also allows you to change how Above/Below pairs are determined (see Computing Transmittance). If you do not enable this option, the computational method associated with each file is inherited by its expanded files.

## Combining Multiple Files

Sometimes it is desirable to combine the observations from multiple files into one file. The reason for doing this is usually to provide a properly weighted average of LAI or ACF for multiple areas (files) based on the numbers of samples in each.

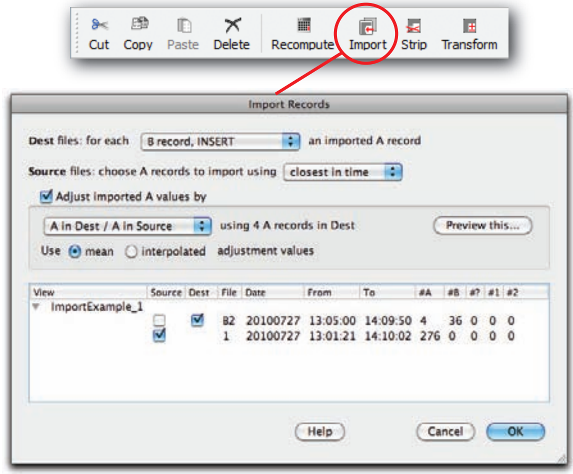
The files to be combined must be in the same view. If none or only one file is selected, then all files will be combined. If more than one file is selected, then you have a choice of combining just the selected files, or all the files in the view. You can name the resulting file. Combining files creates a new file, with its own copy of all the observations. It makes no changes to any of the contributing files.

*Note: Like any LAI file, a combined file will have only one TransComp setting (canopy model, mask, etc.). Thus, if you need to combine files that have different masks, for example, then this version of combine may not work correctly for you.*

1. Put files to be combined into the same view. If there are files in that view that you do not want to combine, then select only the ones you want.
2. Click on the combine icon, or do **File > Combine**.
3. Specify the name of the new file, and click OK.
4. The recomputed dialog will open. You can specify details of how you want the computation done.
5. The new file will be computed and appended to the current view.

# Importing Readings from Separate Files (FV2200)

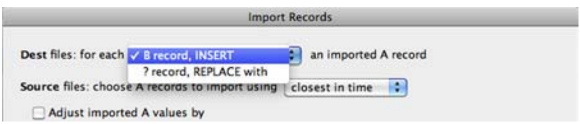
When **A** and **B** readings are in separate files, they must be merged to compute results. If the **A** and **B** readings were collected using two different sensors, the sensors also need to be matched – that is, readings from one sensor should be adjusted so that both sensors read the same under the same conditions. This is accomplished with the Import Records tool.




## The Import Records Dialog Box

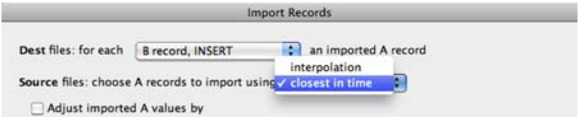
Descriptions of fields in the Import Records dialog box are below.

Dest files: This refers to the files that have the **B** readings and need **A** readings. The program will try to find **A** readings for each of the **B** readings in the destination files. The dialog box gives two options:



With LAI-2200 data files, you will always use the INSERT option. The REPLACE is for LAI-2000 data files collected in Remote Below mode, which use "?" as record placeholders.

Source files: This refers to the source of the **A** records. The dialog box provides two options for selecting **A** records:




"closest in time" will import the **A** record that is just that; "interpolate" will cause the program to find the nearest two **A** records in time, then use them to interpolate a value.

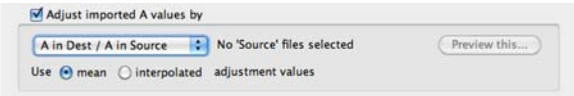
Adjust imported **A** values: This check box enables or disables applying match data to imported **A** records. If the above and below units were matched to each other prior to data collection, you can leave this box unchecked.


"A in Dest / A in Source" puts the matching data (**A** records) in the below file along with the normal **B** records.

"B in Match / A in source" puts the matching data (**B** records) in separate files.

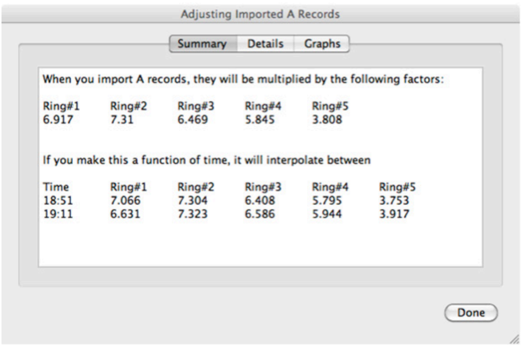
"B / A pairs in Match" puts the **A** and **B** match data together in one place, which might be useful for archival purposes, and it means the program does not have to find the **A** records as when using the files as match files.

Mean and Interpolated Radio Buttons: This determines whether the match data used to correct imported **A** readings is a constant or interpolated. The best way to determine this is to use the Preview button and compare the Ratio vs. Time plot (shown below).

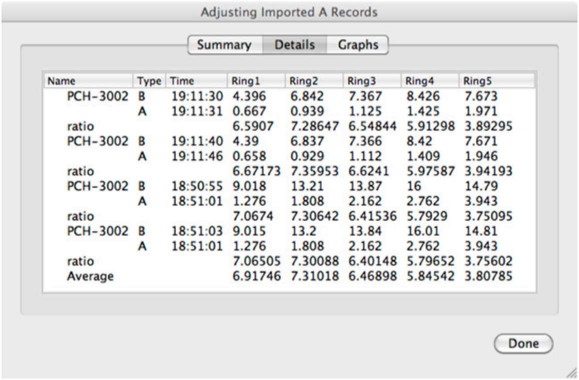



Preview this…: This button allows you to see in advance what the adjustment values will be. The preview dialog has three tabs: Summary, Details, and Graphs.

The **Summary** tab shows what the adjustment factors will be, whether using a mean or interpolating over time.



The **Details** tab shows all the pairs of A and B readings that will be used for match data.



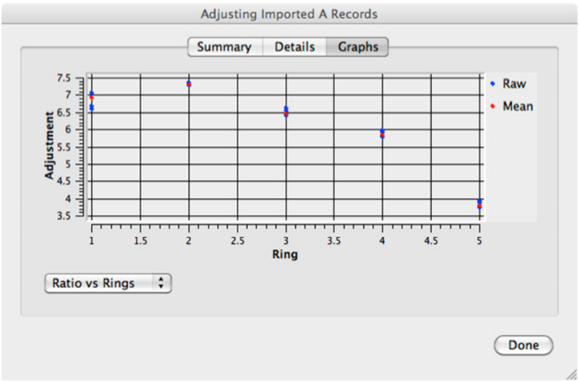
Adjusting Imported A Records

Summary | Details | Graphs

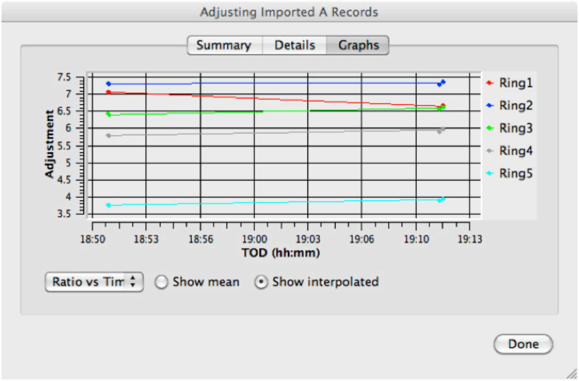
| Name | Type | Time | Ring1 | Ring2 | Ring3 | Ring4 | Ring5 |
| --- | --- | --- | --- | --- | --- | --- | --- |
| PCH-3002 | B | 19:11:30 | 4.396 | 6.842 | 7.367 | 8.426 | 7.673 |
| | A | 19:11:31 | 0.667 | 0.939 | 1.125 | 1.425 | 1.971 |
| ratio | | | 6.5907 | 7.28647 | 6.54844 | 5.91298 | 3.89295 |
| PCH-3002 | B | 19:11:40 | 4.39 | 6.837 | 7.366 | 8.42 | 7.671 |
| | A | 19:11:46 | 0.658 | 0.929 | 1.112 | 1.409 | 1.946 |
| ratio | | | 6.67173 | 7.35953 | 6.6241 | 5.97587 | 3.94193 |
| PCH-3002 | B | 18:50:55 | 9.018 | 13.21 | 13.87 | 16 | 14.79 |
| | A | 18:51:01 | 1.276 | 1.808 | 2.162 | 2.762 | 3.943 |
| ratio | | | 7.0674 | 7.30642 | 6.41536 | 5.7929 | 3.75095 |
| PCH-3002 | B | 18:51:03 | 9.015 | 13.2 | 13.84 | 16.01 | 14.81 |
| | A | 18:51:01 | 1.276 | 1.808 | 2.162 | 2.762 | 3.943 |
| ratio | | | 7.06505 | 7.30088 | 6.40148 | 5.79652 | 3.75602 |
| Average | | | 6.91746 | 7.31018 | 6.46898 | 5.84542 | 3.80785 |

Done

The **Graph** tab can show the match data plotted as a function of sensor ring, or it can show match data plotted as a function of time.



The latter is helpful for determining whether match data should be interpolated or not.



## Export Data in Spreadsheet Format

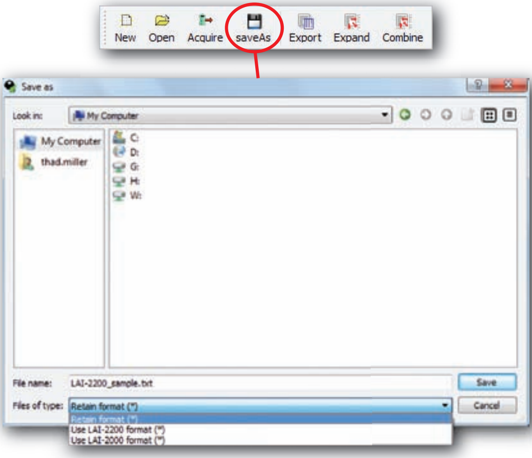
When exporting data in spreadsheet format, you can save the entire file or output a subset of the file.

1. Select the files that you wish to output (page 6-8).
2. Click **File > Export…** or click the **Export** button on the toolbar.
3. In the "Export" dialog box, choose which LAI files in the current view to include (All or Selected). Then, select which variables you wish to include. "Same as View" means the variables shown in the view will be the one included. To select a different group, click the "Other" radio button, then the "Define…" button, and build the list by dragging items from the master list (see Column Headings on page 6-7). Click OK when you are finished defining the rows and columns.
4. The results are shown in plain text, each row tab delimited. This can be copied to the system clipboard and pasted into a spreadsheet and/or saved to disk.

# FV2200 Tools

## Saving a View

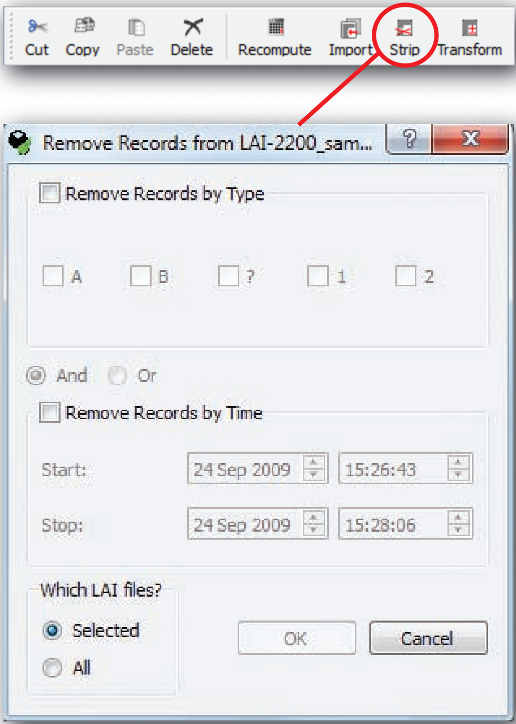
The files within a view can be saved by selecting the **saveAs** button or **File > saveAs…**.




There are two formats available for storing LAI files. Most of the time, you will use the default LAI-2200 format. The LAI-2000 format may be useful if you want to read the stored file with the older FV2000 software. In either case, the resulting file is a text file. The only difference is in the header information. Select "Retain Format" to keep the original formatting of the file.

## Deleting Records

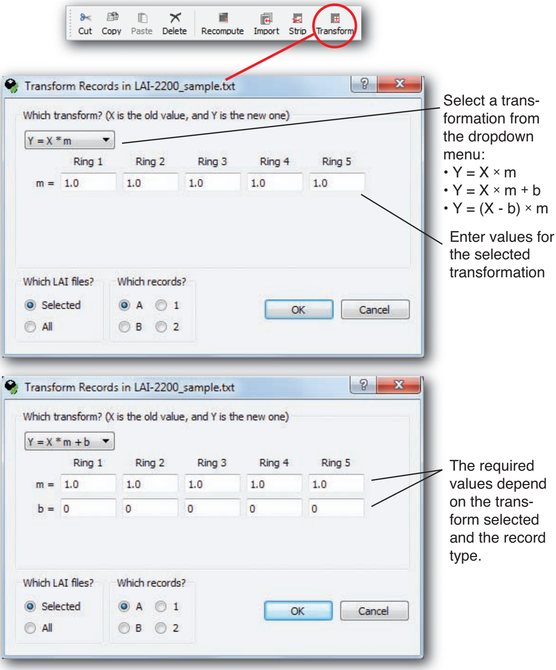
Records can be removed from an LAI file by selecting **Edit > Records > Remove** from the Edit menu or the Records Strip button.




Records can be removed based on type (**A**, **B**, etc.), time stamp, or observation number. To get a summary view of an LAI file's records, use the As Read tab of the File Details window.

# Transforming Records

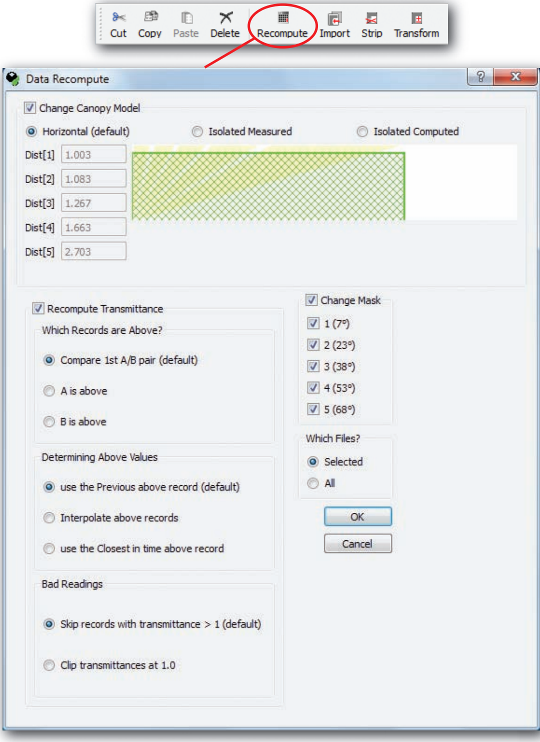
The raw values of records can be mathematically modified. Click the Transform button, select a transformation and enter the parameters.



# The Recompute Dialog Box

The recompute dialog box is used to specify three major groups of settings:

1. What is the canopy shape (see Canopy Models, page 6-24).
2. How is transmittance computed (see Computing Transmittance, page 6-27).
3. Which rings are used (see Masking Rings, page 6-29).



It can be accessed for multiple files from the Main Window toolbar (or **Edit > Recompute**) or for individual files from the **Header** tab in the **File Details** window.

## Canopy Models

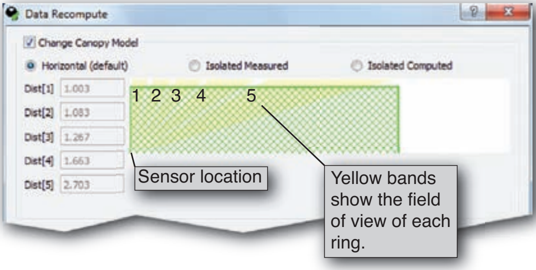
The LAI-2200 theory is based on measurements of gap fraction at 5 zenith angles. The only other data that needs to be supplied are the path lengths of view through the canopy at those 5 angles. These path lengths are the 5 values labeled DISTS in LAI-2200 files.

FV2200 supplies three canopy models (methods) as an aid in determining the correct path lengths: Horizontal is the default LAI-2200 setting. The basic assumption is that all of the sensor's rings see out the top of the flat canopy. Isolated Canopy, Measured Distances is for canopies that are not sufficiently wide and flat, the default path lengths may not be appropriate. Path lengths are measured and entered. Isolated Canopy, Computed Distances is for canopies that are not sufficiently wide and flat, path lengths are computed based on measurements of the canopy profile.

Canopy model is an attribute of each LAI file in FV2200. Model type can be displayed in a view (variable: Model) and modified in the Recompute Dialog box.

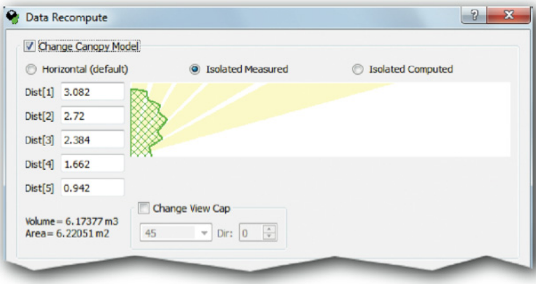
*Horizontal*

Path length is a simple function (1/cosine) of the zenith angle. Canopy height can be ignored – it cancels out of the equation for LAI. If you wish to know foliage density (foliage density/canopy volume), however, divide the reported LAI value by canopy height (m).



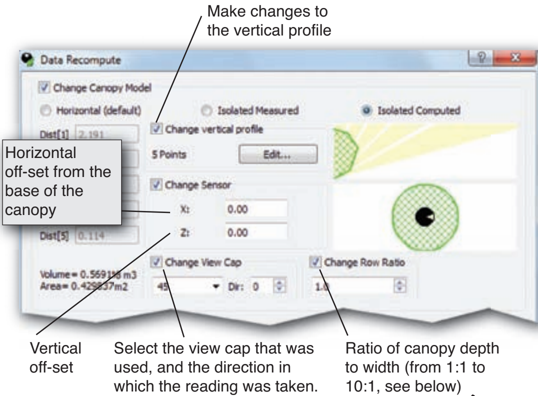

*Isolated Measured*

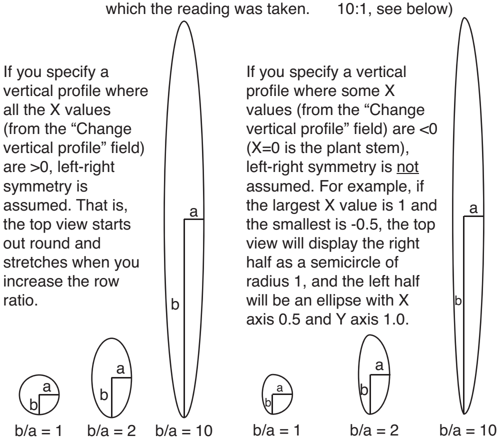
The user measures and enters each path length. In this case, the reported LAI value is foliage density ($m^2$ foliage area/$m^3$ canopy volume). Distance values should be entered in units of m. *Note: it is assumed that the entered distances are appropriate for all azimuthal angles of view (i.e., the canopy is round).*



### *Isolated Computed*

Path lengths are computed based on a vertical profile of the canopy, and where the sensor is in relation to it. Azimuthal asymmetry is allowed, meaning that the canopy can be round or stretched out like a hedge. If the canopy is asymmetric, then the average path length for each ring will be a function of the view cap.




The vertical canopy can be adjusted in the Profile Editor window (click **Edit…** under the Change

Vertical Profile check box). By default there are four points (X,Z coordinates). To add a coordinate, right click on the canopy shape and select **Add point**. The "Change Row Ratio" field can range from 1.0 to 10.0 It is the ratio of across-row (x) to in-row (y) dimensions of a plant.

To see an example of an asymmetric row, go to **File > Sample files > Menu Example** and open the file called **ROW2**. In the Recompute dialog, set the row ratio to 1. The right side of the canopy will have a hemispherical radius and the left will have an ellipse.

## Computing Transmittance

The method for computing transmittance is condensed into a 2-character code, which indicates:

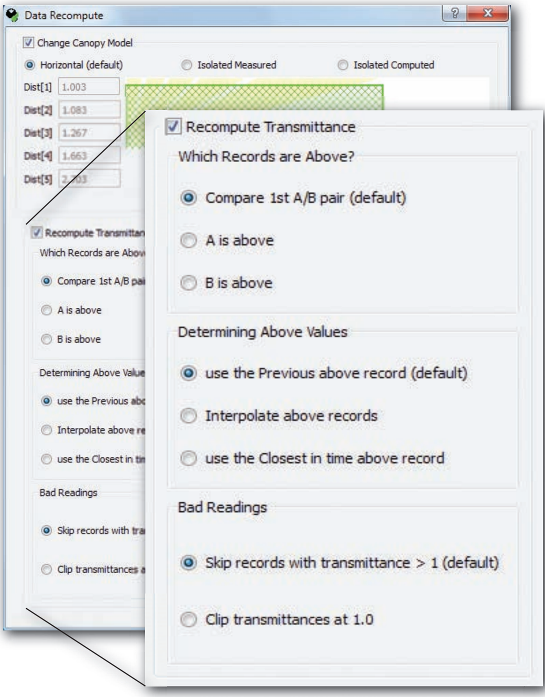
1. What is the relation between Above, Below, and **A**, **B** records?
2. How to determine Above-canopy values?
3. What to do with bad readings?

| FV2200 Code | Description | Console Setting |
|---|---|---|
| First Character: Determine the role of A and B records | | |
| A__ | (Default) A records are Above, B are Below | A |
| B__ | B records are Above, A are Below | B |
| C__ | Compare A & B to find which are above (largest values) | Compare |
| Second Character: Determine the Above values | | |
| _P_ | (Default) Use the previous record | Previous |
| _I_ | Interpolate between the nearest (time) Above readings | Interpolate |
| _C_ | Use the closest in time Above reading | Closest |
| Third Character: When a Below record has a value > its corresponding Above value | | |
| __S | (Default) Skip that record | Skip |
| __C | Clip the transmittance (Below/Above) to be 1.0 for that ring | Clip |

Thus, the method for computing transmittance is summarized in a three-character code such as "AIC" or "CPS". This code can be viewed for a file via the variable Transcomp in the Main Window. When FV2200 stores a file in FV2200 format, these codes are in the Transcomp line, just like the LAI-2200 console does it.

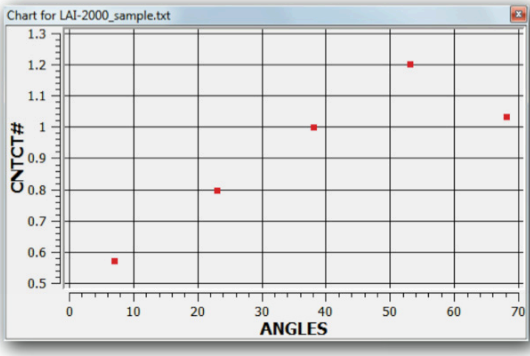
If you store a file in FV2000 format, the software tucks the three letters after the LAI label. Also, the code for "Compare" is represented with the letter F, and the code for "Clip" is a T in files saved in FV2000 format.

The method used to compute the transmittance can be changed in the Recompute Dialog box.

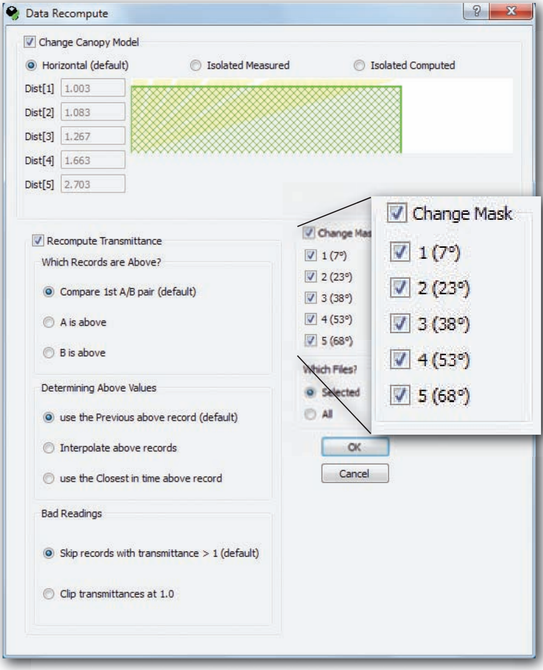


## Masking Rings

The LAI-2200 sensor has 5 concentric rings that make up a field of view that extends from the zenith (0°) to near the horizon (74°). Sometimes it is necessary to reanalyze LAI-2200 data by neglecting ("masking") certain rings. For example, if the field of view of the reference readings was not sufficiently wide, one or more of the outer rings should be ignored. Also, if a plot of contact number versus angle is not monotonic, as illustrated below, excess scattering is indicated, and the 5th ring should be ignored.



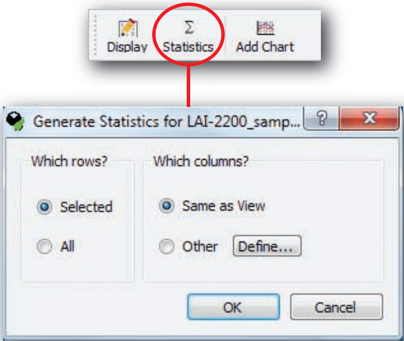

The mask setting can be adjusted in the Recompute Dialog box. See Excluding Rings from Analysis (page 6-11) for a step-by-step example.

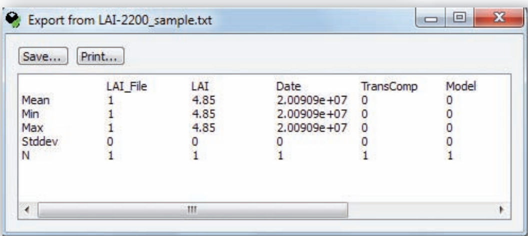

Data Recompute
Change Canopy Model
Horizontal (default)
Isolated Measured
Isolated Computed
Dist[1] 1.003
Dist[2] 1.083
Dist[3] 1.267
Dist[4] 1.663
Dist[5] 2.703
Recompute Transmittance
Which Records are Above?
Compare 1st A/B pair (default)
A is above
B is above
Determining Above Values
use the Previous above record (default)
Interpolate above records
use the Closest in time above record
Bad Readings
Skip records with transmittance > 1 (default)
Clip transmittances at 1.0
Change Mask
1 (7°)
2 (23°)
3 (38°)
4 (53°)
5 (68°)
Which Files?
Selected
All
OK
Cancel

# Summary Statistics

Mean, range, and standard deviation are readily computed on any numeric FV2200 variable.

1. Highlight the files to be included. If none are highlighted, all will be included.
2. Click the Statistics tool.
3. In the **Generate Statistics** dialog box, select the variables to be included. They can be the same as the Main Window or you can define a different set (click on **Define…**).
4. Click **OK**. View the results, which are shown in a window that can be printed or saved.



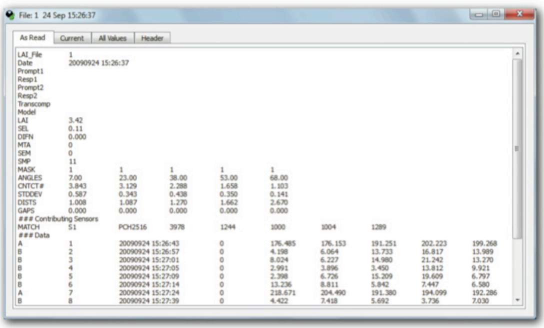



# File Details

This dialog, accessed by double-clicking an entry in the Main Window, presents four views of the selected file.

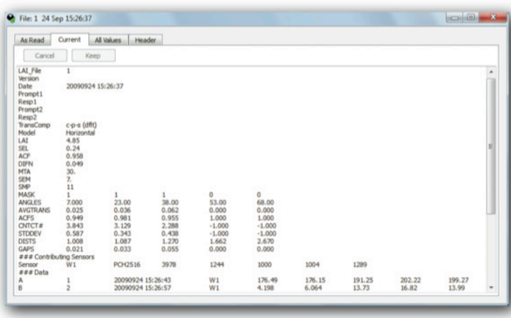
## As Read

This view shows the file in the form in which it is stored on the disk. Data is not editable in this view.



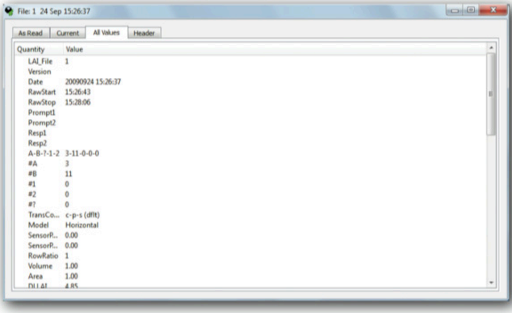

## Current

This shows an editable view of the file. Changes can be made by selecting the numbers in a field and keying in new values (e.g., masking rings). Click **Cancel** to undo changes or **Keep** to save changes and view the results.



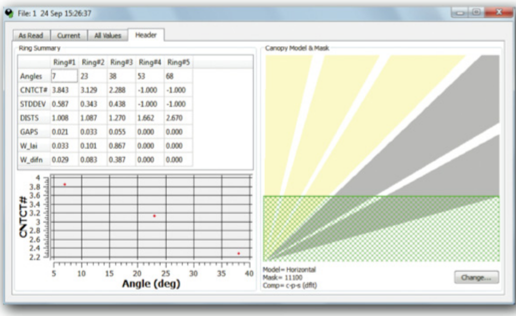
## All Values

The All Values view shows all of FV2200's variables (except raw data) for the file.



## Header

The Header view shows a summary statistics table, statistics graph, and the canopy model and mask. Any variables shown in the ring summary table can be displayed in the graph by selecting the column of interest. Data in the Header tab reflects changes that were implemented in the Current tab. To change the canopy model and mask for the selected file, click the **Change…** button.



## Computing LAI

FV2200 duplicates the LAI computation done in the LAI-2200 console (LAI-2000 Method), and also provides some alternatives: the Lang Method, Ellipsoidal Method, and Constrained Least Squares Method. These are described below.

There are some points to remember when interpreting these results:

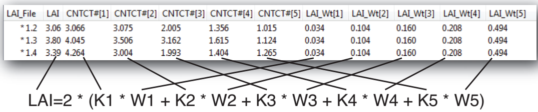
1. The "L" in LAI (Leaf Area Index) is traditional, and not necessarily a fact. Anything that blocks light will be included in the result: branches, stems, animals, etc. Thus, "Foliage Area Index" is a better way to think of this.
2. LAI could be foliage area index ($m^2$ foliage/$m^2$ground), or foliage area density ($m^2/m^3$) canopy. It is the path lengths (Dist[*]) that determine which units are appropriate. For standard path lengths (Horizontal Uniform model), LAI is foliage area index. For any other path lengths (Isolated Canopy, Measured Distances, and Isolated Canopy, Computed Distances), LAI should be interpreted as foliage density.
3. The LAI values include a correction (log average transmittances) for clumping. Thus, especially if narrow view caps were used, measured LAI is closer to $L$ (true LAI) than $L_e$ (effective LAI). If you want $L_e$, multiply LAI by ACF, the apparent clumping factor.

## LAI-2000 Method

LAI is computed from (see Chapter 9 for the derivation):

$$L = 2\sum_{i=1}^{5} \overline{K}_i W_i \qquad \text{6-1}$$

where $L$ is the leaf (all light blocking objects) area index (LAI), $\overline{K}_i$ is the mean contact number for the i[th] ring (contact#[*]), and $W_i$ is the weighting factor for the i[th] ring (LAI_W[*]).



| LAI_File | LAI | CNTCT#[1] | CNTCT#[2] | CNTCT#[3] | CNTCT#[4] | CNTCT#[5] | LAI_Wt[1] | LAI_Wt[2] | LAI_Wt[3] | LAI_Wt[4] | LAI_Wt[5] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *1.2 | 3.06 | 3.066 | 3.075 | 2.005 | 1.356 | 1.015 | 0.034 | 0.104 | 0.160 | 0.208 | 0.494 |
| *1.3 | 3.80 | 4.045 | 3.506 | 3.162 | 1.615 | 1.124 | 0.034 | 0.104 | 0.160 | 0.208 | 0.494 |
| *1.4 | 3.39 | 4.264 | 3.004 | 1.993 | 1.404 | 1.265 | 0.034 | 0.104 | 0.160 | 0.208 | 0.494 |



The mean contact number is a function of the transmittance and the path length $S_i$ (Dist[*]). For $n$ Above/Below pairs of observations,

$$\overline{K}_i = \frac{\frac{1}{n}\sum_{i=1}^{n} -\ln\left(\frac{B_j}{A}\right)}{S_i} \qquad \text{6-2}$$

Weighting factor $W_i$ is computed from

$$W_i = \Delta\theta_i \sin\overline{\theta}_i \qquad \text{6-3}$$

where $\overline{\theta}_i$ is the mean zenith angle and $\Delta\theta_i$ is the ring width (radians) associated with $i^{th}$ ring. Values for $\Delta\theta_i$ are given in Table 6-1 below. The weighting factors are



6 Data Analysis with FV2200

normalized to sum to 1.0, so when one or more rings are masked, the remaining weighting factors increase.

*Table 6-1. Ring widths and weighting factors.*

| Ring | Width (°) | Weighting Factor |
|---|---|---|
| 1 | 12.2 | 0.041 |
| 2 | 12.2 | 0.131 |
| 3 | 11.8 | 0.201 |
| 4 | 13.2 | 0.290 |
| 5 | 13.2 | 0.337 |

## Lang Method

A simple method of computing LAI from the slope and intercept of a plot of contact number vs. angle was proposed by Lang (1987).

$$L_{lang} = 2(m + b) \quad \text{6-4}$$

where $L_{lang}$ is leaf area index (LangLAI), $m$ is the slope and $b$ is the intercept of contact number (CNTCT#[*]) plotted as a function of angle (in radians). LangLAI can be added to views or viewed in the "All Values" tab of any data file.

## Ellipsoidal Method

Another method of inverting gap fraction data is to use an ellipsoidal-based description of leaf angle distribution. Refer to Norman and Campbell (1989), and Campbell (1986).

Variables computed with the Ellipsoidal Method include:

**EllipLAI** – LAI (or foliage density) obtained from the ellipsoidal distribution method.

**EllipMTA** – Mean Tip Angle obtained from the ellipsoidal method.

**EllipX** – The ratio of horizontal to vertical radii of an ellipsoid whose surface area fractions describe the foliage angle distributions in the canopy.

These variables can be added to views or viewed in the "All Values" tab of any data file.

## Constrained Least Squares Method

An alternative method of inverting gap fraction data is that of constrained least squares. Refer to Norman and Campbell (1989) and Perry et al. (1988). The outputs associated with this method are listed below:

**CLS_LAI** – LAI (or foliage density) by method of the constrained least squares.

**CLS_c** – The smallest constraint that yields all positive area fractions.

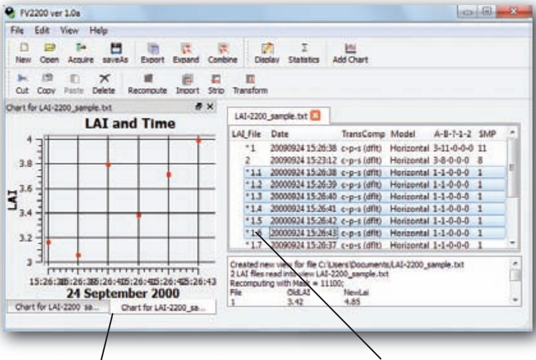
**CLS_LAD[*]** – foliage angle distribution. The angle classes are 9°, 27°, 45°, 63°, and 81° (90 divided evenly by 5). If one or more rings are masked, there will be fewer angle classes.

**CLS_MTA** – Mean Tip Angle based on the distribution (S).

**CLS_Mu, CLS_Nu** – Mu, Nu of the Beta distribution (Goel and Strebel, 1984).

# Graphical Analysis

Any data within an LAI-2200 file, or across multiple files in a view, can be plotted. Select the file(s) to be included, and click on the Add Chart button, or click **View > Add Chart…**. Charts will open in a separate window when they are created, but they can be added to the Main Window by dragging and dropping the chart into the window.




One or more charts can be placed in the main window. Chart names are displayed on tabs when multiple charts are displayed.

Select files that are to be displayed on a chart.

Here is a simple example that plots LAI as a function of time in a sample file.

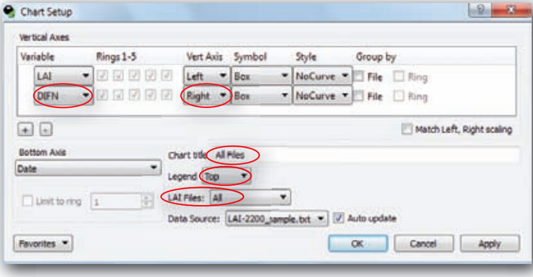
1. Open **File > Sample Files > Manual Examples**.
2. Click the **Add Chart** button.
3. Click the **Favorites**, Select "LAI History: LAI vs. Date".
4. Click OK.

This example below describes in detail how might make the same plot with your own data.

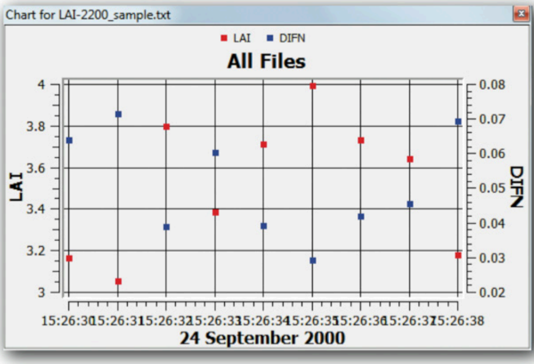
1. Select a file that has data that you would like to chart (the sample file LAI-2200_sample.txt under **File > Sample Files** will suffice. Open the file, select LAI_File 1, then click the **Expand** button. Click on **OK** and select a file from the new list).
2. Click the Add Chart button, set the parameters as shown below, and click the **OK** button.


The resulting chart will appear in a new window. Only one file was selected, so only one point appears in the plot. If you had selected all the files, or chosen "All" under the "LAI Files:" menu, values for all files would appear in the chart.

3. Click through the list of files to change the selected file. Select a range of files with Shift+Click or select multiple files with Ctrl+Click (PC) or ⌘+Click (Mac). Notice how the chart updates when different files are selected.
4. Double click anywhere in the chart to bring back the configuration dialog box, and make the following changes:

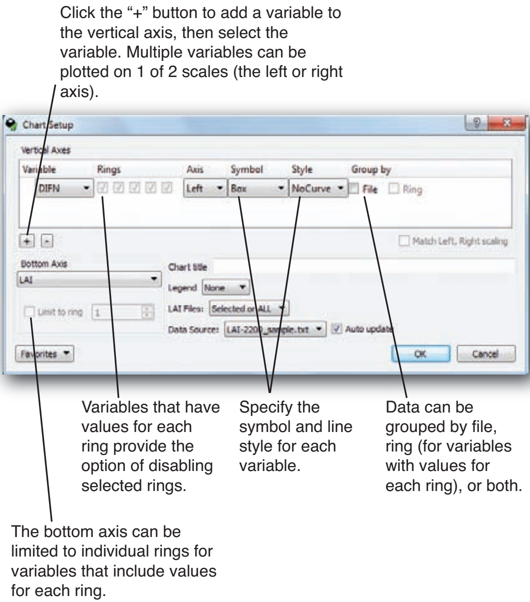



5. Click OK. The chart will be redrawn using all the files in the view, regardless of what is selected. Note the addition of the 2nd variable on the right axis, the legend, and a title.



# Chart Definition Dialog Box

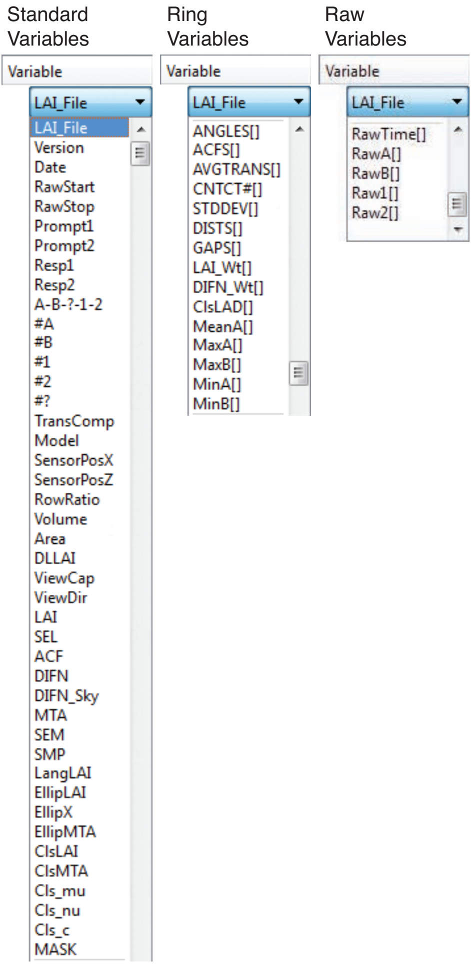
Individual charts are defined using the dialog box shown below, accessed by clicking the Add Chart button or double clicking an existing chart.




## Selecting Variables

Variables for plotting are selected from the three-part list box shown below. 61 variables are available to choose from. These variables can be grouped into three categories: Standard, Ring, and Raw.

Standard variables are single-valued variables. Ring values are 5-valued (one for each ring) summaries. Raw measurements are the observations (A and B).




## Description of Variables

Items in the list below are variables output from the LAI-2200. Items marked with * are unique to FV2200.

**Header Items**

**LAI_File -** LAI file name (Numeric for LAI-2000, alpha-numeric for LAI-2200).
**Version** - Software version (defined for LAI-2200 only)
**Date** - Timestamp in the file header. For LAI-2000, year defaults to 2000.
**RawStart*** - Starting time for the raw data
**RawStop*** - Ending time for the raw data
**Prompt1**
**Prompt2**
**Resp1**
**Resp2**
**A-B-?-1-2*** - Number of each record type. '?' defined only in LAI-2000
**#A*** Number of **A** records
**#B*** Number of **B** records
**#1*** Number of **1** (light sensor) records
**#2*** Number of **2** (light sensor) records
**#?*** - Number of '?' records
**Transcomp** - 3 character code for how transmittance is computed
**Model** - Canopy model:
**Horizontal** (The default. Distances are 1/cos).
**IsoFixed** (Isolated canopy, fixed distances, user entered).
**'IsoComputed** (Isolated canopy, distances computed from vertical and horizontal profiles).
<items specific to IsoFixed / IsoCompted >
**ViewCap*** - Size (degrees open) and direction (0 = +x direction)
**SensorPosX*** - Sensor position in X direction (across row)
**SensorPosZ*** -Sensor position in Z direction (vertical)
**RowRatio*** - Ratio canopy Y to X direction (Y = along row, X = cross row). 1 = round canopy
**Volume*** - Computed canopy volume (in view of sensor)

**Area*** - Drip line area (in view of sensor)
**DLLAI***- Drip line LAI = foliage density * Volume / Area
**ViewCap*** - size of opening of view cap
**ViewDir*** - direction of view, relative to row, 0=cross row
**LAI** - Leaf Area Index (or Foliage Density if canopy model is not Horizontal).
**SEL** - Standard error of LAI
**ACF** - Apparent clumping factor for LAI
**DIFN** - Diffuse non-interceptance
**DIFN_Sky*** - Diffuse non-interceptance weighted for the measured sky brightness distribution
**MTA** - Mean tip angle, degrees
**SEM** - Estimate of standard error of mean tip angle
**SMP** - Number of Above/Below pairs used to compute LAI
**LangLAI** - LAI using Lang method
**EllipLAI*** - LAI using Campbell method of elliptical foliage angle distribution
**EllipX*** - 'X' factor for the elliptical angle distribution (ratio of radii)
**EllipMTA*** - Mean tip angle from elliptical method
**ClsLAI***- LAI determined from constrained least squares method (CLS)
**ClsMTA*** - Mean tip angle from CLS
**Cls_mu*** - mu parameter for beta distribution of foliage angle from CLS
**Cls_nu*** - nu parameter for beta distribution of foliage angle from CLS
**Cls_c*** - final CLS constraint factor
**Mask***- 5 values of 1 or 0 for rings 1 to 5, indicating if the ring was used or ignored.

11111 - all used
11110 - ring 5 ignored

**Ring Related Items**

**Angles** - The angle values for each ring

**ACFs** - Apparent clumping factor for each ring $\ln \overline{p(\theta)} / \overline{\ln p(\theta)}$

**AvgTrans** - Average transmittance for each ring

**CNTCT#** - Contact number (average of the log of the individual transmittances divided by distance)

**STDDEV** - Standard deviation of the contact numbers

**DISTS** - Canopy path length for each ring

**GAPS** - Gap fraction based on average of the log of the individual transmittances

**LAI_Wt** - Weighting factors for Contact numbers when computing LAI

**DIFN_Wt** - Weighting factors for Gaps when computing DIFN

**ClsLAD** - Leaf angle distribution from CLS inversion

**MeanA** - Mean of the **A** readings, ring by ring

**MeanB** - Mean of the **B** readings, ring by ring

**MaxA** - Max value of the **A** readings, ring by ring

**MaxB** - Max value of the **B** readings, ring by ring

**MinA** - Min value of the **A** readings, ring by ring

**MinB** - Min value of the **B** readings, ring by ring

**Raw Readings**

**RawTime** - Time stamp for the raw record

**RawA** - **A** record, with 5 ring values

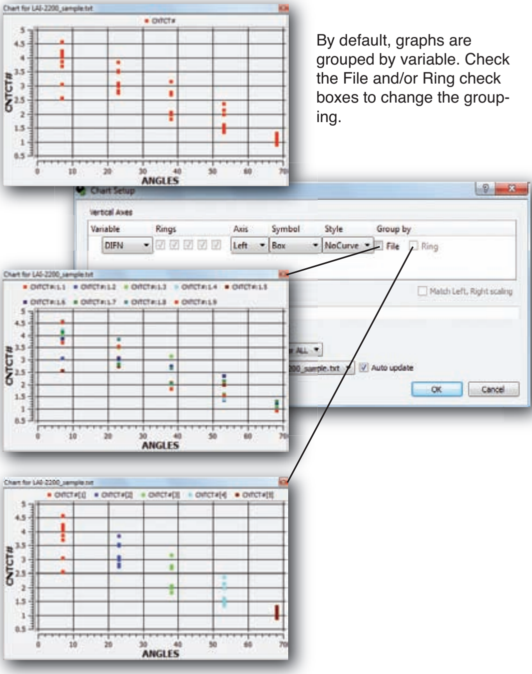
**RawB** - **B** record, with 5 ring values

**Raw1** - 1 type record

**Raw2** - 2 type record

## Grouping Options

Data can be displayed in groups by selecting File or Ring.




By default, graphs are grouped by variable. Check the File and/or Ring check boxes to change the grouping.

**Group by File** will give each file a distinct symbol. Plotting 10 files will result in 10 symbols, and 10 items in the legend. If the plot has both left and right axes, there will be 20 symbols (and 20 legend entries). When graphing a large number of files, you may wish to not use this option, or turn off the legend.

**Group by Ring** applies to variables that have a separate value for each ring. Values for each ring are assigned a symbol. When grouped by ring, there will be 5 symbols, - one for each ring. If a ring variable is plotted on both dependent axes, there will be 10 symbols in the legend.

## Chart Context Menu

Right-clicking on a chart will bring up the context menu:

**Edit…** – Brings up the Chart Setup dialog.
**Auto-update** – Enable/disable the auto update feature of the chart.
**Data Source**– Has a submenu of all the current views. Pick the one to use with this plot.
**Page Setup…** – Provides page setup parameters for the selected plot.
**Print…**– Send the chart to a printer.
**Capture…** – Save the chart as a .pdf or .ps file.
**Remove this Chart** – Deletes the chart.

# 7 Tutorials and Examples

This section serves as a guide for two advanced topics: collecting and processing data isolated canopies and practical strategies for multi-sensor operation. Six complete examples are given below, and each has a corresponding data file in FV2200 software Menu Examples (see the Sample files).

## A Simple Isolated Canopy

Consider the example given on page 5-13. In this example, the plant is a hemispherical shrub with measured path lengths of 0.7 m. Launch the FV2200 software. Click on **File > Sample files > Manual Examples.txt**. Double click on the file called **SHRUB** to view file details, then select the "As Read" tab. The data file for this shrub looks something like this:

```
...
MODEL      IsoMeasured
...
LAI        6.69
SEL        0.00
ACF        1.000
DIFN       0.092
MTA        49
SEM        2
SMP        1
MASK       1      1      1      1      1
ANGLES     7.00   23.00  38.00  53.00  68.00
AVGTRANS   0.059  0.068  0.097  0.084  0.131
ACFS       1.000  1.000  1.000  1.000  1.000
CNTCT#     4.035  3.850  3.338  3.539  2.903
STDDEV     0.000  0.000  0.000  0.000  0.000
DISTS      0.700  0.700  0.700  0.700  0.700
GAPS       0.059  0.068  0.097  0.084  0.131
...
A: 1   20090924   12:13:44  109.23  108.96  102.21  96.61  100.67
B: 2   20090924   12:14:05  6.480   7.360   9.880   8.110  13.19
```

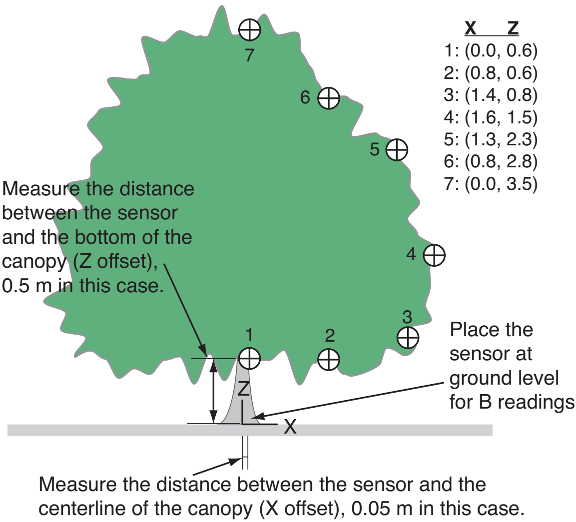
The LAI value is foliage density. There are two ways to tell this by looking at the file. One is the "Model" line. "Horizontal" means the canopy model is horizontally infinite, or at least large enough that the default DISTS vectors apply. "IsoMeasured" means an isolated canopy. The other way to know this is to look at the DISTS values. Since they are not the default values (1.008, 1.086, 1.269, 1.662, and 2.669), then LAI should be interpreted as foliage density.

Click on the "Header" tab, then click "Change…". In the **Recompute** dialog, check **Change Canopy Model**, then check **Change View Cap**. Select the 90 degree cap and observe changes in the Volume and Area fields, which are used to compute Drip Line LAI (DLLAI).

# Isolated Tree

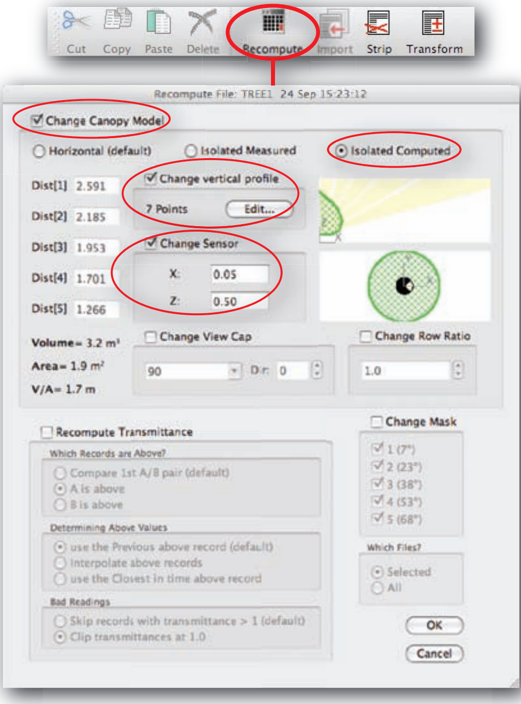
Below is an example of the procedure that could be used to measure LAI for an isolated plant. The steps below will generate a file much like the example file maned TREE1 in the FV2200 software, which is accessed by going to **File > Sample files > Manual Examples**.

1. Create a new file with default Transcomp settings. Use a 90° view cap and take one AB pair in each of the four directions.
2. Measure the average shape of the tree's crown with several X, Z pairs of points that describe the profile, as shown below (a photo of the profile with a meter stick for scale could be used as well).
3. Measure the X and Z offsets, as shown below.




4. Open the file with the FV2200 software.

5. Select the file and click the **Recompute** button. Check the **Change Canopy Model** box.
6. Check the **Isolated Computed** box, and the **Change vertical profile** box.
7. Click the **Edit…** button and enter the X, Z coordinates to define the canopy shape. Right click on the profile to add more points. Click OK when finished.
8. Enter the X and Z sensor position. Observe changes in volume and area values as these fields are updated.



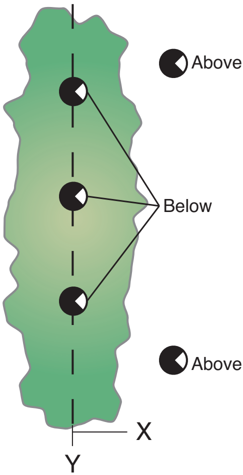
9. Click **OK** to implement the changes. The new LAI value, along with a summary of the procedure, will be visible in the log.
10. Save the file to retain any changes.

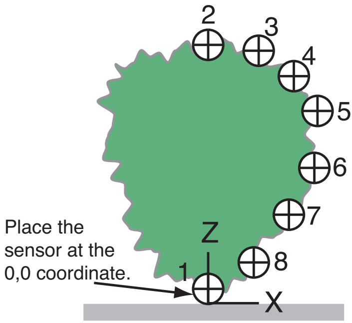
# Isolated Row 1

There are two approaches that can be used to measure an isolated row, such as a grape vine or hedge. The first is described here, and the second is described in example 2 below.

The steps below will generate a file much like the example named ROW1 in the FV2200 software, which is opened by **File > Sample files > Manual Examples**.

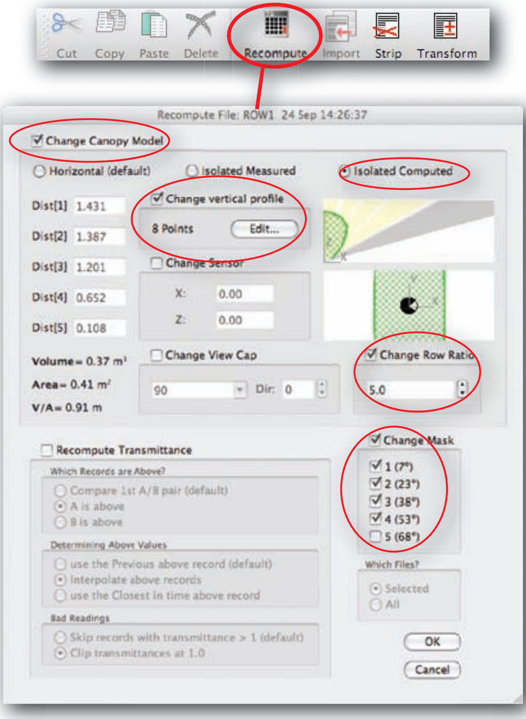
1. Set the console Transcomp settings to Define Above: A; Determine Above: Interpolate; Bad Readings: Clip. Place a view cap with a 90° opening over the lens and create a new file.
2. Make an above-canopy reading, multiple below-canopy readings, and a second above-canopy reading. Make the below canopy readings with the sensor at the base of the canopy, as shown.
3. Measure several X, Z coordinates (meters) to characterize the vertical profile, perpendicular to the centerline of the hedge. This example uses 8 coordinates. See the figure below.






| | X | Z |
|---|---|---|
| 1: | (0.0, | 0.0) |
| 2: | (0.0, | 1.47) |
| 3: | (0.31, | 1.39) |
| 4: | (0.51, | 1.27) |
| 5: | (0.67, | 1.05) |
| 6: | (0.63, | 0.79) |
| 7: | (0.54, | 0.51) |
| 8: | (0.25, | 0.14) |

4. Measure the width (Y) and depth (X) of the hedge to compute the row ratio (Y/X), 5 in this case.
5. Open the data file in the FV2200 software.
6. Click the **Recompute** button. In the Recompute Dialog box, select **Change Mask**. Deselect ring 5 because it did not "view" any foliage.
7. Next, check the **Change Canopy Model** check box, then the **Isolated Computed** radio button. Check the **Change vertical profile** button, then select **Edit…**.
8. Enter the X, Z coordinates to define the shape of the hedge. Right click on the canopy profile to add more points.
9. Check the **Change Row Ratio** box and set the row ratio to 5. Click **OK**.



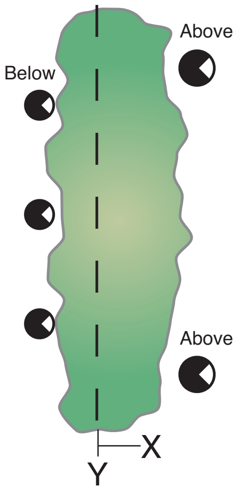

10. The new LAI values are displayed in the Log. Save the file to retain changes.

If the hedge were asymmetrical, two files would be required, one for each side of the canopy (or example 2 below could be used).

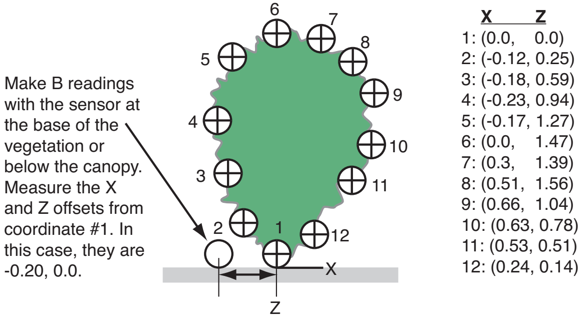
# Isolated Row 2

The steps below will create a file similar to the example **ROW2** in the FV2200 software, which is opened by **File > Sample files > Manual Examples**.

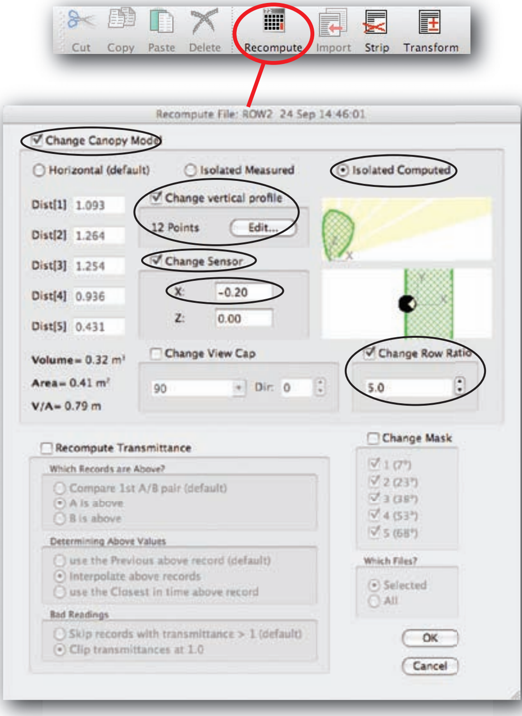
1. Set the console Transcomp settings to Define Above: A; Determine Above: Interpolate; Bad Readings: Clip. Place a view cap with a 90° opening over the lens and create a new file.
2. Make an above-canopy reading, several below canopy readings, and a final above-canopy reading. Take the below-canopy readings along a line that is parallel to the centerline of the shrub, but not directly under the shrub, as shown.




3. Measure a number of X, Z coordinates (meters) to characterize the vertical profile, perpendicular to the centerline, of the hedge. Measure the distance between where the **B** readings were taken and the centerline of the hedge (X offset), -0.20 in this case, and the distance between the vegetation and the sensor (Z offset) in meters (0.0 in this case), as shown in the figure below.




4. Measure the width (Y) and depth (X) of the hedge to compute the row ratio (Y/X).
5. Open the data file in the FV2200 software.
6. Click the **Recompute** button. In the Recompute Dialog box, check the **Change Canopy Model** check box, then the **Isolated Computed** radio button. Check the **Change vertical profile** button, then select **Edit…**.
7. Enter the X, Z coordinates to define the shape of the hedge. Right click on the canopy profile to add more points.
8. Check the **Change Sensor** check box.
9. Check the **Change Row Ratio** box and set the ratio. Click **OK**.




The new LAI value is shown in the Log. Save the file to retain changes.

7 Isolated Plant Examples

# Practical Strategies for Multi-Sensor Operation

When using two sensors to collect data for a single project, both sensors must be matched. That is, one sensor is adjusted so that both read the same under the same conditions. As a practical matter, however, this can be problematic. For example:

- Using an LAI-2200 with an LAI-2000
- Using multiple below canopy sensors
- Matching may be a function of time-of-day

Below are two simple strategies that solve all of these problems. To summarize both: don't worry about matching the sensors in the field; rather, simply collect a little extra data that can be used later to match the readings. This is made easier using FV2200 (version 1.2 and above), which will use this data and automatically combine the steps of matching sensors and importing **A** records.

## Method #1: Match Data Embedded in the Below File

Use this method if it is convenient to start and stop each below canopy file at the location of the **A** unit.

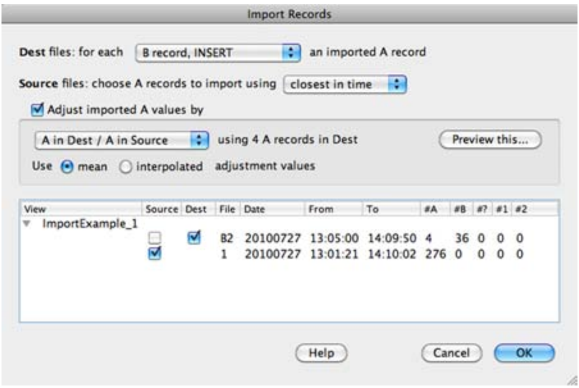
1. (**A** unit) Set up the above canopy unit in a suitable location, and start logging above readings to the unit. If using both an LAI-2000 and LAI-2200, use the LAI-2000 to collect the A readings.
2. (**B** unit) Create a new file for the first below canopy transect.
3. (**B** unit) Use the button on the wand to set the reading to **A** and log 2 or 3 **A** readings with the below sensor level and side-by-side with the **A** sensor, viewing the exact same region of the sky.

4. (**B** unit) Toggle the readings to **B**, and collect all the below-readings for the first transect.
5. (**B** unit) When finished with the transect, return to the **A** unit and repeat step 3. Then close the file.
6. Repeat steps 2 through 5 for the remaining transects.

A sample data set created using this method is in FV2200 (**File > SampleFiles > ImportExample-1**).

Data Processing for Method #1

1. Load the above and below files into FV2200. They can be in the same or separate views.
2. Click the Import Records button and set the dialog box as shown below, with appropriate files checked for source (**A** readings) and destination (**B** readings).
3. When you click OK, **A** records will be imported from the file(s) marked as *Source* and inserted before each **B** record in the files marked as *Dest*. In addition, the imported **A** readings will be adjusted according to the matching data you have indicated.



## Method #2: Match Data in Separate Files

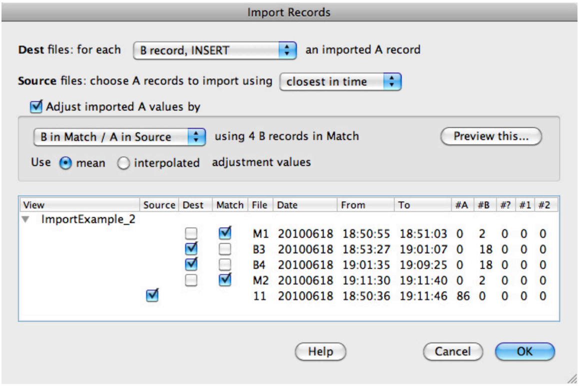
Use this method if it is not convenient to return to the **A** sensor between below canopy transects.

1. (**A** unit) Set up the above-canopy unit in a suitable location and start automatic data logging on the unit. If using both an LAI-2000 and an LAI-2200, use the LAI-2000 to collect these readings. If using multiple LAI-2200s use a detached wand for these readings.
2. (**B** unit) Before leaving the **A** sensor location, create a new file (name it M1, M2, etc., or MCH1, MCH2, etc., to indicate that this is the Match file) and log 2 or 3 readings in it, with the sensor side-by-side with the **A** unit sensor, and viewing the exact same region of sky. Close the match file.

A sample data set created using this method is in FV2200 (**File > SampleFiles > ImportExample-2**).

Data Processing for Method #2

1. Load the above, below, and match files into FV2200. They can be in the same or separate views.
2. Click the Import Records button and set the dialog as shown below.
3. When you click OK, **A** records will be imported from the file(s) marked as *source* and inserted before each **B** record in the files marked as *dest*. In addition, the imported records will be adjusted according to the matching data you have indicated.


Import Records
Dest files: for each
B record, INSERT
an imported A record
Source files: choose A records to import using
closest in time
Adjust imported A values by
B in Match / A in Source
using 4 B records in Match
Preview this...
Use
mean
interpolated
adjustment values
View
Source
Dest
Match
File
Date
From
To
#A
#B
#?
#1
#2
ImportExample_2
M1 20100618 18:50:55 18:51:03 0 2 0 0 0
B3 20100618 18:53:27 19:01:07 0 18 0 0 0
B4 20100618 19:01:35 19:09:25 0 18 0 0 0
M2 20100618 19:11:30 19:11:40 0 2 0 0 0
11 20100618 18:50:36 19:11:46 86 0 0 0 0
Help
Cancel
OK

# 8 Instrument Software Reference

This section provides a description of the functions that are available through the LAI-2200 Control Unit software.

## Main Menu

### 1 Wand Setup

Select Wand X (name) or Y (name)

#### 1.1 Set Name

These fields are used to name the optical sensors. When an optical sensor is named, the name is stored in the optical sensor. For example, if an optical sensor is attached to the X port and named “PCH3102”, and later attached to the Y port, it will still be called “PCH3102”.

#### 1.2 Clock

##### *1.2.1 Set*

The **Set** function is used to manually enter the time for the optical sensor clocks (HH:MM, YYYY/MM/DD).

##### *1.2.2 Sync*

The **Sync** function sets the optical sensor clock based on the control unit clock. Presents Yes/No verification.

#### 1.3 Cal Values

Calibration multipliers are set from this field. Use the arrow and numeric keys to enter calibration values. Press OK to store the values. These values should match the calibration sheet.

### 1.4 Match Values

These functions pertain to the match values for the selected wand.

#### *1.4.1 View / Set Values*

**View/Set** allows you to view and/or edit the current values, or reset them to the calibration values by pressing LOG.

#### *1.4.2 Compute Values*

Two wands must be connected for this. The wand selected when entering the menu will be matched to the other. **Compute** will determine the values by measurement: You will need a second wand connected to do this, and both wands positioned and stable, viewing the same view of the sky (Don't do this indoors with artificial light, or looking out a window - tiny variations in views can cause large errors in those environments.) When you select "Yes", the match will be performed.

### 1.5 Auto Log

#### *1.5.1 On/Off*

#### *1.5.2 Start Time*

#### *1.5.3 Stop Time*

#### *1.5.4 Frequency*

**Auto Log** and the subsequent menu options are used to configure automatic logging, start time, stop time, and frequency.

## 2 Log Setup

These settings apply to new data, not existing data.

### 2.1 Transcomp

#### *2.1.1 Define above:*

This field defines how the sensor determines which readings are above-canopy and which are below-canopy.

**Compare:** the console will compare adjacent records to determine which type (A or B) has consistently higher values for active (non-masked) rings. That type will then be considered the above-canopy record type.

**A:** means that readings taken while the optical sensor "Above" LED is illuminated will be considered above-canopy readings when calculating LAI.

**B**: readings taken while the optical sensor "Above" LED is not illuminated will be considered below-canopy readings when calculating LAI.

### *2.1.2 Determine Above:*

This field defines how the sensor uses above-canopy readings when computing LAI.

**Previous:** uses the previous above-canopy record in the file to compute LAI.

**Interpolate:** interpolates between two closest-in-time above-canopy records to generate each required above-canopy record. This is particularly useful when sky conditions are changing rapidly.

**Closest:** associates each above-canopy record with the closest below-canopy record (in time) to compute LAI.

### *2.1.3 Bad Readings:*

Bad readings occur when a below reading exceeds the value of a corresponding above reading (see page 4-7). There are two options:

**Skip:** the instrument will beep if a below reading has transmittance >1.0. It will log the below reading, but it will not use the record when computing LAI.

**Clip:** The transmittance for that ring in that record will be taken to be 1.0 when LAI is computed.

## 2.2 Prompts

**Prompt1:**
**Resp1:**
**Prompt2:**
**Resp2:**

Set prompts to prompt the user for additional information that will be recorded with each data file.

## 2.3 Obs Remarks

Remarks can be entered for each logged record. Remarks are set at this menu level or changed for individual records by entering the Log Setup menu while in logging mode. Changes to the remark are saved with each subsequent data file.

## 2.4 Angles

### *2.4.1 Sensor Angles:*

1: 7.00
2: 23.00
3: 38.00
4: 53.00
5: 68.00

Angles in these fields are set to reflect the view of each ring in the sensor.

## 2.5 Distances

### *2.5.1 Distance Vectors*

1: 1.008
2: 1.087
3: 1.270
4: 1.662
5: 2.670

The values are the average path length each rings sees through the canopy. By default, the values are $1/\cos\Theta$. For large, flat uniform canopies, this is sufficient; canopy height does not matter. For isolated canopies, the values should represent actual path lengths in meters.

## 2.6 Masks

### *2.6.1 Use Ring*

Ring1: <YES | NO>
Ring2: <YES | NO>
Ring3: <YES | NO>
Ring4: <YES | NO>
Ring5: <YES | NO>

Determines which rings are used in LAI calculations. To exclude a ring, set its value (use ← and →) to No. To reset (all rings to Yes), press the Log button while viewing this screen.

## 2.7 Controlled Sequence

Use: Yes|No
Reps: up to 41
Pattern:

## 2.8 PAR Sensors

### *2.8.1 Port 1*

### *2.8.2 Port 2*

Enabled: < On | Off >
Name: Port 1
Cal: xxxxx

These fields are used to configure LI-COR Biosciences radiation sensors. Enable the port by selecting On, Name the sensor, and enter the calibration multiplier for the sensor.

# 3 Data

## 3.1 Wand Data

Download – to transfer data from the wand to the control unit.
Purge – to delete data files from the wand.

8 Instrument Software Reference

## 3.2 Console Data

### *3.2.1 Select data file:*

#### 3.2.1.1 View

##### 3.2.1.1.1 View Header

Shows file name, time and date created, responses to prompts, LAI, SEL, ACF, DIFN, MTA, SEM and SMP (sample size).

##### 3.2.1.1.2 View ANGLES/MASK

Shows angles and masks used to compute the selected data file.

##### 3.2.1.1.3 View CNTCT #/STDDEV

Shows contact number and standard deviation computed for the selected data file.

##### 3.2.1.1.4 View AVGTRANS/GAPS

Shows average transmittance and gap fraction computed for the selected data file.

##### 3.2.1.1.5 View DISTS/ACFS

Shows distances and apparent clumping factors for each ring.

##### 3.2.1.1.6 View Observations

Shows ring values for each above and below reading in the file. Use the left/right arrow keys to scroll through readings.

#### 3.2.1.2 Edit

These options pertain to the selected data file only.

##### 3.2.1.2.1 Edit Angles

Sensor Angles: Edit the angles used in computations. Press OK to save new settings, EXIT to cancel, and LOG to reset to default settings.

##### 3.2.1.2.2 Edit Mask

Use Mask: Apply a mask to any ring that is not to be used in computations. Press OK to save the new settings, EXIT to cancel, and LOG to reset to default values.

##### 3.2.1.2.3 Edit Distances

Distance Vectors: Change these values to alter distances used in computations. Press OK to save the new settings, EXIT to cancel, and LOG to reset to default values.

3.2.1.2.4 Edit Transcomp

Use this field to change how the instrument defines above-canopy readings, determines above-canopy readings, and treats bad readings. A full description is in section 2.1 above.

3.2.1.2.5 Import Observations

This function can be used to import **A** or **B** records from another file.

3.2.1.2.6 Strip Observations

This function can be used to remove all **A** or **B** records from a file.

3.2.1.3 Recompute

Recomputes values for the selected data file. Use recomputed if any changes have been made to the file.

3.2.1.4 Delete

Permanently deletes the selected file.

3.2.1.5 Rename

Prompts for a new file name for the selected file.

# 4 Console Setup

## 4.1 Set Time

### *4.1.1 Console Time*

Prompts for time and date. Use the up and down arrow keys set time and date.

## 4.2 Auto Off Timer

Set the duration that the control unit will remain "On" before powering off automatically. The auto off timer can be set to 5-60 minutes in increments of 5 minutes using the up/down arrow keys.

## 4.3 Beeper

Turns the instrument beeper "On/Off". Select the desired setting and press **OK**.

# 5 Firmware

## 5.1 Console

### *5.1.1 Info*

### *5.1.2 Upgrade*

See page 10-2 for details.

## 5.2 Wand

### *5.2.1 Info*

### *5.2.2 Upgrade*

See page 10-2 for details.

# 9 Theory

The LAI-2200 measures the probability of seeing the sky when looking up through a vegetative canopy in different directions. These measurements essentially contain two pieces of structural information about the canopy: 1) the amount of foliage in the canopy and 2) the foliage orientation. This section describes the details of how the LAI-2200 extracts this information from its measurements.

## Calculations

As a beam of light passes through a plant canopy, there is a certain probability that it will be intercepted by foliage. The probability of interception is proportional to the path length, foliage density (area of foliage per volume of canopy), and foliage orientation. If foliage elements are small compared to the overall canopy, and they are randomly distributed in the sensor view, then it is well known that a beam of light from zenith angle θ has a probability of $P(\theta)$ of non-interception:

$$P(\theta) = e^{-G(\theta)\mu S(\theta)} \quad \textit{9-1}$$

where $G(\theta)$ is the fraction of foliage projected toward $\theta$, $\mu$ is foliage density ($m^2$ foliage per $m^3$ canopy volume), and $S(\theta)$ is path length (m) through the canopy at angle $\theta$. Miller (1967) gives the exact solution for μ as

$$\mu = 2\int_0^{\pi/2} -\frac{\ln P(\theta)}{S(\theta)} \sin\theta d\theta \quad \textit{9-2}$$

## Foliage Density and Leaf Area Index

In a horizontally large, homogeneous canopy, path length, S(θ) is related to canopy height *h* by

$$S(\theta) = \frac{h}{\cos\theta} \qquad \textit{9-3}$$

In such a canopy, the relation between leaf area index *L* and foliaged density μ is

$$L = \mu h \qquad \textit{9-4}$$

Substituting these into (9-2) yields

$$\mu = \frac{2}{h}\int_0^{\mu/2} -\ln P(\theta)\cos\theta \sin\theta \, d\theta$$

$$L = \mu h = 2\int_0^{\pi/2} -\ln P(\theta)\cos\theta \sin\theta d\theta \qquad \textit{9-5}$$

Thus, we can use a common formula (9-2) for computing either *L* or μ: For *L*, we use S(θ)=1/cosθ (height *h* does not matter because it cancels out of (9-5)), and for computing μ we use actual values of S(θ). The difference between L and μ is driven by S(θ).

## Clumping

When multiple observations of P(θ) are available, there are two ways they could be combined: The values of P(θ) could be averaged:

$$\mu = 2\int_0^{\pi/2} -\frac{\ln \overline{P(\theta)}}{S(\theta)} \sin\theta d\theta \qquad \text{9-6}$$

or the values of ln*P*(*θ*) averaged:

$$\mu = 2\int_0^{\pi/2} -\frac{\overline{\ln P(\theta)}}{S(\theta)} \sin\theta d\theta \qquad \text{9-7}$$

Eqn. (9-7) will account for clumping (on spatial scales larger than the field of view of the sensor), but Eqn. (9-6) is appropriate for determining effective leaf area index *L*, which by definition must ignore clumping.

The LAI-2200 computes both of these, and uses Eqn. (9-7) for its reported leaf area index value $L_e$, and the ratio of (9-6) and (9-7) for computing $\Omega_{app}$, the apparent clumping factor (Ryu et al. 2010).

$$\Omega_{app} = \frac{2\int_0^{\pi/2} -\frac{\ln \overline{P(\theta)}}{S(\theta)} \sin\theta\, d\theta}{2\int_0^{\pi/2} -\frac{\overline{\ln P(\theta)}}{S(\theta)} \sin\theta\, d\theta} \qquad \text{9-8}$$

Effective leaf area index, $L_e$, can be computed by

$$L_e = L\Omega_{app} \qquad \text{9-9}$$

## Foliage Orientation

Once $L$ or μ is determined from Eqn. (9-1), Eqn. (9-2) can be solved for the orientation function $G(\theta)$.

$$G(\theta) = \frac{-\ln P(\theta)}{\mu S(\theta)} \qquad \textit{9-10}$$

Figure 9-1 shows the theoretical values of $G(\theta)$ for an ideal canopy whose foliage is random both in position and azimuthal orientation, but inclined at a fixed angle. Curves for ten different foliage inclination angles are shown.

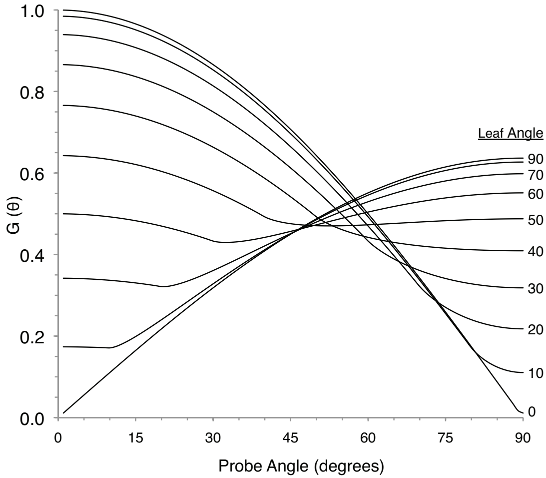



*Figure 9-1. Idealized relationship between projected foliage area and direction for various foliage inclination angels, after Warren Wilson (1959).*

The LAI-2200 calculates foliage mean tilt angle $\overline{\alpha_f}$ after the manner of Lang (1986), using an empirical polynomial relating inclination angle to the slopes of the idealized curves between 25° and 65° (data in table 9-1, plot in Figure 9-2).

*Table 9-1.*

| MTA (degrees) | Slope | MTA (degrees) | Slope |
|---|---|---|---|
| 1 | -.6964 | 50 | -.1547 |
| 10 | -.6859 | 60 | .1180 |
| 20 | -.6546 | 70 | .3164 |
| 30 | -.5855 | 80 | .4131 |
| 40 | -.4105 | 89 | .4431 |

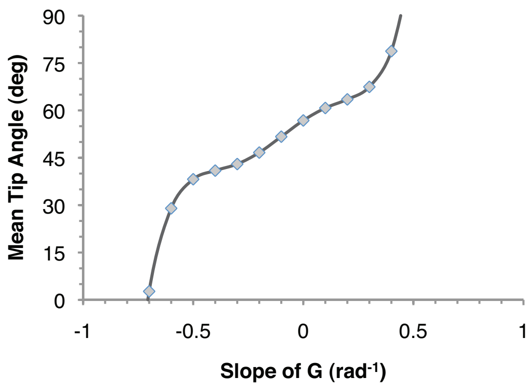



*Figure 9-2. Plot of equation 9-22, which relates slope of the foliage orientation function to average inclination angle. 0° leaf angle is horizontal, and 90° is vertical.*

## Implementation Algorithms

In this section, the subscript $i$ refers to optical sensor rings ($i$=1…5), and the subscript $j$ refers to observational pairs ($j$=1…$N_{obs}$). $B_{ij}$ is the $j^{th}$ below-canopy observation, $i^{th}$ ring, and $A_{ij}$ is its corresponding above canopy reading.

### AVGTRANS

The average probability of light penetration into the canopy is computed by

$$\overline{P(\theta_i)} = \frac{1}{N_{obs}} \sum_{j=1}^{N_{obs}} \frac{B_{ij}}{A_{ij}} \tag{9-11}$$

The 5 values of $\overline{P(\theta_i)}$ are labeled AVGTRANS in the LAI-2200 data file.

### GAPS

The probability of light penetration based on averaging the logarithms of transmittance for the $i^{th}$ ring is computed from

$$G_i = e^{\left(\overline{\ln P(\theta_i)}\right)} = e^{\left(\frac{1}{N_{obs}} \sum_{j=1}^{N_{obs}} \ln \frac{B_{ij}}{A_{ij}}\right)} \tag{9-12}$$

The values of $G_i$ are labeled GAPS in the data file.

## LAI and CNTCT#

The leaf area index $L$ for the file, labeled LAI, is computed from

$$L = 2\int_0^{\pi/2} -\frac{\overline{\ln P(\theta)}}{S(\theta)} \sin\theta \, d\theta = 2\sum_{i=1}^{5} \overline{K_i} W_i \qquad \textit{9-13}$$

where

$$\overline{K}_i = \frac{1}{N_{obs}} \sum_{j=1}^{N_{obs}} \frac{-\ln\left(\frac{B_{ij}}{A_{ij}}\right)}{S_i} \qquad \textit{9-14}$$

and

$$W_i = \sin\theta_i d\theta_i \qquad \textit{9-15}$$

$K_i$ is sometimes called the contact number, and is reported with the label CNTCT# in the data file. For further explanation of $W_i$, see Weighting Factors, below.

## ACF and ACFS

An apparent clumping factor for each ring, labeled ACFS in the LAI-2200 data file, is computed from

$$\Omega_i = \frac{\ln \overline{P(\theta_i)}}{\overline{\ln P(\theta_i)}} = \frac{\ln\left(\frac{1}{N_{obs}} \sum_{j=1}^{N_{obs}} \left(\frac{B_{ij}}{A_{ij}}\right)\right)}{\frac{1}{N_{obs}}\left(\sum_{j=1}^{N_{obs}} \ln\left(\frac{B_{ij}}{A_{ij}}\right)\right)} \qquad \textit{9-16}$$

A total apparent clumping factor, $\Omega_{app}$, labeled ACF in the data file, is computed from

$$\Omega_{app} = \frac{2\int_0^{\pi/2} -\dfrac{\ln \overline{P(\theta)}}{S(\theta)} \sin\theta\, d\theta}{2\int_0^{\pi/2} -\dfrac{\overline{\ln P(\theta)}}{S(\theta)} \sin\theta\, d\theta} = \frac{2\sum_{i=1}^{5} -\dfrac{\ln \overline{P(\theta_i)}}{S_i} W_i}{2\sum_{i=1}^{5} \overline{K_i} W_i} \qquad 9\text{-}17$$

**SEL and STDDEV**

Standard error $L_{se}$ of the leaf area index value is reported as SEL, and is computed from

$$L_{se} = \sqrt{\frac{\dfrac{1}{N_{obs}} \sum_{j=1}^{N_{obs}} L_j^2 - \overline{L}^2}{N_{obs}}} \qquad 9\text{-}18$$

where $L_j$ is the leaf area index calculated for an individual A/B pair

$$L_j = 2\sum_{i=1}^{5} K_{ij} W_i \qquad 9\text{-}19$$

where $K_{ij}$ is the contact value for the pair.

$$K_{ij} = \frac{-\ln\left(\dfrac{B_{ij}}{A_{ij}}\right)}{S_i} \qquad 9\text{-}20$$

The standard deviation $K_{\sigma i}$ of the contact numbers is reported as STDEV, and computed from

$$K_{\sigma i} = \sqrt{\frac{1}{N_{obs} - 1} \sum_{j=1}^{N_{obs}} \left( K_{ij} - \overline{K}_i \right)^2} \qquad \textit{9-21}$$

## MTA

Mean Tip Angle $\overline{\alpha_f}$ is the average inclination of the foliage in degrees from the horizontal (0=flat, 90=vertical), and is computed from a 5th order polynomial $\alpha(m)$ (see figure 9-2):

$$\alpha(m) = a_0 + \left(a_1 + \left(a_2 + \left(a_3 + \left(a_4 + a_5 m\right) m\right) m\right) m\right) m \qquad \textit{9-22}$$

where

$a_0$=56.81964
$a_1$=46.84833
$a_2$=-64.62133
$a_3$=-158.69141
$a_4$=522.06260
$a_5$=1008.14931

The value of $\alpha(m)$ is constrained so that $0 \le \alpha(m) \le 90$. The independent variable *m* is the slope of the mean contact numbers (*K*) plotted against ring angle $\theta$ in radians.

$$\overline{\alpha}_f = \alpha\left(\frac{m}{L}\right) \qquad \textit{9-23}$$

### SEM

Standard error of the mean tip angle is estimated from

$$\alpha_{se} = \left| \overline{\alpha}_f - \alpha\left(\frac{m \pm m_{se}}{L}\right) \right| \qquad \textit{9-24}$$

where $m_{se}$ is the standard error of the slope $m$. When $m > 0$, we use $(m-m_{se})$; otherwise, we use $(m+m_{se})$.

### DIFN

Diffuse non-interceptance $D$ is the fraction of sky radiation that will penetrate the canopy, averaged over the hemisphere (Norman and Welles, 1983). Note: this is computed from $\overline{\ln P(\theta)}$ not $\ln \overline{P(\theta)}$.

$$D = \frac{\int_0^{\pi/2} G(\theta) \sin\theta \cos\theta d\theta}{\int_0^{\pi/2} \sin\theta \cos\theta \, d\theta} = 2\sum_{i=1}^{5} \overline{G}_i W'_i \qquad \textit{9-25}$$

where $W'_i$

$$W'_i = \sin\theta_i \cos\theta_i d\theta_i \qquad \textit{9-26}$$

This value is reported as DIFN in the data file. The FV2200 makes a related computation ($D_{sky}$, labeled DIFN_SKY), that is weighted by sky brightness distribution based on the A readings.

$$D_{sky} = \frac{\int_0^{\pi/2} A(\theta) G(\theta) \sin\theta \cos\theta \, d\theta}{\int_0^{\pi/2} A(\theta) \sin\theta \cos\theta \, d\theta} = \frac{\sum_{i=1}^{5} \overline{A}_i G_i W'_i}{\sum_{i=1}^{5} \overline{A}_i W'_i} \qquad \textit{9-27}$$

where $\overline{A_i}$ is the average of the $N_A$ above canopy readings in the file.

$$\overline{A}_i = \frac{1}{N_A} \sum_{j=1}^{N_A} A_{ij} \qquad \textit{9-28}$$

## Weighting Factors

The weighting factors for LAI and DIFN work out to be (when no rings are masked)

| $\theta_i$ | $d\theta_i$ | $W_i$ <br> $\sin\theta\, d\theta$ | $W'_i$ <br> $\sin\theta\, \cos\theta\, d\theta$ |
|---|---|---|---|
| 7 | 12.2 | 0.041 | 0.033 |
| 23 | 12.2 | 0.131 | 0.097 |
| 38 | 11.8 | 0.201 | 0.127 |
| 53 | 13.2 | 0.290 | 0.141 |
| 68 | 13.2 | 0.337 | 0.102 |

When a ring is masked (excluded from the computations), its weighting value is set to 0. This will increase the weighting of the remaining rings, since their sum must be

$$\sum_{i=1}^{5} W_i = \int_0^{\pi/2} \sin\theta\, d\theta = 1 \quad \text{9-29}$$

and

$$\sum_{i=1}^{5} W'_i = \int_0^{\pi/2} \sin\theta \cos\theta\, d\theta = 0.5 \quad \text{9-30}$$

The values of $W_i$ are available on the FV2200 as the LAI_wt, and the values of $W'_i$ are shown as DIFN_wt.

## Alternative Methods

Gap fractions have been measured using fisheye photographs (Anderson, 1971; Bonhomme and Chartier 1972), by traversing a sunward-pointed sensor beneath the canopy (reviewed by Ross, 1981; Lang et al. 1985; Perry et al. 1988), by linear light sensors (Walker et al. 1988), and by pushing metal probes through the canopy (Warren Wilson, 1959).

See Norman and Campbell (1989), Welles (1990), Welles and Cohen (1996), Gower et al. (1999), Machado and Reich (1999), de Jesus et al. (2001), Mussche et al. (2001), Breda (2003) Hyer and Goertz (2004), Keane et al. (2005), Garrigues et al. (2008) for additional reviews and comparisons.

Mathematical techniques for deducing foliage density and angle distribution from measurements of gap fraction (or contact frequency) have been presented by many authors, including Warren Wilson (1959), Miller (1963, 1967), Philip (1965), Ross (1981), Anderson (1984a, 1984b), Lang (1986, 1987), Lang et al. (1985), Perry et al. (1988), and Norman and Campbell (1989).

## Derivation of Formulae for determining # of B Readings

The guideline presented in Chapter 4 for determining the number of **B** readings comes from the following analysis:

$$M = m \pm t(n)E \qquad \textit{9-31}$$

where $M$ is the true mean of a population, $m$ is the mean of a sample of that population, $t(n)$ is the value of the t distribution (ignoring sign) for a 5% probability, and $E$ is the standard error of $m$. We rewrite equation 9-31 in terms of an acceptable uncertainty δ:

$$\frac{M}{m} = 1 \pm \delta \qquad \textit{9-32}$$

Since standard error E is standard deviation D divided by the square root of the number of samples n, we can express $\delta$ as:

$$\delta = \frac{t(n)D}{m\sqrt{n}} \qquad \textit{9-33}$$

To solve equation 9-33 for sample size $n$, we find a functional relationship for $t(n)$ by fitting a curve to the form

$$t(n) = \frac{1}{a+bn} + c \qquad \textit{9-34}$$

and find $a$ = -0.11528, $b$ = 0.060798, and $c$ = 2.9817. Substituting equation 9-34 into 9-33 and solving for $n$ yields

$$n = \frac{-B + \sqrt{B2 - 4bC}}{2b} \qquad \textit{9-35}$$

where

$$B = a - bc\left(\frac{D}{m\delta}\right)^2 \text{ and } C = -(1+ac)\left(\frac{D}{m\delta}\right)^2 .$$

As a practical matter, the term $D/(m\delta)$ can be determined by a "trial measurement" with the LAI-2200 using some number of **B** readings. These readings should be a fair representation of the diversity of the foliage density. Given *LAI*, *SEL*, and *SMP*, the $D/(m\delta)$ term can be computed from

$$\frac{D}{m\delta} = \frac{(SEL)\sqrt{(SMP)}}{(LAI)\delta} \qquad \textit{9-36}$$

Table 9-2 below, from equation 9-35, predicts the number of samples necessary for a 95% confidence that a sampled mean is within some error $\delta$ of a population mean.

*Table 9-2.*

| $D/(m\delta)$ | $n$ | $D/(m\delta)$ | $n$ | $D/(m\delta)$ | $n$ |
|---|---|---|---|---|---|
| 0.2 | 2 | 1.2 | 8 | 2.2 | 19 |
| 0.4 | 3 | 1.4 | 10 | 2.4 | 22 |
| 0.6 | 4 | 1.6 | 12 | 2.6 | 25 |
| 0.8 | 5 | 1.8 | 14 | 2.8 | 28 |
| 1.0 | 7 | 2.0 | 16 | 3.0 | 30 |

Table 4-1 (page 4-4) is in terms of SEL and LAI, rather than D and m, and is based on a sample of 6 (SMP) with $\delta$=0.1.

# 10 Appendices

## Appendix A: Software Updates and Other News

The FV2200 software application can notify you of software updates and other LAI-2200 related developments if the computer that is running the application has Internet access. Each time it is launched, FV2200 checks to see if there are any notifications that it has not already told you about, and if so, shows them to you. You can view the latest notifications at any time by clicking **Help > Latest LAI-2200 News**. This notification summary has links that will take your web browser to the appropriate locations. There is also a **Help > Check for Software Updates** item that will show the latest versions of FV2200, console, and wand software, and, if you choose, download them from the FV2200 application.

All of this information resides (as of this writing) at http://download.opensource.licor.com/projects/fv2200 so you can simply direct your web browser there and accomplish the same things.

# Appendix B: Updating the Firmware

There are two firmware components in the LAI-2200 – the console firmware and the wand firmware. Any updates will be available for download from the LI-COR Biosciences web site. The following procedures describe how to update the firmware.

## Console Firmware Update

1. Acquire a console firmware file. It will have a name similar to "lai01.img". It can be downloaded from the LI-COR Biosciences web site or by following the steps in Appendix A: Software Updates and Other News.
2. Attach the LAI-2200 console to a computer using the USB connection. After the LAI-2200 has been recognized by the computer, copy the new firmware file to the LAI-2200 mass storage device root directory.
3. Next, "eject" the disk, then disconnect the LAI-2200 from your computer. Power on the control unit and navigate to **Main Menu > Firmware > Console > Upgrade**. Select the new firmware file and press **OK**. The new firmware will take several minutes to install, and a "Complete OK" message will be displayed when it is finished. Press the "OK" when the firmware update is complete.

## Optical Sensor Firmware Update

1. Acquire an optical sensor firmware file. It will have a name similar to “wand01.bin”. Subsequent versions will have a larger number.
2. Copy the file to the Console memory as in step 2 in the previous example.

*Note that the wand firmware can only be updated through “port X”. The firmware version can be checked through port X or Y, but updates can only be delivered to wands connected to the X terminal.*

3. Disconnect the LAI-2200 from the computer. Connect the wand to “port X”, turn on the console, and navigate to **Main Menu > Firmware > Console > Upgrade**. Select the new file and press “OK”. The update will take several seconds to complete.

# Appendix C: Replacing the internal Lithium battery

The following steps describe how to replace the internal lithium battery. The battery should last up to 7 years. Always use a BR1225 watch battery (p/n 442-08614).

1. Using a #1 Phillips screwdriver, loosen the four screws that secure the top and bottom of the control unit. The four screws are located in the corners of the back of the control unit, under the gray protective rubber. Nudge the rubber out of the way of the screws.
2. Gently separate the two halves.
3. The battery is located in a round coin cell battery holder (see below). Lift the silver tab slightly and slide the battery out. It may be necessary to lift the battery slightly with the blade of a standard screwdriver.

4. Slide the new battery into the holder with the positive (+) terminal facing up.
5. Join the top and bottom halves of the control unit. Be sure the rubber seal is seated properly.
6. Gently tighten the four screws that hold the two halves of the case together. Be very careful not to over tighten the screws, as they may strip the plastic.

# Appendix D: Troubleshooting

**Console will not power up:**
This could be one of three things: low batteries, a locked processor (try removing the batteries for a few seconds), or a short in a wand (try disconnecting all sensors).

**Can't match sensors:**
Be sure both sensors see the same diffuse view. If the sensors see direct sunlight or artificial light, then this procedure is futile.

**Instrument will not turn off:**
The LAI-2200 will not power off if a data file is open or if it is reading data from the internal memory. Wait a few moments for the data transfer to finish and close any open data files, then try again. If the control unit continues to be unresponsive, press and hold the power button for 5 seconds. Open data files may be lost. If the LAI-2200 continues to be unresponsive, remove the "AA" batteries for a moment. Replace the batteries. Stored data will not be at risk, but open data files may be lost.

**Instrument (wand or console) locks up:**
For both the wand and console, simply remove and re-inserting the batteries.

**Wand not recognized or does not respond to light:**
Disconnect then reconnect the wand. After a few seconds, the control unit should begin displaying values associated with the wand.

**LAI=0**
Check the raw readings on the console or using FV2200. Are there both **A** and **B** records in the file? Do the relative magnitudes of the **A** and **B** records

seem correct? Check the number of samples used. If it is 0, then the unit threw out all the **A** and **B** pairs because of bad readings. Set the Transcomp settings to APC and recompute the file.

**Questionable MTA results:**
This may indicate a problem, or be due to the method used by the control unit to compute MTA. Check the DISTS values. If they do not reflect the canopy being measured (isolated canopy or large area), MTA and LAI will be incorrect. Also, the method used by the control unit has the drawback of losing resolution near the extremes of 0° (horizontal leaves) and 90° (vertical leaves). Refer to figure 8-2 for a plot of the polynomial used. Note that slight changes in slope (the independent variable) make a big difference at the extremes of MTA. It is not uncommon in a canopy of relatively horizontal foliage for the control unit to give MTA values from 0° to 20° or even 30° from one measurement to the next. If more accurate MTA's are needed, use the FV2200 software to compute a mean tip angle with the Constrained Least Squares technique.

# Appendix E: Specifications

## LAI-2270 Control Unit

***Sensor Inputs:*** 2 6-pin bulkhead connectors for LAI-2250 Optical Sensors. 2 3-pin bulkhead connectors for LI-COR Biosciences Light Sensors.

***Memory:*** 128 MB of FAT16 memory.

*Limits of FAT:*
Number of files: 65536
8.3 file name convention (8 character name, 3 character extension)

***File Storage Capacity:*** ~70 bytes for each record; ~500 bytes for data file overhead.
Ex: 500 bytes/file + 70 bytes/record *100 records = 7,500 bytes; 128 MB/7,500 bytes =
17,030 files containing 1.7 million records.

***Keypad:*** 22 button tactile response keypad. 10 key numeric keypad with full alphabetic capabilities with 9 function/control keys

***Display:*** 128x64 graphics LCD display.

***Communications:***
USB (as mass storage device);
RS-485: Baud rate - 115,200, 8 data bits, no parity, 1 start, 1 stop;
RS-232: Selectable baud - 9600, 38400, 57600, and 11520, 8 data bits, no parity, 1 start, 1 stop.

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

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

***Battery Life:*** 140 hours with 4 “AA” alkaline batteries, no optical sensor attached.
80 hours with 4 “AA” alkaline batteries, with one optical sensor attached.

***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:* 1 6-pin bulkhead connector for control unit interface.
*Memory:* 1 MB flash memory for record storage; 1KB EEPROM for calibration and configuration storage.
*Keypad:* 2 button, tactile response keypad.
*Indicators:* 3 sunlight readable LEDs to indicate: power status, logging status, above/below status.
*Clock:* Year, Month, Day, Hour, Minute, Second. ± 3 minutes per month.
*Power Requirements:* 2 "AA" batteries (alkaline, NiMH, lithium).
*Battery Life:* 180 hours of typical operation (with 2 alkaline batteries).
*Low Battery Warning:* LED indication when <15% of battery life remains.
*Optics:* 1.00° maximum decentering error as measured from center of mass of ring 0.50° maximum magnification error as measured from the center of mass of ring 4.
*Wavelength Range:* ≈320-490 nm
*Radiation Rejection:*
>99% from 490-650 nm.
>99.9% above 650 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 0°, 10°, 45°, 90°, 180°, and 270°.
*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.

# LAI-2200 General

**Environmental Conditions:**

*Operating Temperature Range:* -20 to 50° C.
*Humidity Range:* 0 – 95% RH, non-condensing conditions.
*Storage Temperature Range:* -40 to 65° C.

# Appendix F: Part Numbers

The following is a partial list of parts available from LI-COR Biosciences.

Contact sales (envsales@licor.com), call 1-800-447-3576 (US & Canada), 1-402-467-3576 (international), or order the parts from the LI-COR Biosciences eCommerce website (go to http://www.licor.com/env/ and click on “Order”).

| **Description** | **Part #** |
|---|---|
| LAI-2270 Control Unit | LAI-2270 |
| LAI-2250 Plant Canopy Sensor | LAI-2250 |
| Optical Sensor Cable | 392-11542 |
| View Restrictor Cap Set | 9920-005 |
| Lens Cap | 6520-020 |
| View Restricting Cap 90° Opening | 6520-021 |
| View Restricting Cap 180° Opening | 6520-022 |
| View Restricting Cap 45° Opening | 6520-023 |
| View Restricting Cap 270° Opening | 6520-029 |
| View Restricting Cap 10° Opening | 6520-030 |
| 9 Pin Connector Dust Cap | 9914-008 |
| Bulkhead Connector Caps | 620-10306 |
| 3 V Lithium Battery BR1225 | 442-08614 |
| Optical Sensor Battery Compartment Cap | 345-10735 |
| Storage Case | 9922-125 |
| Light Sensor Adapter Cable | 392-10657 |

# Appendix G: Differences between the LAI-2000 and the LAI-2200

1.0 Operational

1.1 The LAI-2200 uses menus instead of Fct codes. Access the menu by pressing the Menu key. The full structure is given in Chapter 8. Changes are shown below, along with the equivalent Fct codes that the LAI-2000 used.

Main Menu
- Wand Setup
  - <user picks wand>
  - Set Name
  - Clock
  - Cal Values "Fct 01 XCal or Fct 02 YCal"
  - Match Values "Fct 03 Vectors"
  - Auto Log "Fct 11 Set Op Mode" for remote above logging.
- Log Setup
  - Transcomp "Fct 16 Bad Reading", plus other new options.
  - Prompts "Fct 12 Set Prompts"
  - Angles "Fct 07 Set Angles"
  - Distances "Fct 06 Set Dists"
  - Masks
  - Control Sequence "Fct 11 Set Op Mode"
  - PAR Sensors "Fct 08 1,2 Channels"
- Data
  - Wand Data
    - Download
    - Purge
  - Console Data
  - <user picks file>
    - View "Fct 27 View"

View Header
View Ang/Dst
View Cntct#/StdDev
View Ang/Gap Frac
View Observations
Edit "Fct 25 Edit"
Edit Angles
Edit Mask
Edit Distances
Edit Transcomp
Import Observations
Strip Observations
Recompute "Fct 26 Recompute"
Delete
Rename
Console Setup
Set Time "Fct 05 Set Clock"
Upgrade Firmware
Auto Off Timer
Beeper

1.2 Optical Sensors (Wands) are Smart.

1.2.1. The console can detect when one is attached, and which port it is attached to.

1.2.2. The wands carry their own identity and calibration information with them.

1.2.3. The wands can log data without being attached to a console. Here's the thing to remember: If a wand is attached to the console, and a log file is open, pressing the LOG key on the console or on the wand will add a record to the file in the console. Otherwise (not attached, or attached but no file open), pressing LOG will add a record to the memory of the wand. Also, automatic logging can be set up for a wand (define start time, stop time, and frequency). Any autologged data always goes the wand memory. To get records out of a wand, attach it to a console, and do

**Menu > Data > Wand Data > Download**. You can put the data into a new file, or append it to an existing file.

1.3 Less Dependence on Operating Mode. The LAI-2000 had a list of operating modes to choose from (1 Sensor X, 1 Sensor Y, etc.). These have essentially gone away. To illustrate this, we show below how to do the most common of the former modes using the LAI-2200:

A) 1 Sensor X or Y:

Power on.

Attach a wand.

Press Start/Stop. Name the file.

Use the A/B button on the wand to select if the next reading is A or B.

Log readings.

Press Start/Stop to close the file.

If you want to do a predetermined sequence (↑↓↓↓, etc.), you can set that up via **Menu > Log Setup > Control Sequence**.

B) Remote Below, and Remote Above:

Power ON

Attach Both Sensors.

Match one to the other (**Menu > Wand Setup > (pick one to adjust) > Match Values**)

Setup autolog. (**Menu > Wand Setup > (pick the A wand) > Auto Log**)

Detach and deploy the A wand.

Collect B file(s) with the console and remaining wand.

Retrieve the A data. Reattach the A wand, and do **Menu > Data > Wand Data > Download**, and name a new file.

Merge the A and B readings. Do **Menu > Data > Console Data > (pick a B file) > Edit > Import**

**Observations**, and select the A file. Repeat for remaining B files.

2.0 Computational

2.1 Weighting Factors. Both instruments compute LAI by applying weighting factors to the contact values computed for each ring (Equation 9-14, page 9-7). The LAI-2000 assigned ring data to the entire interval between 0 and $\pi/2$, while the LAI-2200 only uses the discrete bands actually viewed by the rings. Refer to Table 6-1, page 6-36 for LAI-2200 weighting factors.

2.2 Ignoring rings. The LAI-2200 allows rings to be ignored in the computation of LAI. To set this for new data files: Menu > Log Setup > Masks. To change this on an existing data file Menu > Console Data > (pick a file) > Edit > Edit Mask

2.3 ACF. The LAI-2200 computes a new value, Apparent Clumping Factor (ACF), which is a value 1 (no clumping) or less (clumping). The LAI-2200 reports an ACF value for each ring (the log of the average transmittance divided by the average of the logs of the transmittances), and a weighted average for all the rings. This is discussed further on page 9-7.

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# Appendix I: Warranty

For the most current warranty information, see the Standard Terms and Conditions of Sale at http://www.licor.com/corp/terms.jsp.

Each LI-COR, Inc. instrument is warranted by LI-COR, Inc. to be free from defects in material and workmanship; however, LI-COR, Inc.'s sole obligation under this warranty shall be to repair or replace any part of the instrument, which LI-COR, Inc.'s examination discloses to have been defective in material or workmanship without charge and only under the following conditions, which are:

1. The defects are called to the attention of LI-COR, Inc. in Lincoln, Nebraska, in writing within one year after the shipping date of the instrument.

2. The instrument has not been maintained, repaired, or altered by anyone who was not approved by LI-COR, Inc.

3. The instrument was used in the normal, proper, and ordinary manner and has not been abused, altered, misused, neglected, involved in an accident or damaged by act of God or other casualty.

4. The purchaser, whether it is a DISTRIBUTOR or direct customer of LI-COR or a DISTRIBUTOR'S customer, packs and ships or delivers the instrument to LI-COR, Inc. at LI-COR Inc.'s factory in Lincoln, Nebraska, U.S.A. within 30 days after LI-COR, Inc. has received written notice of the defect. Unless other arrangements have been made in writing, transportation to LI-COR, Inc. (by air unless otherwise authorized by LI-COR, Inc.) is at customer expense.

5. No-charge repair parts may be sent at LI-COR, Inc.'s sole discretion to the purchaser for installation by purchaser.

6. LI-COR, Inc.'s liability is limited to repair or replace any part of the instrument without charge if LI-COR, Inc.'s examination disclosed that part to have been defective in material or workmanship.

There are no warranties, express or implied, including but not limited to any implied warranty of merchantability or fitness for a particular purpose on underwater cables or on expendables such as batteries, lamps, thermocouples and calibrations.

Other than the obligation of LI-COR, Inc. expressly set forth herein, LI-COR, Inc. disclaims all warranties of merchantability or fitness for a particular purpose. The foregoing constitutes LI-COR, Inc.'s sole obligation and liability with respect to damages resulting from the use or performance of the instrument and in no event shall LI-COR, Inc. or its representatives be liable for damages beyond the price paid for the instrument, or for direct, incidental or consequential damages.

The laws of some locations may not allow the exclusion or limitation on implied warranties or on incidental or consequential damages, so the limitations herein may not apply directly. This warranty gives you specific legal rights, and you may already have other rights, which vary from location to location. All warranties that apply, whether included by this contract or by law, are limited to the time period of this warranty which is a twelve-month period commencing from the date the instrument is shipped to a user who is a customer or eighteen months from the date of shipment to LI-COR, Inc.'s authorized distributor, whichever is earlier.

This warranty supersedes all warranties for products purchased prior to June 1, 1984, unless this warranty is later superseded.

DISTRIBUTOR or the DISTRIBUTOR'S customers may ship the instruments directly to LI-COR if they are unable to repair the instrument themselves even though the DISTRIBUTOR has been approved for making such repairs and has agreed with the customer to make such repairs as covered by this limited warranty.

Further information concerning this warranty may be obtained by writing or telephoning warranty manager at LI-COR, Inc.

# Index

## A



## B



## C



## D

## E



## F

# G



# H



# I



# K



# L

# M



# O



# P



# Q



# S

## T



## U



## V



## W

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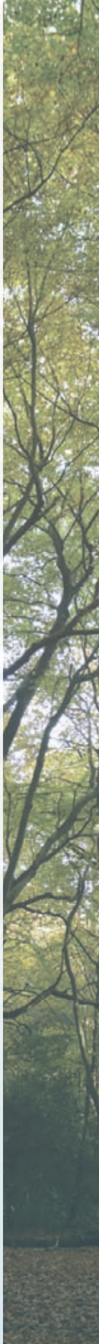

LI-COR® Biosciences

LI-COR, Inc. • 4647 Superior Street • Lincoln, NE 68504
Phone: 402-467-3576 • Fax: 402-467-2819
Toll-free 1-800-447-3576 (U.S. & Canada)
envsales@licor.com • envsupport@licor.com
www.licor.com

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