

AccuPAR PAR/LAI Ceptometer

Model LP-80

Operator's Manual



Decagon Devices, Inc.

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1 Introduction

Welcome to Decagon's AccuPAR model LP-80 PAR/LAI Ceptometer. The AccuPAR measures Photosynthetically Active Radiation (PAR) and can invert these readings to give Leaf Area Index (LAI) for your plant canopy. This manual is designed to help you accomplish your research goals, and understand how to get the most out of your AccuPAR.

1.1 Customer Support

If you ever need assistance with your AccuPAR or have any questions or feedback, there are several ways to contact us. Decagon has Customer Service Representatives available to speak with you Monday through Friday, between 7am and 5pm Pacific time.

Note: If you purchased your AccuPAR LP-80 through a distributor, please contact them for assistance.

Email:

support@decagon.com or **sales@decagon.com**

Phone:

509-332-5600

Fax:

509-332-5158

If contacting us by email or fax, please include as part of your message your instrument serial number, your name, address, phone number, fax number, and a description of your problem or question.

1.2 About This Manual

This manual includes instructions for setting up your AccuPAR LP-80, verifying the calibration of the instrument, preparing samples, and maintaining and caring for your instrument. Please read these

instructions before operating the LP-80 to ensure that the instrument performs to its full potential.

1.3 Warranty

The AccuPAR has a one year warranty on parts and labor. Your warranty is automatically validated upon receipt of the instrument.

1.4 Seller's Liability

Seller warrants new equipment of its own manufacture against defective workmanship and materials for a period of one year from the date of receipt of equipment.

Note: We do not consider the results of ordinary wear and tear, neglect, misuse, accident and excessive deterioration due to corrosion from any cause as defects.

The Seller's liability for defective parts shall in no event exceed the furnishing of replacement parts Freight On Board the factory where originally manufactured. Material and equipment covered hereby which is not manufactured by Seller shall be covered only by the warranty of its manufacturer. Seller shall not be liable to Buyer for loss, damage or injuries to persons (including death), or to property or things of whatsoever kind (including, but not without limitation, loss of anticipated profits), occasioned by or arising out of the installation, operation, use, misuse, nonuse, repair, or replacement of said material and equipment, or out of the use of any method or process for which the same may be employed. The use of this equipment constitutes the buyer's acceptance of the terms set forth in this warranty. There are no understandings, representations, or warranties of any kind, express, implied, statutory or otherwise (including, but without limitation, the implied warranties of merchantability and fitness for a particular purpose), not expressly set forth herein.

2 About the LP-80

The AccuPAR model LP-80 is a menu-driven, battery-operated linear PAR ceptometer, used to measure light interception in plant canopies, and to calculate Leaf Area Index (LAI). It consists of an integrated microprocessor-driven data logger and probe. The probe contains 80 independent sensors, spaced 1 cm apart. The photosensors measure PAR (Photosynthetically Active Radiation) in the 400 to 700 nm waveband. The AccuPAR displays PAR in units of micromols per meter squared per second ($\mu\text{mol m}^{-2}\text{s}^{-1}$). The instrument is capable of hand-held or unattended measurement.

2.1 AccuPAR LP-80 Instrument Specifications

Operating Environment:

0° to 50° C (32° – 122° F)

0 to 100% relative humidity

Probe Length: 84 cm

Number of Sensors: 80

Overall Length: 99 cm (40 in)

Probe Cross-Section: 19 x 9.5 mm (.75 x .375 in)

Micro Controller Dimensions: 15.8 x 9.5 x 3.3 cm (6.2 x 3.75 x 1.3 in)

PAR Range: 0 to 2,500 $\mu\text{mol m}^{-2}\text{s}^{-1}$

Resolution: 1 $\mu\text{mol m}^{-2}\text{s}^{-1}$

Minimum Spatial Resolution: 1 cm

Data Storage Capacity: 1 MB Flash

Unattended Logging Interval: User selectable, between 1 and 60 min

Instrument Weight (w/ Batteries): 0.55 kg (1.21 lbs)

Data Retrieval: direct via RS-232

Keypad: 7-Key menu-driven

Clock: 24-hour ± 1 minute per month

Interface Cable: RS-232 cable

Power: Four AAA Alkaline cells.

External PAR Sensor Connector: Locking 5-pin sealed circular connector

2.2 Overview of the LP-80

Decagon designed the menu-driven LP-80 interface for ease of use. There are four menus to choose from: the PAR/LAI menu, Log menu, Data menu, and Config menu. You navigate between the menus by pressing the MENU button, and select items within each menu using the up and down arrow keys, and the ENTER or ESC keys.

The AccuPAR can be operated in environments with temperatures from 0 to 50° C, and in relative humidities of up to 100%. The instrument ships with an RS-232 interface cable to allow for downloading data to a computer, an external PAR sensor to allow for calibration, and simultaneous above and below canopy PAR measurements. The AccuPAR operates on four AAA alkaline batteries.

2.3 Components of the LP-80 System

The AccuPAR and its accessories arrive in a durable foam-padded carrying case. Your shipment should arrive with the following items.

- AccuPAR model LP-80
- RS-232 Cable
- Operator's Manual
- External PAR Sensor
- #1 Phillips Screwdriver
- USB Adapter Cable

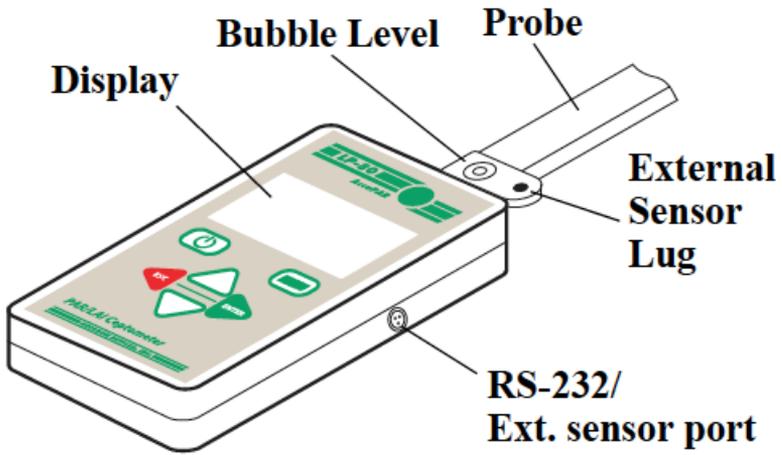


Figure 1: Product Features

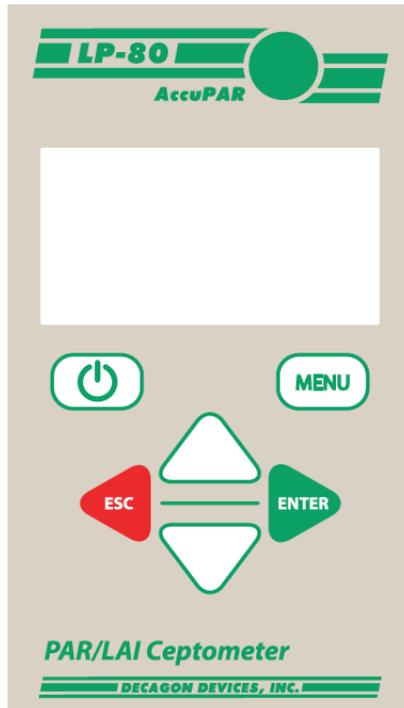


Figure 2: LP-80 Keypad

The LP-80 keypad is a 7-key panel, designed for ease of use and intuitive navigability through the operating system. Here is a brief description of the key functions, refer to Figure 2 for Keypad descriptions.

ON/OFF Key: Located in the upper left corner, it turns the instrument on or off. The AccuPAR turns itself off automatically after 10 minutes of inactivity.

MENU Key: Cycles between the four menus.

UP and DOWN ARROW KEYS: In PAR Sampling menu, they initiate above (up arrow) and below (down arrow) canopy PAR readings. In other menus, they are used to navigate to items within those menus and to change numeric values in sub menus.

Round Green Key: The circular key in the upper right corner of the keypad (by the AccuPAR logo) also serves the same function as the Down-arrow key. It is designed as an ergonomic alternative when taking multiple below-canopy PAR samples

ESC: Cancels the current PAR reading displayed in the lower half of the PAR sampling menu, cancels out of menu options, and navigates to the left in the annotation screen.

ENTER: Saves the current PAR readings in the PAR sampling menu, selects items in other menus, and navigates to the right in the annotation screen.

2.4 Turning on the instrument

When you first turn on the instrument, it opens in the PAR sampling menu with real-time PAR data displayed in the center portion of the screen. If you have the external PAR sensor connected, you also see its real-time PAR data.

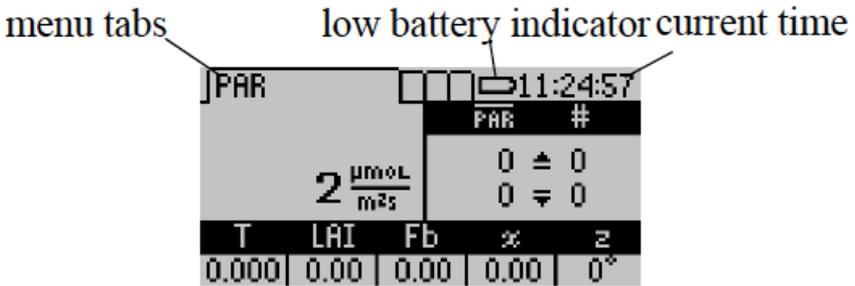


Figure 3: PAR Data Return Screenshot

At any time, you can cycle between the four menus by pressing the MENU key. The menus are indicated by the tabs on the top of the screen, with the active menu in the foreground. If the battery is low, a low battery indicator appears to the right of the menu tabs. Later chapters discuss each menu in detail and how to use the features that each provides.

3 Definitions

The AccuPAR LP-80 uses several variables to calculate Leaf Area Index, and displays values for these variables on the screen as measurements are taken. This chapter discusses these variables and their definitions. If you are not familiar with them, we recommend that you review this chapter before proceeding with measurements.

PAR

PAR (photosynthetically active radiation) is the radiation in the 400 to 700 nanometer waveband. It represents the portion of the spectrum which plants use for photosynthesis. Under a plant canopy, radiation levels can vary from full sun to almost zero over the space of a few centimeters. Therefore, reliable measurement of PAR requires many samples at different locations under the canopy.

The AccuPAR measures PAR either manually or in unattended logging mode. Intercepted PAR data can be used for determining important parameters of canopy structure and for the calculation of LAI. An external point sensor may be used to collect instantaneous above canopy PAR measurements when sampling under or within a canopy. You also have the option of segmenting the probe to reflect spatial changes in the plant canopy. This is useful when evaluating discontinuous and irregular canopies, or to limit the number of active sensors along the probe.

Tau (τ)

Tau is another variable in the LAI inversion equations. It is defined as the ratio of below canopy PAR measurements to the most recent above canopy PAR value. It is measured automatically by the instrument, based upon the PAR readings you make. The current τ value is displayed and updated in the lower left corner of the screen in the PAR menu. Chapter 9 provides further explanation of the significance of Tau.

LAI(L)

LAI (Leaf Area Index) is defined as the area of leaves per unit area of soil surface. It is a valuable measurement in helping to assess canopy density and biomass. The AccuPAR calculates LAI based on the above and below-canopy PAR measurements along with other variables that relate to the canopy architecture and position of the sun. These variables are the zenith angle, a fractional beam measurement value, and a leaf area distribution parameter (also known as χ) for your particular canopy. The AccuPAR automatically calculates both the zenith angle and fractional beam reading, and requires you to input a value for χ in the setup menu.

External Sensor

An external PAR sensor is provided with the AccuPAR to allow you to make simultaneous above and below canopy PAR measurements. This is useful if you want to be able to make multiple PAR measurements under the canopy in variable light conditions without having to keep moving the instrument in and out of the canopy to update the above canopy PAR reference. The external sensor is also the PAR standard to which the wand is calibrated.

Zenith Angle (z)

Zenith angle can be defined as the angle the sun makes with respect to the zenith, or the point in the sky directly overhead, vertical to where you stand. The zenith is defined as being 0° and the horizon is 90° . The zenith angle of the sun is necessary for calculation of certain canopy structure parameters, such as LAI. It is calculated by the AccuPAR based on your global position and the time of day, and is displayed in the lower right corner of the screen when taking above and below PAR measurements. To make sure this value is accurate, you must first correctly set the longitude, latitude, date, and time of day in the setup menu.

Fraction of Beam Radiation (F_b)

Fractional beam radiation is the ratio of direct beam radiation coming from the sun to radiation coming from all ambient sources like the atmosphere or reflected from other surfaces. A fractional beam radiation value is necessary for calculation of LAI using PAR data. The AccuPAR obtains this value by comparing the above canopy PAR measurement to the calculated value of potential incoming solar radiation at your location and zenith angle. The current calculated F_b is displayed and updated at the bottom of the screen in the PAR menu.

Leaf Distribution Parameter (χ)

Leaf Distribution Parameter (also known as chi, or χ) refers to the distribution of leaf angles within a canopy. The parameter χ is the ratio of the length of the horizontal to the vertical axis of the spheroid described by the leaf angle distribution of a canopy. It can also be measured as the ratio of the projected area of an average canopy element (a leaf, for example) on a horizontal plane to its projection on a vertical plane. The default value for χ is 1.0, which assumes the canopy angle distribution to be spherical. Onions are a good example of a strongly vertical crop. For onions, χ would be about 0.7. On the other extreme, strawberries, a crop with a strongly horizontal nature, would have a χ value of about 3.

Table 1 gives some typical values for χ . In some cases a range of values is given, indicating the variability that is to be expected for χ in any canopy. Fortunately, the value of LAI computed is not strongly dependent on the value of χ chosen. The AccuPAR uses a value of $\chi=1.0$ as its default.

Table 1: Typical χ Values

Crop	χ	Crop	χ
Ryegrass	0.67 to 2.47	Rape	1.92 to 2.13
Maize	0.76 to 2.52	Cucumber	2.17
Rye	0.80 to 1.27	Tobacco	1.29 to 2.22
Wheat	0.96	Potato	1.70 to 2.47
Barley	1.20	Horse Bean	1.81 to 2.17
Timothy	1.13	Sunflower	1.81 to 2.31
Sorghum	1.43	White Clover	2.47 to 3.26
Lucerne	1.54	Strawberry	3.03
Hybrid Swede	1.29 to 1.81	Jerusalem Artichoke	2.16
Sugar Beet	1.46 to 1.88		

4 PAR/LAI Menu

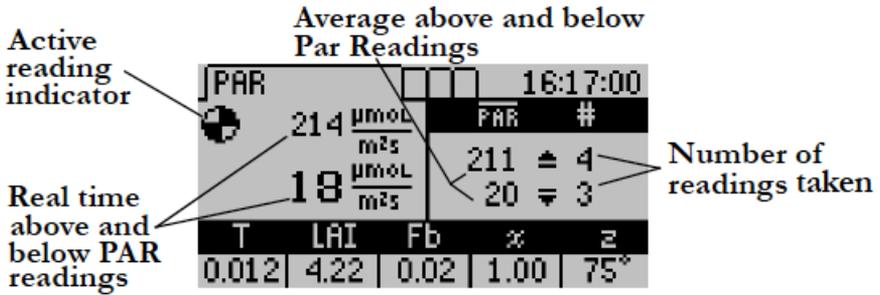
The first menu option is the PAR/LAI sampling menu, which is used for measurements with the AccuPAR. The default screen is similar to the PAR screen.

PAR		23:20:45	
2 $\frac{\mu\text{mol}}{\text{m}^2\text{s}}$		PAR	#
		0 \uparrow 0	0 \downarrow 0
T	LAI	Fb	∞ \geq
0.000	0.00	0.00	0.00 0 ^v

This PAR screen indicates that the current real-time PAR level is 2 $\mu\text{mol}/\text{m}^2\text{s}$ (this example was taken indoors) and that the user did not take any above or below PAR measurements. If the external sensor is attached, the real-time PAR value measured by the external sensor also display above the real-time light bar PAR data.

4.1 Taking Measurements

To make an above-canopy PAR measurement, press the up-arrow key in this menu. The resulting value displays in the upper right section of the screen. To make measurements below the canopy, press the down-arrow key or the green circular key in the upper right corner of the keypad. You must plug in a external sensor or take an above canopy PAR reading first before the summary data can update. The LP-80 recalculates summary data after each below canopy PAR reading. Other relevant data displays at the bottom of the screen.



LP-80 updates and displays the current calculated Tau (τ), LAI value, beam fraction (F_b), leaf distribution parameter (χ) and zenith angle (z) values are updated and displayed at the bottom of the screen with each subsequent below canopy PAR measurement. If the external sensor is attached and you press an up or down arrow, the LP-80 records both above and below canopy readings.

Pressing ENTER brings up the Save screen which allows you to save as is, annotate, or discard. Pressing ESC discards the values. Both options clear the screen for new data. The values displayed at the bottom of the screen are dependent on how you have set up your instrument in the Setup menu. Please refer to chapter 3 Definitions or chapter 8 Theory for a more detailed description of these variables and their definitions.

With each above or below canopy measurement, a number appears to the right of the PAR value that indicates the number of completed measurements. The displayed PAR value reflects the sample average. The LP-80 made four above and three below canopy measurements in the previous PAR screen shot. Therefore, in the above sample screen, four above and three below canopy measurements have been made, so the average of the four above-canopy PAR values is 211 μmol , while the average of the three below-canopy values is 20 μmol .

Note: When you connect the external sensor, the LP-80 uses readings from the external sensor as above PAR readings to calculate LAI. Summary data on the bottom of the screen are recalculated using the last above canopy reading with each subsequent below canopy reading.

4.2 Saving and Annotating Readings

To save a reading once you are done taking above and below PAR data, press ENTER. The Save Method screen appears.

Save Method				
		PAR	#	
<input checked="" type="radio"/>	Save			
<input type="radio"/>	Annotate	211	±	4
<input type="radio"/>	Discard	20	∓	3
T	LAI	Fb	%	z
0.012	4.22	0.02	1.00	75°

You have three options at the Save Method screen.

1. Select “Save” and press ENTER to save your information. Data stores with the time and date you take the measurement.
2. Select “Discard” and press ENTER to return to the main screen and start over with a new reading.
3. Select “Annotate” and press ENTER to give your data a file name or description, e.g. “Plot 1.” Selecting “Annotate” causes the Annotate screen to appear.

Annotate				
ID:		PAR	#	
ROSE BUSH		211	±	4
		20	∓	3
T	LAI	Fb	%	z
0.012	4.22	0.02	1.00	75°

The Annotate screen has a series of lines with a set of arrows above and below the first. If you have annotated a previous reading, the old annotation will remain to be changed or deleted. Use the arrow keys to select a letter or number and press ENTER to move to the next character. When you finish, keep pressing ENTER until the screen returns to the PAR menu.

5 Log Menu

When you advance to the LOG menu, the Log screen appears.

<input type="checkbox"/> Log	<input type="checkbox"/>	16:29:52		
570 $\frac{\mu\text{mol}}{\text{m}^2\text{s}}$	Log: Off			
12 $\frac{\mu\text{mol}}{\text{m}^2\text{s}}$	Wake: 1 min			
	Count: 0			
T	LAI	Fb	α	z
0.000	0.00	0.00	0.00	0°

The Log menu allows you to put the instrument in an unattended PAR data logging mode. In this mode, the AccuPAR will automatically measure and store PAR data at an interval that you specify.

Note: LAI and Tau are calculated more accurately by manually sampling PAR beneath a canopy at random locations, instead of leaving the LP-80 in one place and collecting data in log mode.

You can select the measurement interval by pressing the up or down arrows. This will allow you to select any value between 1 and 60 minutes. In the previous Log screen shot, the LP-80 is set to make and store a measurement every one minute. To activate the logging mode, press the ENTER button. To cancel the logging mode press Escape. When you enable the logging mode, the screen will begin to return data.

<input type="checkbox"/> Log	<input type="checkbox"/>	16:30:06		
<input checked="" type="checkbox"/> 549 $\frac{\mu\text{mol}}{\text{m}^2\text{s}}$	Log: 0:00:57			
13 $\frac{\mu\text{mol}}{\text{m}^2\text{s}}$	Wake: 10 min			
	Count: 1			
T	LAI	Fb	α	z
0.023	2.88	0.91	1.00	77°

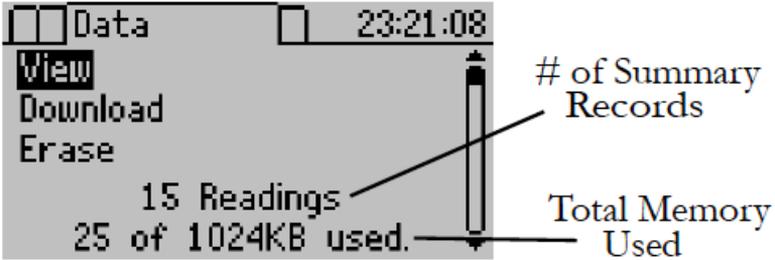
The LP-80 stores data taken in this mode automatically without annotation to memory.

Note: You can move from this menu to other menus while the logging mode is activated. While activated, the LP-80 continues to log data whether or not the AccuPAR display is on or if you are in a different menu.

Caution: This mode is for short-term experiments (one or two days). We did not design the LP-80 to be left in the field for long periods of time as damage from moisture may occur.

6 Data Menu

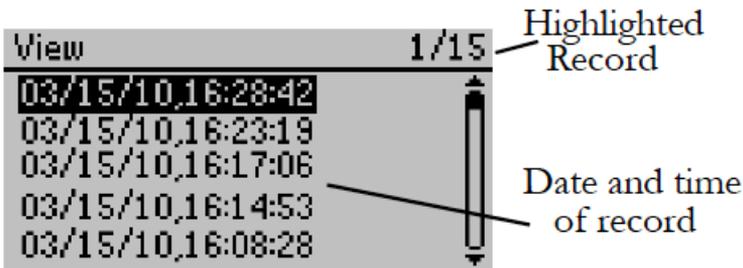
The Data menu allows you to view, download, and erase the data that you store with your AccuPAR. When you advance to this menu, the Data screen appears.



You can view summary records and their relevant data, download the data to your computer terminal for analysis, or erase the data memory from the Data screen. To select one of the options in this menu, scroll to the desired item and press the ENTER key.

6.1 View

When you select "View" from the Data menu, the View screen shows a list of all the summary readings saved to memory.



You can scroll between different readings using the up and down arrows. To view detailed data from a selected record, press the ENTER key while highlighting the record. The LP-80 displays the stored data.

Annotation			Sample 3B		1/15		Record #
Date and Time of Reading			Mar 15, 2010		PAR #		Average above and below PAR readings
16:28:42					517 ▲ 2		
					28 ▼ 2		
T		LAI	Fb	%	z		Number of Readings Taken
0.055		1.75	0.20	1.00	47*		

6.2 Download

The download option allows you to download stored data to your computer via the RS232 or USB cable that came with your system. You can download the data using the LP-80 Utility (free software included with your system), Windows Hyperterminal or any similar terminal software. See Chapter 7 for more information on using the LP-80 Utility software program.

If you are unable to use the LP-80 Utility, you can use terminal software to transfer the data from your LP-80 to your computer. The following steps should apply to most terminal software programs.

Downloading using Windows Hyperterminal

Follow steps 1 through 9 for instructions on downloading with Windows Hyperterminal, which comes with Windows XP and earlier Windows operating systems. (You will need to use a third party terminal program for newer operating systems such as Windows Vista and Windows 7.)

1. Open Windows Hyperterminal from the Start menu, select Programs > Accessories > Communications > Hyperterminal. Click on the Hypertrm.exe icon.
2. At the dialog box prompt, select a name for the new connection, and an icon (if desired).
3. At the "Connect To" dialog box, select an available COM port at the bottom of the screen in the "Connect Using" box.

4. In the Communication Properties Dialog box, select these: 9600 bits per second, 8 data bits, no parity, 1 stop bit, and no flow control.(Figure: 4)

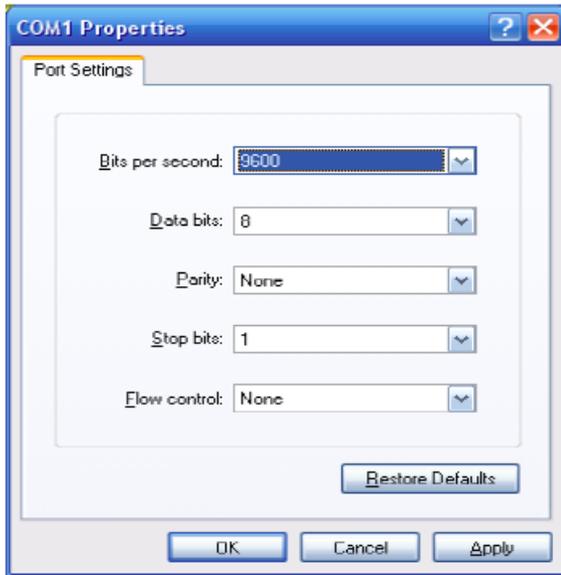


Figure 4: Communication Properties Dialog Box

5. Once the terminal window opens, click on the File menu and select Properties. Click on the Settings tab, and then click on the "ASCII Setup" button. Check the box that says "Append line feeds to incoming line ends," and the "Wrap lines that exceed terminal width," and then click OK.
6. To set up the terminal program to capture the data, click on the Transfer menu and select "Capture Text." Select the directory where you want to place the data text file and then click Start.
7. Select Download from the AccuPAR File menu. The list of current files will appear as in the View menu. Use the up and down arrows to select the file you wish to download, then press the ENTER key to send the data to your computer. The data will appear on the screen.
8. To finish capturing the text, click on the Transfer menu again

and select “Capture Text > Stop.” Before closing Hyperterminal, save the session with a name you will be able to recognize. The next time you need to download, you will just need to open the Hyperterminal folder and select the name you saved.

9. You may now open the text file in a word processing program or a spreadsheet program like Microsoft Excel.

The AccuPAR data output will emerge as a series of numbers, similar to the following numbers. Please refer to Section 6.3 for a detailed breakdown of the return items.

1757, ABV, 321969922, 3.20, 2.00, 1.60, 1.20, 1.10, 1.20, 0.90, 0.70, 0.00

1758, BLW, 321969937, 41.80, 58.00, 98.70, 159.10, 325.30, 477.90, 669.10, 750.30, 0.00

1759, SUM, 321969941, 1.50, 322.50, 1.000, 0.00, 1.00, 0.02, 50, 1757, 47, -117, SAMPLE3

6.3 Description of Outputs

RID (1757): The Record ID is a unique identifier for each record. RID are store sequentially in memory and can be used or downloading data.

Type (ABV): “ABV” or “BLW” – which is used to identify the data record type.

Time (321969922): Time in Decaseconds. This is the number of seconds since the epoch date of Jan 1, 2000 00:00:00 To convert this into excel time use the following formula:

Decaseconds = Excel Time
or 321969941 = DATEVALUE(“1/1/2000”)+A2/86400

Note: Make sure to convert cell B2 to a Data/Time format

Individual PAR readings (3.20...0.70): One from each of the eight segments. *Note: Segment 1 is closest to the controller Segment 8 is closest to the tip of the light bar.*

- External Sensor** (0.00): PAR reading from the External Sensor
- RID** (1759): The Record ID is a unique identifier for each record. RID store sequentially in memory and can be used for keeping track of downloaded data.
- Type** (SUM): “SUM” – which is used to identify the data record type.
- Time** (321969941): Time in Decaseconds. This is the number of seconds since the epoch date of Jan 1, 2000 00:00:00 To convert this into excel time use the following formula:
- Decaseconds=Excel Time
or 321969941+=DATEVALUE(“1/1/2000”)+A2/86400
- Note: Make sure to convert cell B2 to a Data/Time format*
- MeanAbv** (1.50): The average of all the above canopy PAR readings for the raw records associated with the summary record.
- MeanBlw** (322.50): The average of all the below canopy PAR readings for the raw records associated with the summary record.
- Tau** (τ) (1.000): Tau is the ratio of below canopy PAR measurements.
- LAI** (0.00): Leaf Area Index (LAI) is the area of leaves per unit area of soil science.
- Chi**(χ) (1.00): The leaf distribution parameter Chi or χ is the ratio of projected area of an average canopy element on a horizontal plane to its projection on a vertical plane.
- F_b** (0.02): The Beam Fraction is the ratio of direct beam radiation coming directly from the sun to radiation coming from all ambient sources.
- Zenith Angle** (50): The zenith angle is the angle in degrees the sun makes with respect to the zenith (point in sky directly overhead).
- RawRID** (1757): RawRID is the RID of the first raw record associated with the summary record. Any record between the

RawRID and the RID of the summary record is also associated with the summary record.

Latitude (47): Latitude location in degrees.

Longitude (-117): Longitude location in degrees.

Annotation (SAMPLE3): The annotation is a string used to identify a record in a user readable format.

6.4 Erase

To erase all data, select “Erase” from the Data menu and press the ENTER button. To escape, press the ESC button. If you proceed, you will see the words “Please Wait” while the instrument deletes the files. This may take a few seconds to complete.

7 LP-80 Utility Software

The AccuPar LP-80 comes with the LP-80 Utility software on a USB key that allows you to download stored data to your computer via the RS-232 cable that came with your system.

7.1 Downloading Data

Follow steps 1 through 9 to download data.

1. Make sure the RS-232 serial cable is properly connected to your LP-80, and to a serial port on your computer, or to a USB-to-serial adapter.
2. Open the LP-80 Utility Program.
3. Select the appropriate COM port from the drop-down menu on the main screen.
4. Turn on your LP-80 by pressing the power button.
5. Click the “Download” button in the lower left of the screen, or click File > Download Data.
6. The “Save LP-80 Data” dialog box will appear.
7. Name your file, and choose a format to save it in, and click Save. (For more information, see Data File Formats.)
8. A progress bar will appear on the main screen.
9. When the download is finished, you will be prompted to optionally erase the data on the LP-80.

7.1.1 Data File Formats

Data files are saved in one of the following file formats:

Excel (.xls): Saves the file as a workbook that can be directly opened using Microsoft Excel 97 or newer.

Note: The Excel format includes column headers by default. These are titles at the top of each column. These can be disabled by using the Preferences Menu.

Tab Delimited Text (.txt): Saves the file in tab delimited format, where all values are separated with tabs.

CSV (Comma Delimited) (.csv): Saves the file in comma delimited format, where all values are separated with commas.

7.1.2 Data Organization

Data from the LP-80 saves in several columns.

1. Record Type—The data record type (SUM, ABV, or BLW).
2. Date and Time Measurement—Date and time you take reading.
3. Annotation—The annotation is a string that a user may use to identify the reading.
4. Average Above PAR—The average of all the above canopy PAR readings for the raw records associated with the summary record.
5. Average Below PAR—The average of all the below canopy PAR readings for the raw records associated with the summary record.
6. Tau (τ)—Tau is the ratio of below canopy PAR measurements (MeanBlw) to the above canopy PAR measurements (MeanAbv).
7. Leaf Area Index (LAI)—LAI or Leaf Area Index is defined as the area of leaves per unit area of soil surface.
8. Leaf Distribution (χ)—The leaf distribution parameter Chi is the ratio of projected area of an average canopy element on a horizontal plane to its projection on a vertical plane.
9. Beam Fraction (Fb)—The Beam Fraction is the ratio of direct beam radiation coming directly from the sun to radiation coming from all ambient sources.

10. Zenith Angle—The zenith angle is the angle the sun makes with respect to the zenith (point in sky directly overhead).
11. Latitude—Latitude location in degrees.
12. Longitude—Longitude location in degrees.
13. Segment 1-8 PAR—Individual PAR readings from each of the 8 segments.
14. External Sensor PAR—PAR reading from the External Sensor.
15. Record ID—The Record ID is a unique identifier for each record.
16. Raw Record ID—RawRID is the RID of the first raw record associated with the summary record. Any record between the RawRID and the RID of the summary record is also associated with the summary record.

7.2 Erasing Data

You can use the LP-80 Utility to erase the data stored on your LP-80.

Caution: Once data has been erased, it cannot be recovered.

1. Make sure the LP-80 is properly connected to your computer.
2. Click the Erase button in the lower left of the screen, or go to File > Erase Data. (If you encounter an error message after clicking the Erase button, please see the Troubleshooting section.)
3. You will be asked if you wish to continue. Click OK to do so, or Cancel to return to the Main screen.
4. If you click OK, a progress bar will appear on the main screen, indicating that data is being erased. “Done erasing data stored in LP-80” will be displayed when all data has been removed from your LP-80.

7.3 Setting the Date and Time

You can use the LP-80 Utility to easily set your device date and time. Make sure you properly connect the LP-80 to your computer. Then choose “Set LP-80 Date/Time” from the Actions menu. (If you encounter an error message after click the Download button, please see Troubleshooting.) By default, the LP-80 Utility automatically sets the date and time on your LP-80 each time you connect. You can turn the feature off by using the Application tab under The Preferences Menu.

7.4 Viewing LP-80 Information

Use the Utility to view information about your LP-80 by choosing “Actions > View Informati...”



This screen will display the following information:

- LP-80 serial number
- Firmware version (the software that runs your LP-80)
- Firmware checksum status
- Battery level
- Number of stored readings

- Current date and time as set in your LP-80

You can also update the time on this screen.

7.5 The Preferences Menu

Use the Preferences Menu to modify aspects of the Utility that relate to downloading and organizing data. The Preferences menu consists of three tabs: the Data File, Communications, and Application tabs. Figure 5 shows each tab.

7.5.1 Data File Tab

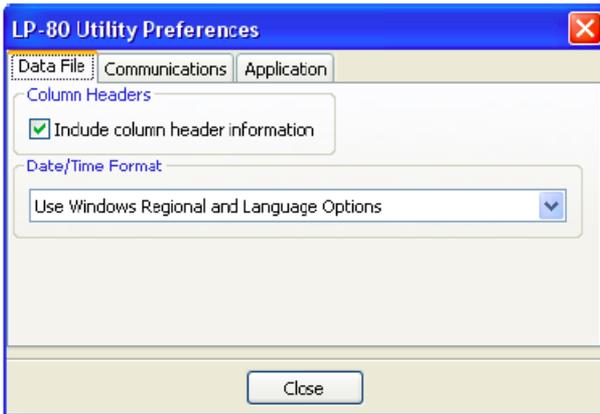
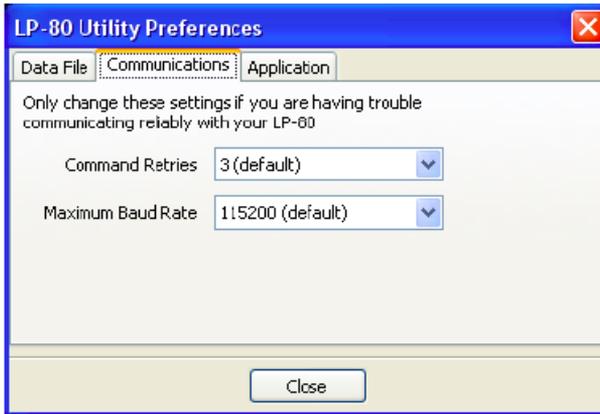


Figure 5: Preferences Menu

Downloaded files contain column headers (see Data File Formats). Uncheck this box to save data files without headers. The date and time for downloaded readings use the formatting of the Windows Regional and Language Options (accessible in the Windows Control Panel). You can set the formatting to use a day/month/year format with 12- or 24-hour time.

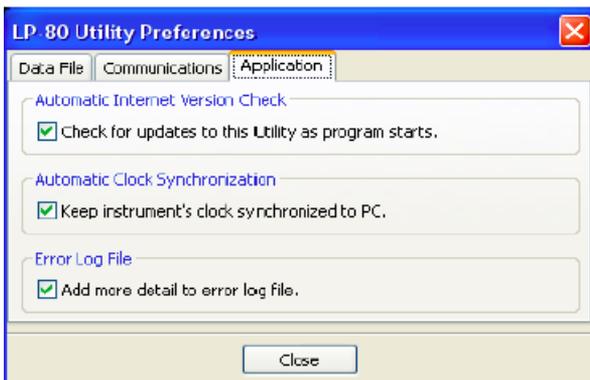
7.6 Communications Tab



Command Retries: If you are having trouble communicating with your LP-80, then set the program to automatically re-send commands to the LP-80, up to ten times.

Maximum Baud Rate: Baud rate is the number of bits per second transferred between a device and your computer. By default, the LP-80 is set to transfer data at 115200 baud. Use a lower baud rate if you encounter difficulty communicating with your device. (See Troubleshooting.)

7.7 Application Tab



Automatic Internet Version Check: If you selected this box, the program will automatically check for updates as soon as it starts (only if you are connected to the Internet).

Automatic Clock Synchronization: Keeps the LP-80 clock synchronized to the time on your computer.

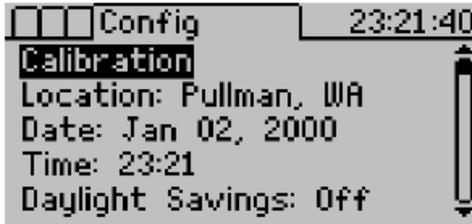
Error Log File: Adds more detail to error files, which can be sent to Decagon for troubleshooting.

7.8 Software and Firmware Updates

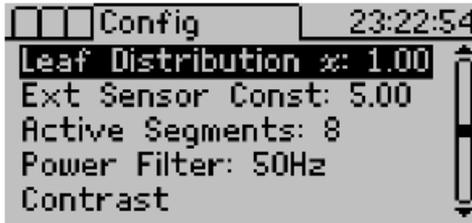
Use Decagon's version check web engine for updates to the LP-80 Utility or firmware. Your computer must be connected to the Internet for this feature to work. To check for a newer version of the LP-80 Utility, choose "Check for Utility Updates..." from the Help menu. To check for updates to the firmware in your LP-80, connect your LP-80 to your computer, select the appropriate comm port, and choose "Check for Firmware Updates" from the Help menu. You can also view the latest information about the LP-80 Utility and firmware by visiting the Decagon website at <http://www.decagon.com/support/downloads>.

8 Config Menu

The Config menu is where you configure and set most of the parameters that affect the functionality of your AccuPAR. When you scroll to this menu, the Config screen appears with numerous options.



Scrolling further down.



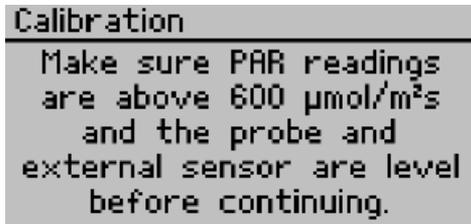
And further.



Use the up and down arrows to scroll through the menu items.

8.1 Calibration

The LP-80 has a calibrated external PAR sensor that it uses for making simultaneous above and below canopy PAR measurements. The LP-80 also uses this sensor to calibrate the AccuPAR probe, ensuring that the PAR response between the external sensor and the probe are the same. When you select this option, the Calibration screen appears.

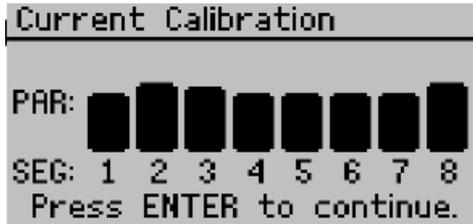


```
Calibration
-----
Make sure PAR readings
are above 600 μmol/m²s
and the probe and
external sensor are level
before continuing.
```

For best results, attach the external PAR sensor to the LP-80 by inserting the bolt attached to the external sensor through the hole in the bubble level. This will ensure that the sensor and probe are both level. The directions state to level the probe and sensor, however you can also calibrate the AccuPAR on a flat board or platform that you can prop up at an angle to get more direct light from the sun.

The PAR level must be above $600 \mu\text{mols m}^{-1} \text{s}^{-1}$. Values below this will not update the calibration, so check the PAR levels before proceeding with the calibration. In general, a clear day where the sun is visible will be above $600 \mu\text{mols}$. Overcast days are typically less than $600 \mu\text{mols}$.

When you have the instrument ready to calibrate, move out of the probe area to minimize reflection off your body, and press the ENTER button to perform the calibration (it is important not to affect light levels on the probe through shading or reflection). The current probe calibration displays graphically. If you have no external sensor attached while performing the calibration, the calibration will return an error.

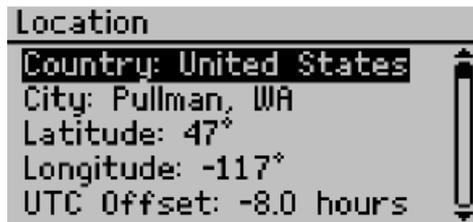


Press ENTER again to complete the calibration.



8.1.1 Location

You will need to set the correct longitude and latitude for your location to make accurate LAI calculations. This is due to the fact that zenith angle calculation is based not only on the time and date, but the longitude and latitude of the site. When you select the Location menu item, you will see the currently configured location.



Highlight the item you would like to change and press Enter. In the next screen, use the up and down arrows to change it and then press ENTER to save the change. Northern latitudes are designated positive and Southern latitudes negative, while Eastern longitudes are positive and Western longitudes negative. To exit the location menu, press MENU or ESC.

8.1.2 Date and Time

Set your current time and date in this menu. The instrument uses the time and date provided here to calculate its zenith angle and F_b values, so make sure it is accurate. Use the up and down arrow keys to change the values of each item, and use the ENTER key to move to the next item. Time must be entered in 24 hour format (i.e. 3 pm should be entered as 15:00). Once you have set the time and date correctly, press the Enter key to exit the menu and store the result in memory.

Daylight Savings Time

Press ENTER to toggle on or off for daylight savings time (summer time). The LP-80 uses this parameter to calculate zenith angles and F_b values, so make sure it is accurate. When adjusting for daylight savings time, the time will automatically adjust.

Leaf Distribution (χ)

Use the χ menu is used to set the χ (leaf distribution) parameter for the plant canopy you plan to measure. See the next chapter for further explanation of the χ parameter. To change the value of the χ parameter, use the up and down arrow keys. When the value is correct, press ENTER.

External Sensor Const

This menu option stands for “External Sensor Constant.” This menu is for adjusting the calibration constant of the external sensor. You should only adjust this value either when using a new external sensor, or after the external sensor has been recalibrated. To make sure this value is correct, check the tag attached to the external sensor cable. The value shown should correspond with the value shown in this menu. If you need to adjust the value, press the up or down arrow keys to the correct value, then press the ENTER key.

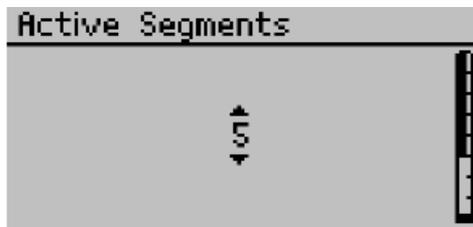
As with most electronic components, the sensitivity of the exter-

nal sensors drift over time and periodically need recalibration. We recommend that you have your external sensor recalibrated. If you use it heavily each year, we suggest this be done on a yearly basis. If you only make periodic measurements, one recalibration every two to three years should be adequate. Contact Decagon for more details about recalibrating the external sensor.

We recommend you calibrate, or match, the LP-80 to the external sensor at least once an hour to maintain a stable calibration between the two sensors.

Active Segments

For some measurement purposes, you may not want to use the entire length of the probe. For such applications, you can turn off sections of the probe, starting from the base and continuing down the probe to the end. When you select this menu, the following screen will appear:



This screen shows that 5 segments are on. To change this number, press the up or down-arrow keys until you reach the desired number of active segments. The icon on the right side of the screen will illustrate the active segments as you reduce or increase them. Once you have selected your desired number of segments, press the ENTER button. If you have selected active segments smaller than eight, the number of segments will also appear in the PAR/LAI sampling menus to remind you that it is in segmented mode.

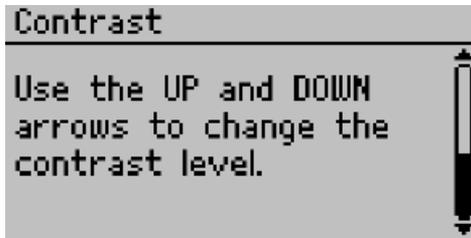
Note: If LP-80 segments are deactivated, those segments will show zero when they dump their data. These deactivated segment numbers will not be used in LAI calculation.

Power Filter

Artificial lighting uses AC electrical power and can add a significant amount of noise to the AccuPAR LP80 sensor measurements. We designed the power filter setting to eliminate the electrical noise that comes from the AC powered light source. You should set the value of the Power Noise Filter to match the frequency of the power where you live. In North America and most of Asia, this is 60 Hz (the default value). In most of Europe the electrical frequency is 50 Hz.

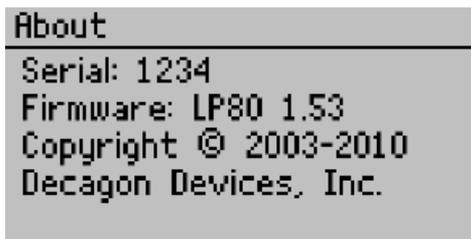
Contrast

The Contrast screen allows you to adjust the contrast of the display to make the display easier to read in sunlight or inside. Use the up and down arrows to change the contrast. Press ENTER to save your changes or ESC to cancel.



About Menu

The About menu shows you data about the operating system of the AccuPAR.



The About menu provides you with the serial number, firmware version number, and copyright info.

9 PAR and LAI Theory

The AccuPAR is useful for a number of applications, including the measurement of average and intercepted PAR. The LP-80 calculates LAI and other attributes of the canopy structure with these measurements.

9.1 PAR (Photosynthetically Active Radiation)

PAR is the radiation in the 400 to 700 nanometer waveband. It represents the portion of the solar spectrum which plants use for photosynthesis. Under a plant canopy, radiation levels can vary from full sun to almost zero over the space of a few centimeters. Therefore, reliable measurement of PAR requires many samples at different locations under the canopy.

9.2 Average and Intercepted PAR

Monteith (1977) observed that dry matter production of a plant canopy is directly related to the amount of photosynthetically useful radiation intercepted by the canopy. Dry matter production is modeled as the product of three terms:

$$P = e f S \quad (1)$$

where P is the amount of dry matter produced, S is the flux density of incident radiation intercepted by the crop, f is the fraction of incident radiation intercepted by the crop, and e is a conversion efficiency. Conversion efficiency and fractional interception (f) are determined by crop physiology and management.

Incident solar radiation is the only environmental factor. If you monitor f and S over the period of crop growth and measure P at harvest, you can determine e . You can interpret the results of experimental treatments or the influence of genetics in terms of their effect on e and f .

The radiation incident on a canopy can be absorbed by the canopy,

transmitted through the canopy and absorbed or reflected at the soil surface, or reflected by the canopy. In principle, only PAR absorbed by the canopy is useful in producing dry matter, so f should be the fractional absorption. If t is the fraction of incident radiation transmitted by the canopy, r is the fraction of incident radiation reflected to a sensor above the canopy, and r_s is the reflectance of the soil surface, then the absorbed radiation fraction is calculated from:

$$f = 1 - t - r + tr_s \quad (2)$$

The last two terms are often ignored, so approximate fractional interception with equation 3.

$$f \cong 1 - t \quad (3)$$

The error resulting from this approximation is usually small when t , r , and r_s are measured in the PAR waveband because most of the PAR is absorbed by a closed canopy. The error becomes much more significant when measurements of total solar radiation are used because of large scattering coefficients of leaves for near infrared radiation.

As a first-order estimate of error, assume that

$$r = (1 - t)r_c + tr_s \quad (4)$$

where r_c is the reflectance of the vegetation. Equation 2 becomes.

$$f = (1 - t)(1 - r_c) \quad (5)$$

The error resulting from using equation 3 is approximately equal to r_c , which is typically less than 0.05 in the PAR waveband. Since the AccuPAR sensors are sensitive only to radiation in the PAR waveband, equation 3 will be fairly accurate for making measurements of intercepted radiation. However, measurement of the other terms needed for equation 2 is simple and we will deal with them later.

Sampling for Fractional Interception

The functions needed to perform these calculations are available in the PAR sampling menu of the AccuPAR. The measurements needed

for fractional interception are those from which you calculate t , r , and r_s . If S is the PAR reading from an upward-facing AccuPAR above the plant canopy, R is the reflected PAR above the plant canopy (inverted AccuPAR above the crop), T is the upward-facing AccuPAR below the plant canopy, and U is the reflected PAR from the soil surface, then t , r , and r_s can be calculated with equations 6 through 8.

$$t = T/S \quad (6)$$

$$r = R/S \quad (7)$$

$$r_s = U/T \quad (8)$$

Assume you need to know only t and measure S above the crop canopy. Level the AccuPAR above the canopy and press the up-arrow key. The reading displayed in the upper right portion of the screen is the value for S .

Measure T by placing the AccuPAR below the plant canopy. Carefully place it below all of the leaves and try to keep the instrument level. Press the down-arrow key to make below-canopy measurements. The resulting values are displayed below the above-canopy values on the screen. Since the light below the canopy is extremely variable, several samples at different locations will be necessary for a reliable reading. The number of necessary samples can be determined by taking, for example, ten individual readings and computing the coefficient of variation with equation 9.

$$CV = \frac{s}{\bar{T}} \quad (9)$$

Where s is the standard deviation of the 10 readings.

$$s = \sqrt{\frac{\Sigma(T_i - \bar{T})^2}{n - 1}} \quad (10)$$

Where n is the number of samples taken. The fractional error in the measurement of T will be CV divided by the square root of the number of samples.

Once you have taken the first below-canopy PAR reading, you will

see the current τ value displayed in the lower left corner of the screen. With each subsequent below-canopy measurement, the τ value will be updated. After you have taken sufficient measurements, use the displayed τ value in the lower left corner for t (see equation 6).

To find r , level the AccuPAR above the canopy and press the up-arrow. Then invert the AccuPAR at a height of 1 or 2 m above the crop canopy. Leveling is not critical for this measurement since the radiation reaching the sensor is not directional. Press the down-arrow key in the PAR sampling menu. Multiple readings are typically not necessary, since R is not usually variable. r for equation 7 is shown in the T location at the bottom of the AccuPAR screen.

To find r_s , invert the AccuPAR over the soil below the canopy and take measurements at several locations. Average and store these measurements as before. This reading is the value U . Calculate r_s from equation 8 using U and T . A value in the range of 0.1 to 0.2 should be obtained, but it is possible that the light level below the canopy will be so low that U will not be accurately measured. If a value outside of the expected range is obtained, there will be negligible error in f by assuming $r = 0.15$. As mentioned before, evaluation of intercepted radiation normally involves the measurement of t .

Only measurements below the canopy have been discussed. Obviously, measurements throughout the canopy are possible. Profiles of interception with height can be useful in determining at what location most of the photosynthesis occurs in the canopy.

9.3 Using PAR to determine Leaf Area Index

The PAR measured by the AccuPAR within a plant canopy is a combination of radiation transmitted through the canopy and radiation scattered by leaves within the canopy. A complete model of transmission and scattering is given by Norman and Jarvis (1975), but it is very complex and not suitable for inversion.

We use the Norman-Jarvis model to test and fit two simpler models which invert more easily. Equation 11 is a simple light scattering

model suggested by Goudriaan (1988). Equation 11 gives the fraction of transmitted PAR, τ (ratio of PAR measured below the canopy to PAR above the canopy), below a canopy of LAI, L , as

$$\tau = f_b \exp(-\sqrt{a}) + (1 - f_b) \exp(-0.87\sqrt{a}) \quad (11)$$

where f_b is the fraction of incident PAR which is beam, a is the leaf absorptivity in the PAR band (AccuPAR assumes 0.9 in LAI sampling routines), and K is the extinction coefficient for the canopy. The extinction coefficient can be modeled in various ways. If you assume an ellipsoidal angle distribution function (Campbell 1986), then

$$K = \frac{\sqrt{\chi^2 + \tan^2 \Theta}}{\chi + 1.744(\chi + 1.182)^{-0.733}} \quad (12)$$

where Θ is the zenith angle of the sun and χ is a leaf angle distribution parameter (see Chapter. 3 for definition). When $x = 1$, the angle distribution is spherical, and K simplifies to:

$$K = \frac{1}{2\cos\Theta} \quad (13)$$

John Norman suggests a different equation for predicting scattered and transmitted PAR, equation 14.

$$\tau = \exp \left\{ \frac{A(1-0.47f_b)L}{(1-\frac{1}{2K})f_b-1} \right\} \quad (14)$$

where $A = 0.283 + 0.785a - 0.159a^2$.

Both equations predict canopy PAR within a few percent of values from the complete Norman-Jarvis model. Equation 11 is slightly more accurate, but equation 14 is much easier to invert to obtain L . The difference in accuracy of the two equations is smaller than other uncertainties in the method, so the LP-80 uses equation 14 to determine LAI. Inverting equation 14 gives the following:

$$L = \frac{[(1 - \frac{1}{2K})f_b - 1] \ln \tau}{A(1 - 0.47f_b)} \quad (15)$$

9.4 Applications and Examples

This section describes the method of manually collecting PAR data for the determination of LAI in a barley and pea canopy. This example has been included to show how the AccuPAR automatically calculates LAI in the field. PAR was measured above a barley canopy of $391 \mu\text{mol}$ ($\mu\text{mol m}^{-2}\text{s}^{-2}$) on an overcast day. The average of several measurements below the canopy was $62 \mu\text{mol}$. The transmission, τ , is therefore $62/391 = 0.159$. Since the day was overcast, $f_b = 0$. If $a = 0.9$, then $A = 0.86$. From equation 15, $L = -\ln(0.159)/0.86 = 2.14$. If you make a measurement under overcast skies, it was not necessary to have canopy structure information or solar elevation angle. Measurements on overcast days are the simplest for LAI determination and do not require assumptions about canopy structure.

The next example uses measurements on a sunny day. $1614 \mu\text{mol}$ was measured above a pea canopy and $80 \mu\text{mol}$ under the canopy. The fraction of PAR transmitted by the canopy was therefore $\tau = 80/1614 = 0.05$. The solar zenith angle was 30° , and the beam fraction was 0.881 . The A value for equation 15 is again 0.86 . χ for the canopy is unknown, but unless leaves have obvious horizontal or vertical tendencies, a spherical distribution can be assumed and χ set equal to 1. (The AccuPAR default value for leaf distribution parameter is 1.0, which is applicable for many canopies). For a zenith angle of 30° , this gives $K = 0.577$. Substituting these values into equation 14 results in $L = 5.2$. The AccuPAR program utilizes these same equations when the instrument is used to automatically calculate LAI. In the AccuPAR setup menu, you enter your local time, date, and leaf distribution parameter, and it automatically calculates zenith angle and beam fraction. It then couples these parameters with collected intercepted PAR data to determine LAI.

9.5 Extinction Coefficient and Canopy Structure

If the the elements of a canopy are randomly distributed in space, then the probability of a ray of light, or other probe, penetrating the canopy without interception can be calculated from theory. The probability of penetration without interception is equal to the sun-

fleck fraction, which is the beam transmission coefficient, $\tau(\Theta)$, for the canopy. The parameter, Θ , is the zenith angle (angle measured from the vertical) of the probe or solar beam. τ usually varies with zenith angle. The transmission coefficient for a canopy of randomly placed elements is:

$$\tau\theta = \exp(-KL) \quad (16)$$

where L is the leaf area index of the canopy (area of leaves per unit area of soil surface) and K is the extinction coefficient for the canopy, which depends on the leaf angle distribution of canopy elements and the zenith angle of the probe. A number of expressions have been proposed for K . The most useful is from Campbell (1986) where the angle distribution of canopy elements is assumed to be ellipsoidal. One can picture the angle distribution of area in a plant canopy to be similar to the angle distribution of area on the surface of oblate or prolate spheroids, or spheres. The equation for K is

$$K = \frac{\sqrt{\chi^2 + \tan^2\Theta}}{\chi + 1.744(\chi + 1.182)^{-0.733}} \quad (17)$$

The parameter, χ , is the ratio of the length of the horizontal to the vertical axis of the spheroid, and can be measured as the ratio of the projected area of an average canopy element on a horizontal plane to its projection on a vertical plane. See the definition for Leaf Distribution Parameter in Chapter 3 for more discussion of χ and typical values for some canopies.

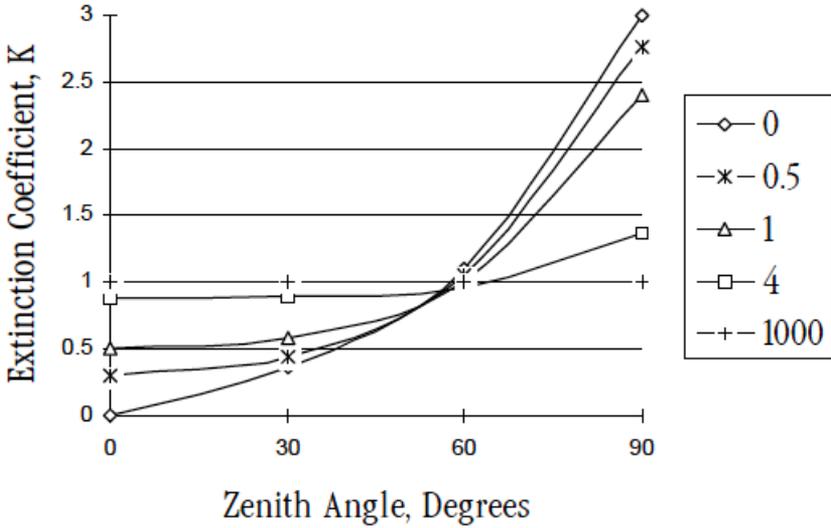


Figure 6: Extinction Coefficient vs. Zenith Angle

Figure 1 shows the extinction coefficient plotted as a function of zenith angle for various values of x . There are two important things to note. First, at a zenith angle of about 57° , the extinction coefficient is near unity for all canopies. When leaves are horizontal (large χ), the extinction coefficient, K , is unity for all elevation angles, but as χ decreases, K becomes smaller at large zenith angles and larger at small zenith angles.

Equation 16 can be used in various ways to determine the leaf area index, and also the leaf angle distribution for a canopy. The simplest application is that of Bonhomme et al. (1974). Since $K = 1$ for zenith angles near 57° , the inversion of equation 16 is simple and gives:

$$L = -\ln(\tau_{57}) \quad (18)$$

If a measurement is made when the zenith angle is about 57° , equation 18 can be used directly to find L . If measurements of the transmission coefficient, τ , are made at several elevation angles, a simple method from Lang (1987) can be used. The measurements of τ are used to compute $y = \cos\theta \ln \tau$. These are regressed on Θ (in radians), giving a slope, B and intercept, A . The leaf area index is given

by:

$$L = 2(A + B) \quad (19)$$

An approximate value for χ is $\chi = \exp(-B/0.4L)$.

Example: Readings were obtained as follows:

Table 2: Sample Readings

Θ -deg	Θ -rad	τ	$-\cos\Theta \ln\tau$
35	0.61	0.21	1.28
41	0.72	0.18	1.29
55	0.96	0.10	1.32

Linear Regression gives:

$$A = 1.21$$

$$B = 0.12$$

$$L = 2(1.21 + 0.12) = 2.64$$

$$\chi = \exp(-0.12 / 0.4 \times 2.64) = 0.9$$

A more precise method for finding χ is as follows. We would like to find values for χ and L which minimize:

$$F = \sum (\ln\tau_i + K_i L)^2 \quad (20)$$

subject to the constraint, $\chi > 0$, where τ_i are transmission coefficients measured at several zenith angles, Θ_i , and the K_i are the extinction coefficients for the corresponding angles.

9.5.1 Correction of PAR for Sun Angle

Canopy transmission (τ), measured at one zenith angle, can be used to predict transmission or radiation interception for other zenith angles. For example, a measurement might be made at $\Theta = 32^\circ$ from which cover (1 - transmission at $\Theta = 0$) is to be calculated. From equation 16:

$$\frac{\ln\tau_1}{\ln\tau_2} = \frac{K_1}{K_2} = p \quad (21)$$

so:

$$\tau(\Theta_1) = \tau(\Theta_2)^p \quad (22)$$

We can calculate p from equation 17:

$$p = \left[\frac{(\chi^2 + (\tan\Theta_1)^2)}{(\chi^2 + (\tan\Theta_2)^2)} \right]^{\frac{1}{2}} \quad (23)$$

If $\Theta_1 = 0$,

$$p = \left[\frac{(\chi^2)}{(\chi^2 + (\tan\Theta_2)^2)} \right]^{\frac{1}{2}} \quad (24)$$

If χ is not known, assume $\chi = 1$. Example: From the measurements in the previous example, find the canopy cover. Take $\Theta = 35^\circ$, $\tau = 0.21$. The χ value is 0.9.

$$p = \left[\frac{(0.9^2)}{(0.9^2 + (\tan 35^\circ)^2)} \right]^{\frac{1}{2}}$$

$$\tau(0) = 0.21^0.79 = 0.29$$

$$\text{Cover} = -\tau(0) = 1 - 0.29 = 0.71$$

Intercepted radiation averaged over an entire day can be estimated from:

$$f = 1 - \tau_d \quad (25)$$

where τ_d is the transmission coefficient averaged over all elevation angles τ_d can be calculated from:

$$-\ln\tau_d = uL^v \quad (26)$$

where u and v are functions of χ which can be calculated from:

$$u = 1 - 0.33\exp(-0.57\chi) \quad (27)$$

$$v = 1 - 0.33\exp(-0.97\chi) \quad (28)$$

Table 3 shows typical values.

Table 3: Values of u and v for equation 26

χ	u	v
0.1	0.69	0.73
0.5	0.75	0.82
1.0	0.81	0.89
2.0	0.90	0.95
4.0	0.96	0.98
8.0	0.99	0.99

Combining equations 16 and 25 gives:

$$\tau_d = \tau(\Theta)^q \quad (29)$$

where $q = uL^{v-1}/K$

Example: Calculate a value for fractional daily interception for the crop in the previous two examples.

$$u = 1 - 0.33\exp(-0.57x0.9) = 0.80$$

$$v = 1 - 0.33\exp(-0.97x0.9) = 0.87$$

$$K = \frac{(0.9^2 + (\tan 35^\circ)^2)^{\frac{1}{2}}}{0.9 + 1.774(0.9 + 1.182)^{-0.733}} = \frac{1.14}{1.94} = 0.59$$

$$q = 0.80 * 2.64^{-0.13} / 0.59 = 1.2$$

$$\tau_d = 0.21^{1.2} = 0.15$$

$$f = 1 - \tau_d = 1 - 0.15 = 0.85$$

9.6 LAI measurements & Non-Random Distribution

There has been much discussion concerning inversion methods to obtain LAI. Since all inversion methods rely on the assumption that elements of a canopy are randomly dispersed in space, errors in the measurement of LAI may result from a non-random arrangement of canopy elements. This is especially true for canopies with heliotropic leaves, conifer forests, row crops before canopy closure, or

for canopies which never close, as in desert vegetation. The degree of error in measurement is a result of the canopy deviation of the canopy from this random dispersion assumption.

Past studies use LAI to relate both actual biomass area and the interception of PAR by a plant canopy. Another proposed view regarding LAI in which L , the actual biomass area, relates to a new term, L_e , which represents the actual orientation of the canopy elements relating to the interception of PAR at a given angle. In situ measurements of LAI using hemispherical photography were equated with this new term “effective plant area index” (L_e), which was defined as:

$$L_e = \Omega L \quad (30)$$

where L_e represents the actual leaf area index (equal to a harvested leaf area measurement) and Ω refers to a clumping index resulting from the non-random distribution of canopy elements.

When a canopy displays random dispersion, Ω is unity; however, when a canopy is clumped, Ω is not unity. In a randomly dispersed canopy, L would be equal to L_e (figure 2). In an under-dispersed canopy (clumped), L would be greater than L_e (see figure 3, leaves preferentially shade the leaves). In an over-dispersed canopy, L would be less than L_e (see figure 4, leaves are in the open spaces). Refer to the next page for illustrations.

The purpose of this discussion is to expose you to possible errors that may occur when making LAI measurements in situ. When setting up an experiment, you should carefully examine the desired end result. If you are only interested in the interception of PAR within a canopy, the apparent leaf or plant area index that is calculated through inversion will be an accurate portrayal of the canopy structure and orientation with respect to light interception. In this instance, while clumping effects within the canopy remain present, these effects do not cause error with regard to light interception and the effective area index for that situation. Alternately, if you are interested in obtaining the actual biomass represented by L in this discussion, all measurements should be performed so that the effects of clumping are minimized. The method used in the LP-80 to compute τ fol-

lows the recommendation of Lang and Yueqin (1986) for minimizing clumping effects. You can also measure only at certain times of day or at positions within the canopy that directly minimize clumping effects.



Figure 7: Randomly Dispersed $L=L_e$

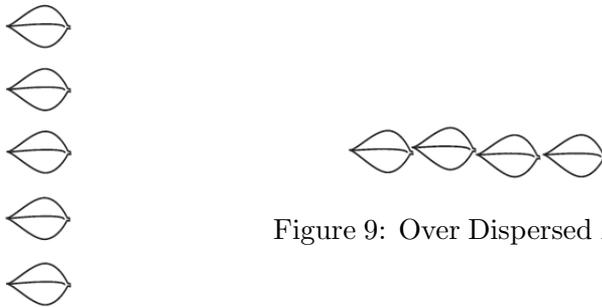


Figure 9: Over Dispersed $L < L_e$

Figure 8: Under Dispersed $L > L_e$

9.7 Zenith Angle and Equation of Time

The formulas for calculating elevation angle are relatively straightforward. The zenith angle is calculated with equation 31

$$\Psi = \arccos(\sin Lat \sin D + \cos L \cos D \cos 0.2618(t - t_0)) \quad (31)$$

Lat is the latitude, D is the solar declination, t is the time, and t_0 is the time of solar noon. The earth turns at a rate of 0.2618 radians

per hour, so the 0.2618 factor converts hours to radians. Time, t , is in hours (local solar time), ranging from 0 to 24. Latitude of a given site is easily found in an atlas or using a GPS system. Users in the Southern hemisphere should enter latitude as a negative number. Solar declination ranges from $+0.409$ radians ($+23.45^\circ$) at summer solstice to -0.409 radians (-23.45°) at winter solstice. It can be calculated from equation 32

$$D = \arcsin[0.39785\sin[4.869 + 0.0172J + 0.03345\sin(6.224 + 0.0172J)]] \quad (32)$$

J is the day of the year. Some values are given in Table 4. The time of solar noon is calculated with equation 33

$$t_0 = 12 - LC - ET \quad (33)$$

LC is the longitude correction and ET is the Equation of Time. LC is $+4$ minutes, or $+1/15$ hour for each degree east of the standard meridian and $-1/15$ hour for each degree west of the standard meridian. Standard meridians are at 0° , 15° , 30° ...etc. Generally, time zones run approximately $+7.5^\circ$ to -7.5° on either side of a standard meridian, but this varies depending on political boundaries, so check an atlas to find both standard meridian and longitude. Typically, longitudes in the Eastern Hemisphere are given as negative values.

The Equation of Time is a 15 to 20 minute correction which depends on the day of the year. It can be calculated from:

$$ET = [-104.7\sin\phi + 596.2\sin 2\phi + 4.3\sin 3\phi - 12.7 \sin 4\phi - 429.3\cos\phi - 2.0\cos 2\phi + 19.3\cos 3\phi]/3600 \quad (34)$$

where $\phi = (279.575 + 0.986J)\pi/180$. Some values for ET are given in Table 4.

Example Calculation:

Find the zenith angle for Pullman, WA at 10:45 PDT on June 30. Convert the time of observation to standard time by subtracting one hour and convert minutes to decimal hours, so $t = 9.75$ hours.

June 30 is $J = 181$.

Pullman latitude is 46.77° , or 0.816 radians, and longitude is 117.2° . The standard meridian for Pullman is 120° . The local meridian is 2.8° east of the standard meridian, so $LC = 2.8/15 = 0.19$ hours. From Equation 34 or Table 4, $ET = -0.06$ hours. Equation 33 then gives $t_o = 12 - 0.19 - (-0.06) = 11.87$. Declination from Table 4 or Equation 32 is 0.4 radians. Substituting these values into Equation 31 gives:

$$\Theta = \arccos\{\sin(0.816)\sin(0.4) + \cos(0.816)\cos(0.4)\cos[0.2618(9.75 - 11.87)]\} = 0.61 \text{ radians, or } 34.9^\circ \quad (35)$$

Table 4: Solar Declination and Equation of Time

Date	Day of Year	D in Radians	ET Hour
Jan 1	1	-0.403	-0.057
Jan 10	10	-0.386	-0.123
Jan 20	20	-0.355	-0.182
Jan 30	30	-0.312	-0.222
Feb 9	40	-0.261	-0.238
Feb 19	50	-0.202	-0.232
Mar 1	60	-0.138	-0.208
Mar 11	70	-0.071	-0.117
Mar 21	80	-0.002	-0.122
Mar 31	90	0.067	-0.072
Apr 10	100	0.133	-0.024
Apr 20	110	0.196	0.017
Apr 30	120	0.253	0.046
May 10	130	0.304	0.060
May 20	140	0.346	0.059
May 30	150	0.378	0.043
Jun 9	160	0.399	0.015
Jun 19	170	0.409	-0.019
Jun 29	180	0.406	-0.055
Jul 9	190	0.392	-0.085
Jun 19	200	0.366	-0.103
Jun 29	210	0.331	-0.107
Aug 8	220	0.286	-0.097

Continued on next page

Table 4 – *Continued from previous page*

Date	Day of Year	D in Radians	ET Hour
Aug 18	230	0.233	-0.065
Aug 28	240	0.174	-0.022
Sep 7	250	0.111	0.031
Sep 17	260	0.045	0.089
Sep 27	270	-0.023	0.147
Oct 7	280	-0.091	0.201
Oct 17	290	-0.157	0.243
Oct 27	300	-0.219	0.268
Nov 6	310	-0.275	0.243
Nov 16	320	-0.324	0.255
Nov 26	330	-0.363	0.213
Dec 6	340	-0.391	0.151
Dec 16	350	-0.406	0.075
Dec 26	360	-0.408	-0.007

Automatic Calculation of Zenith Angle

The AccuPAR automatically determines zenith angle using the above equation and parameters. However, to get the accurate zenith angle for your location, you need to enter the site latitude, longitude and universal time offset in the Setup menu. Once these values are entered, the AccuPAR determines zenith angle without further input. The zenith of the sun angle will then be calculated and stored at the end of each data set.

10 Measurement Tips

10.1 Above Canopy (External) Sensor

The AccuPAR is supplied with an external PAR sensor which connects to the port on the right side of the AccuPAR. The external sensor allows you to take simultaneous above and below canopy PAR readings without having to move the instrument above and below the canopy you are measuring.

For above-canopy PAR data collection, consider connecting the external point sensor to the AccuPAR. This ensures an accurate measurement of intercepted PAR, especially on days where radiation levels vary rapidly. You can mount the sensor on a tripod and level it with a bubble level.

When it is not feasible to use an external point sensor to obtain above-canopy measurements, such as in timber or tropical crops, you have two choices:

1. Use a separate data logger with an attached PAR sensor such as a point quantum sensor, or configure another AccuPAR to log in the unattended mode (one reading per minute, for example) in a clearing outside the canopy. After collecting PAR data within the canopy, you can correlate the data from the two instruments after downloading it from each to a computer.
2. You can use your AccuPAR as an above-canopy reference by regularly collecting above-canopy PAR data in a large clearing within the canopy structure.

10.2 Sample Size

When evaluating experimental protocols for measuring average intercepted PAR and determining average LAI for a large area, make sure that a sufficient number of samples and sampling locations are used. This will reduce errors caused by canopy structure variations.

10.3 Clumping in Canopies

When evaluating discontinuous canopies or canopies with definite clumping, the AccuPAR can be configured such that its active sampling area is reduced, or you can download the data collected by the AccuPAR probe segments. In this way you can gather information that better describes the changes in canopy structure with regard to location. To reduce the sampling size of the probe, refer to the “Set Active Segments” option in the setup menu (see chapter 7). To see the individual PAR readings for each of the eight probe segments, download the stored data to the computer (See Download section in Chapter 6).

10.4 LAI Sampling in Row Crops

One of the common uses for the AccuPAR is measuring the leaf area index of row crops. When doing so, it is important to take measurements in such a way as to give a good row-to-row representation of the entire below-canopy PAR environment both under the plants and between rows. We suggest a sampling regime such as shown below, where the probe either extends from mid-row to mid-row, or extends from mid-row to the middle of the open space between rows, depending on row width and canopy size.

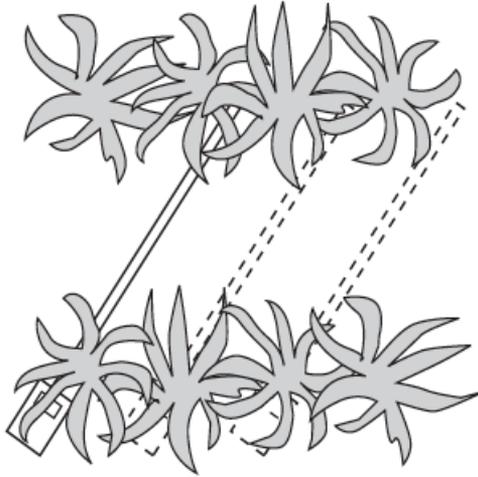


Figure 10: Scenario 1: The two ends of the AccuPAR probe are in the middle of each row, getting a good representative sample of the entire area below and between rows.

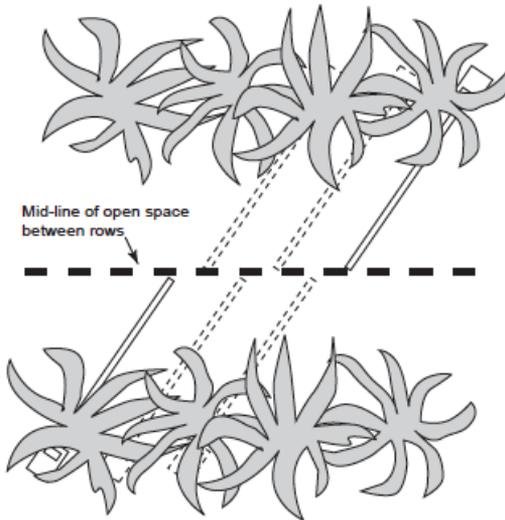


Figure 11: Scenario 2: The base of the probe is in the center of the row, while the end is in the center of the open space between rows. When sampling the next row, the same orientation is maintained, giving an accurate representation of the overall area.

11 Care and Maintenance

11.1 Batteries

The AccuPAR uses four standard 1.5 V AAA alkaline batteries. These batteries are easily obtained and should last for at least two years before they have discharged. If a battery icon appears in the upper right corner of the screen (to the left of the time) or a low battery message is displayed, you will need to change your batteries.

Replacing Batteries

If the alkaline batteries require replacement, remove the four screws on the bottom of the AccuPAR case and lift the cover carefully. The batteries are located on both sides of the circuit board. Be sure to orient them properly; placing them the wrong way in the battery holder can damage the AccuPAR. The battery holders indicate which direction they should be placed. After replacing the batteries, press the reset button at the top left corner of the board.

Note: Data will not be lost when the batteries are replaced. The memory and program sections of the AccuPAR are non-volatile.

11.2 Cleaning the Probe and Controller

The white probe diffuser should always be clean to ensure accurate readings. To clean the probe, use a small amount of isopropyl alcohol and a soft cloth. Rub the surface until it is clean.

To clean the controller, use a soft cloth and water to wash heavy dirt, then use ethyl or isopropyl alcohol to finish cleaning. Make sure to only use a soft cloth when cleaning the LCD window. Tissues made from wood fiber will scratch the surface.

11.3 Recalibration

The AccuPAR calibrates its sensors against the external sensor supplied with the instrument. Therefore, provided your external sensor calibration is good, you simply recalibrate the AccuPAR in the Config menu (see chapter 9) as often as you wish. However, as is the case with all electronic components, shifts in the external sensor sensitivity will occur over time. As a result, we recommend that you periodically send your external sensor in to Decagon's factory for recalibration, depending on how often you use it. If you use it heavily each year, we suggest once a year. For periodic measurements, one recalibration every two to three years should be adequate. Before sending the instrument in, contact Decagon via phone or email so we can prepare for its arrival.

11.4 General Precautions

The AccuPAR is a low maintenance instrument. There are only a few suggestions to keep in mind.

Cautions

Keep the probe clean. The accuracy of readings may decline if there is any debris on the probe which prevents light from entering the sensors.

Although the AccuPAR is splash-resistant, do not immerse the instrument in water, or leave the it in contact with rain for long periods of time.

When transporting the AccuPAR, keep the instrument in its padded hard-sided carrying case to prevent damage.

12 Troubleshooting

The AccuPAR LP-80 is a high performance, low maintenance instrument, designed to have few problems if used with care. Unfortunately, sometimes even the best operators using the best instruments encounter technical difficulties. Below is quick reference guide that will direct you to detailed solutions of some problems that may occur. If these remedies still does not resolve your problem, then please contact Decagon for help (see Customer Support in Chapter 1). Here is a list of some problems that may occur.

Note: If you purchased your Decagon instrument from one of our international distributors, please contact them for local service and support.

Table 5: Troubleshooting Quick Guide

If this problem occurs:	Refer to:
Instrument does not turn on	Problem #1
Display is difficult to see	Problem #2
I get an error message when I try to calibrate	Problem #3
Your LAI output is 0...	Problem #4
Low battery message	Problem #5
Date and time were reset message	Problem #6
Data erase failed message	Problem #7
Missing bootstrap loader message	Problem #8
Firmware corrupted message	Problem #9
Cannot change settings message	Problem #10
Only one mode can be run at a time message	Problem #11
Memory full message	Problem #12
No summary data message	Problem #13
By continuing you will lose custom info msg.	Problem #14
Communication port is already in use	Problem #15
Download data to the Utility failed	Problem #16

1. PROBLEM:

Instrument does not turn on.

SOLUTION:

Make sure that the batteries are inserted correctly, and/or if they have enough power to activate the machine.

2. PROBLEM:

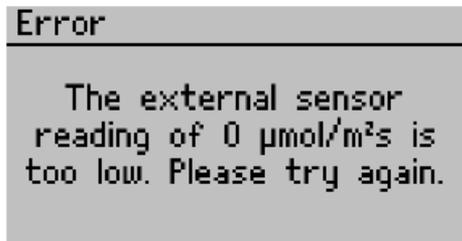
The display is difficult to see.

SOLUTION:

Turn off the LP-80 and then turn it on again. If this does not fix the problem, the LP-80 features a built-in screen for changing screen contrast. See “Contrast” in Chapter 7 for details. You may be able to fix the contrast manually, which can be done using a terminal port program. Contact Decagon for information regarding this procedure.

3. PROBLEM:

Message on screen displays the following:

**SOLUTION:**

The external sensor must be reading a PAR value of $600\mu\text{mol}/\text{m}^2\text{s}$ in order to calibrate. Make sure that the external is attached and is in full view of the Sun. If the day is overcast, wait to calibration the sensor on a sunny day when PAR levels are above $600\mu\text{mol}/\text{m}^2\text{s}$.

4. PROBLEM:

Your LAI output is 0 even though there is a valid above and below canopy PAR reading.

SOLUTION:

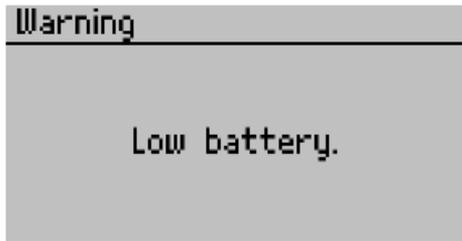
Check your zenith angle (Z). If Z is greater than 90 degrees, the time or latitude/longitude are most likely set incorrectly. Return to the set date/time menu and double check that:

1. Time is set in 24 hour format.
2. You have the proper sign in your latitude and longitude positions. Positive is East and negative West for longitude, and positive is North and negative South for latitude.

Zenith angle should now be 0 to 90 degrees, as expected for daylight hours, and LAI and F_b should now be calculated correctly.

5. PROBLEM:

Message on screen displays the following:



SOLUTION:

The batteries in the instrument may not be properly inserted in the battery holder or they may need to be replaced. If the batteries are not inserted properly, reseal the batteries into the battery holder and cycle the power on the instrument.

6. PROBLEM:

Message on screen displays the following:

```
Warning
-----
Date and time were reset!

Update the date and time.
```

SOLUTION:

After changing the batteries or loading new firmware onto an instrument, this message may appear. Navigate to the configuration menu and verify that the date and time are set properly.

7. PROBLEM:

Message on screen displays the following:

```
Error
-----
Data erase failed! Replace
batteries.

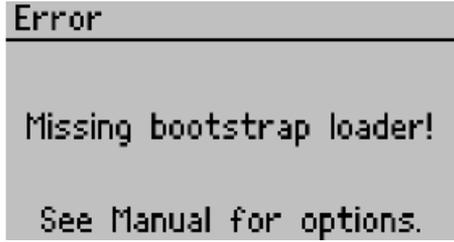
After replacing batteries,
press ENTER to continue.
```

SOLUTION:

This screen will only be displayed when you try to erase the data memory when the batteries are critically low. Replace the batteries and then press ENTER when powered back on to exit this screen.

8. PROBLEM:

Message on screen displays the following:

A screenshot of a device screen showing an error message. The word "Error" is at the top in a bold, black font. Below it, the text "Missing bootstrap loader!" is displayed in a monospaced font. At the bottom, it says "See Manual for options." in the same monospaced font.

```
Error
-----
Missing bootstrap loader!

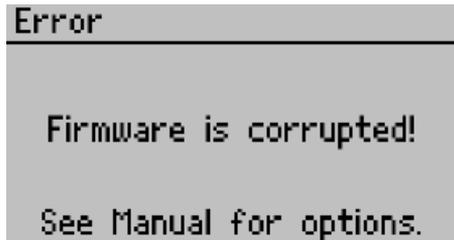
See Manual for options.
```

SOLUTION:

The instrument cannot download new firmware updates. To download new firmware to the LP-80, or to stop this message from displaying, the instrument must be serviced by Decagon.

9. PROBLEM:

Message on screen displays the following:

A screenshot of a device screen showing an error message. The word "Error" is at the top in a bold, black font. Below it, the text "Firmware is corrupted!" is displayed in a monospaced font. At the bottom, it says "See Manual for options." in the same monospaced font.

```
Error
-----
Firmware is corrupted!

See Manual for options.
```

SOLUTION:

This screen means that your firmware was not loaded properly, and that an update is needed. (The firmware for the LP80 is user-upgradeable.) To obtain this, visit Decagon's website to see if new updates are available; if not, contact Decagon for the newest firmware version. Note: You will lose any saved data records when you install the new firmware. Therefore, download any data you wish to save before re-loading the new firmware. If this is not an option, contact Decagon for further help. To obtain new firmware for your LP80, see the section on "Check for Firmware Updates" in Chapter 4 for more information.

10. PROBLEM:

Message on screen displays the following:

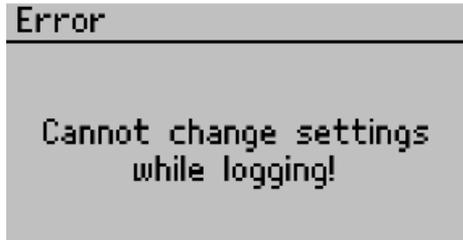


Figure 12: May also say “reading”

SOLUTION:

Anytime a reading or logging mode is activated (indicated by a busy icon in the upper left hand corner of the PAR or Log menu), configuration settings are locked to prevent inconsistent data from being saved. To change settings, navigate to the PAR or Log menu and escape out of the active reading. Once the new settings are changed, you can then begin a new reading.

11. PROBLEM:

Message on screen displays the following:

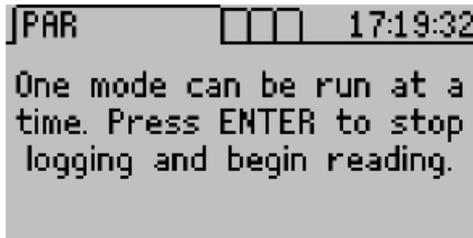


Figure 13: May also happen on the log menu

SOLUTION:

Only one mode may be running at a time. If you are logging, this message will appear on the PAR screen. If you are taking a reading

on the PAR screen, a message similar to this will appear in the Log menu. Press ENTER to stop the currently running mode or press MENU to proceed to the next menu without changing the mode.

12. PROBLEM:

Message on screen displays the following:

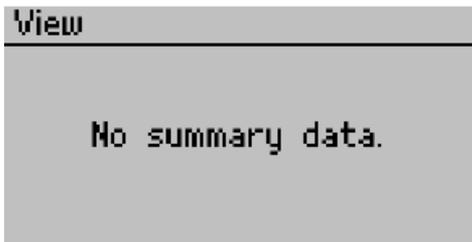


SOLUTION:

This message indicates that the data memory is full. You may continue to view the real-time PAR values, configuration settings, and previously stored data while the memory is full. No more data records can be saved until the data records stored in memory are downloaded to the computer and erased from the LP-80.

13. PROBLEM:

Message on screen displays the following:



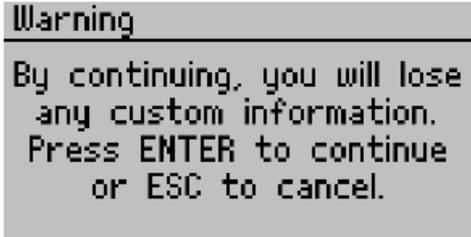
SOLUTION:

The view menu only allows you to view summary records. If you have not saved any records or if you only have saved above and below records, this message will appear when trying to view or download

data. To make this message go away, save a summary record on the PAR or Log menu by pressing ENTER.

14. PROBLEM:

Message on screen displays the following:

A screenshot of a warning message displayed on a screen. The text is as follows:

```
Warning
-----
By continuing, you will lose
any custom information.
Press ENTER to continue
or ESC to cancel.
```

SOLUTION:

If you are trying to change a country or city location and you have custom configured the longitude, latitude or UTC offset, this message will appear. If you continue it will reset the location information to the default settings for that city. If you press ESC, your custom location settings will be preserved.

15. PROBLEM:

The LP80 Utility tells me the communication port I want to use is not available for selection.

SOLUTION:

Disconnect any other applications that may be using the desired communications port. Additionally, some PDA synchronization software monitors serial communication ports. Disable Microsoft's ActiveSync or Palm's HotSync system software while using the serial port with the LP80 Utility.

16. PROBLEM:

Downloading data stops in the middle with an error message saying the Utility lost connection with the LP80.

SOLUTION:

A noisy serial connection can disrupt the connection between the Utility and the LP80. If this error happens regularly, you can try setting your baud rate lower or increasing the number of times a command is sent to the LP80. Choose the “Communications” tab in Preferences to alter this.

13 Support and Repair

Note: If you purchased your LP-80 from one of our international distributors, please contact them. They will be able to provide you with local support and service.

When encountering problems with your LP-80 (that you unable to resolve with the help of this manual), please contact Decagon Customer Support at support@decagon.com, 509-332-5600 or fax us at 509-332-5158. Please have the serial number and model of the instrument ready.

All products returning to Decagon for servicing must be accompanied with a Return Material Authorization (RMA) number. Prior to shipping the instrument, please contact a Decagon customer support representative to obtain an RMA.

Shipping Directions

The following steps will help to ensure the safe shipping and processing of your AccuPAR LP-80.

1. Ship your LP-80 in its original cardboard box with suspension packaging. If this is not possible, use a box that has at least four inches of space between your instrument and each wall of the box.
2. Place the LP-80 in a plastic bag to avoid disfiguring marks from the packaging.
3. Do not ship the power cord or serial cable.
4. If the original packaging is not available, pack the box moderately tight with packing material (e.g. styrofoam peanuts or bubble wrap), ensuring the instrument is suspended in the packing material.
5. On the RMA form, please verify the ship to and bill to information, contact name, and problem description. If anything is incorrect please contact a Decagon representative.

6. Tape the box in both directions for added support.
7. Include the RMA number in the attention line on the shipping label.

Ship to:

Decagon Devices Inc.

ATTN: RMA (insert your RMA #)

2365 NE Hopkins Court

Pullman, WA 99163

13.1 Repair Costs

Manufacturer defects and instruments within the one-year warranty will be repaired at no charge. Non-warranty repair charges for parts, labor and shipping will be billed to you. An extra fee may be charged for rush work. Decagon will provide an estimated repair cost, if requested.

14 Further Readings

The following is a list of references that offer more detail concerning plant canopy characteristics and research.

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Bonhomme, R., Varlet-Grancher, C. and Chartier, P., (1974). The use of hemispherical photographs for determining the leaf area index of young crops. *Photosynthetica*, 8 (3), pp. 299-301.

Campbell, G.S., (1977). An Introduction to Environmental Physics, Springer-Verlag New York Inc., New York, pp. 159.

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15 Declaration of Conformity

Application of Council Directive:	2004/108/EC and 2011/65/EU
Standards to which conformity is declared:	EN 61326-1:2013 and EN 50581:2012
Manufacturer's Name:	Decagon Devices, Inc 2365 NE Hopkins Ct. Pullman, WA 99163 USA
Type of Equipment:	AccuPAR Linear PAR/LAI Cep- tometer
Model Number:	LP-80
Year of First Manufacture:	2003

This is to certify that the AccuPAR model LP-80, manufactured by Decagon Devices, Inc., a corporation based in Pullman, Washington, USA meets or exceeds the standards for CE compliance as per the Council Directives noted above. All instruments are built at the factory at Decagon and pertinent testing documentation is freely available for verification.

16 Appendix A

16.1 External Sensor Information

The external quantum sensor provided with the AccuPAR model LP-80 is the Apogee SQ110. It is calibrated to provide an output of $5 \mu\text{mol m}^{-2}\text{s}^{-1}$ per mV. This sensor offers good accuracy, however you should be aware of potential sources of error. The biggest error is often caused by small changes in the position of the sensor. The sensor must be exactly horizontal for the most accurate measurements.

Specifications

Output: $5 \mu\text{mol m}^{-2}\text{s}^{-1}$ per mV
Dimensions: 24 mm diameter, 27 mm tall
Cable length: 2 m
Range: 0 to $4000 \mu\text{mol m}^{-2}\text{s}^{-1}$ (full sunlight 2000)
Warranty: 1 year parts and labor.

16.2 Spectral Response

An ideal quantum sensor would give equal emphasis to all photons between 400 and 700 nm and would exclude photons above and below these wavelengths. Quantum sensors, such as the Apogee, that approximate the ideal response with filters are accurate to within $\pm 3\%$ for common light sources. The spectral response of the Apogee sensor is such that it underestimates the 400 to 500 nm wavelengths (blue light), matches in the 550 to 650 nm wavelengths (yellow and orange), and has little sensitivity above 650 nm (red light). Fortunately common light sources are mixtures of colors and many spectral errors offset each other.

Cosine Response

The cosine error for the Apogee external sensor for typical applications is less than 1%.

Long-term stability

The output of all radiation sensors tends to drift over time as the detector ages. The long term shift of the sensor is less than 3% per year. We recommend returning the sensor for recalibration at least every three years.

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