

AccuPAR

Linear PAR/LAI ceptometer

Model PAR-80

Operator's Manual
Version 3.4

Decagon Devices, Inc.

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1. Introduction

Welcome to Decagon's AccuPAR, the leader in linear PAR ceptometers for measuring PAR and LAI. AccuPAR measures Photosynthetically Active Radiation (PAR) in the 400-700 nm waveband, and can invert these readings to give you Leaf Area Index for your plant canopy. This manual is designed to helping you accomplish your research goals, and in understanding how to get the most out of your AccuPAR.

Before You Begin: Registration

When you first turn on your AccuPAR, you will see the following screen:

CALL DECAGON
TO REGISTER
THIS ACCUPAR
1-800-755-2751

followed by:

UP KEY-SHUTOFF REGISTRATION CODE: _ SN#: APXXXX	N
----------------------------------------------------------	---

At this point, you are prompted to enter a registration number before you can operate the instrument. This number is available only from Decagon as part of our registration process. To get the registration number for your instrument, call us at **1-800-755-2751** in the US and Canada, **509-332-2756** international, fax us at **(509) 332-5158** or e-mail us at **accupar@decagon.com**. Provide us with your name, instrument serial number, shipping address (no P.O. boxes), phone and fax numbers. The registration process provides us with your current information so we can contact you for news and upgrades. More importantly, it activates your warranty, and ensures to us that you received your instrument safely, and that it is working properly.

The registration number is only necessary when you first turn on the AccuPAR, and following any time when you upload the operating program (like with an upgrade) to the instrument. For your convenience, write the registration number in the

space provided below for future reference:

Serial Number: AP _____
Registration Number: _____

Customer Service and Tech Support

When contacting us via fax or email, include the following information: Your AccuPAR's serial number, your name, address, phone and fax number, and a description of your problem

Phone:

Call Monday through Friday, between 8 a.m. and 5 p.m. PST.

US and Canada (toll-free): 1-800-755-2751 .

Outside of the US and Canada: **(509) 332-2756.**

Fax:

(509) 332-5158.

E-mail:

accupar@decagon.com.

Warranty

AccuPAR has a one year warranty on parts and labor. It is activated upon the arrival of the instrument at your location.

Seller's Liability

Seller warrants new equipment of its own manufacture against defective workmanship and materials for a period of one year from date of receipt of equipment (the results of ordinary wear and tear, neglect, misuse, accident and excessive deterioration due to corrosion from any cause are not considered to be a defect); but Seller's liability for defective parts shall in no event exceed the furnishing of replacement parts f.o.b. the factory where originally manufactured. Material and equipment covered hereby which is not manufactured by the 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 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.

Repair Instructions

If your AccuPAR needs to be sent in for service or repair, call Decagon at **(509) 332-2756** or **1-800-755-2751** (US and Canada). We will ask you for your address, phone number, and serial number. For non-warranty repairs, we will also ask for a purchase order number, a repair budget, and billing address.

When shipping your instrument back to us, include a document listing the complete shipping address, name and department of the person responsible for the instrument, and (most importantly) a description of the problem. This will better help our technicians and our shipping department to quickly expedite repair on your instrument and ship it back to you.

Pack your AccuPAR carefully. Ship it back in the black carrying case, preferably inside a cardboard box. Ship to:

Decagon Devices Inc.
950 NE Nelson Court
Pullman, WA 99163

Repair Costs:

Manufacturer's defects and instruments under warranty will be repaired at no cost. For non-warranty repairs, costs for parts, labor, and shipping will be billed to you. We have a \$50 minimum charge for repair that takes one hour or less. For repair over one hour the labor rate is \$60/hour.

2. About AccuPAR

AccuPAR is a 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 datalogger and probe. The probe contains 80 independent photodiodes, spaced 1cm apart. The photodiodes measure PAR (Photosynthetically Active Radiation) in the 400-700nm waveband. 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.

Specifications

Operating Environment:

- 0° to 50° C (32°-122° F)
- 100% relative humidity

Probe Length: 80 cm

Number of Photodiodes: 80

Overall Length: 108 cm

Probe Cross-Section: 14mm x 15mm

Microcontroller dimensions: 158 x 95 x 45mm (6.2 x 3.7 x 1.8 in.)

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

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

Minimum Spatial resolution: 1cm

Data Storage Capacity: Internal lithium battery-backed 48K RAM.

Unattended sampling interval: 1 second to 24 hour interval between scans, user selectable range.

Unattended recording interval: records as often as every 30 seconds, for up to 99 scans (or until memory is full).

Instrument weight: 900g (2 pounds)

Data retrieval: Via RS-232 at 9600 baud rate

Operating program: User-upgradable

Keypad: 16-Key full alphanumeric.

Clock: 24-hour ± 1 minute per month.

Date: Calendar, US or international format.

Interface Cable: Combination RS-232 cable and battery-charging jack. Length: 122cm (48in.)

Power: Five AA Nickel-Cadmium cells provided, 4 AA Alkaline cells optional.

RS-232/charger interface connector: Locking 5-pin sealed circular connector with captive protective cap.

External PAR sensor connector: Locking 3-pin sealed circular connector with captive protective cap. BNC adapter provided for connection with an external PAR sensor.

AccuPAR and measurement options

AccuPAR is capable of operating in various modes

in order to give you flexibility in accommodating your research needs. You can collect PAR data in three modes (manual, unattended, or continuous), with the option of using an external PAR sensor (provided by user), if desired. There is also an LAI sampling mode, which takes PAR measurements and inverts them to calculate Leaf Area Index in the field.

There are various options for configuring how you want your AccuPAR to take samples. You can program the instrument to take rapid multiple readings for each press of the button, for example. You can also program it to partition the probe into separate sections (up to 80). This allows you to configure your probe to better reflect the structure of the canopy you are measuring. All of this is done internally, without the need of a separate computer to configure the sampling options. You can set up your instrument in the field, as you're using it and as your sampling needs change.

It is sometimes difficult to make reliable measurements of light in plant canopies due to variation in light levels while taking measurements. For example, underneath a plant canopy, radiation levels can vary from full sun to almost zero over the space of a few centimeters. Therefore, a reliable measurement of average intercepted PAR requires

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many samples at many locations within the canopy. AccuPAR provides an easy way of obtaining the necessary samples for an accurate measurement.

The instrument's probe is placed within the canopy and readings are taken depending on which sampling mode you have selected. When a reading is taken, the AccuPAR's microcontroller scans the sensors and processes the PAR data.

AccuPAR can be operated in environments with temperatures from 0° to 50° C, and in relative humidities of up to 100%. The instrument is shipped with a combination RS-232 interface cable/battery charging jack. This allows for easy connection to a computer and convenient way to charge the 5 NiCad batteries. AccuPAR can also operate using four AA alkaline batteries and one dummy cell, if desired.

Since PAR and LAI are directly related to plant biomass, the AccuPAR is ideal for all kinds of research. Here are some applications in which other researchers are using AccuPAR:

- forest studies
- crop and canopy modeling
- plant pathology studies
- environmental impact studies

- water stress studies
- fertilizer, irrigation, and pesticide efficacy

Components of the AccuPAR system

AccuPAR and its accessories come to you in a durable foam-padded carrying case. As you open the case, you should find the following:

- AccuPAR
- RS-232 Cable
- AC Adapter
- Operator's manual
- 3.5" Firmware diskettes
- 25 to 9-pin connector
- quantum sensor adapter
- #1 Phillips screwdriver

3. Operating the AccuPAR

Turning on the instrument

If you have not already registered your AccuPAR, when you turn on the instrument, you will see the following screen:

```
UP KEY-SHUTOFF
REGISTRATION
CODE: _
SN#: APXXXX      N
```

Refer to chapter one for information on registering your AccuPAR.

After your instrument has been registered, the main menu will appear upon power-up:

```
MAIN MENU
F1: SETUP      F2: READ
F3: DATA      F4: OFF
```

This is the main menu, from which you can select the options you want.

Keyboard Operation

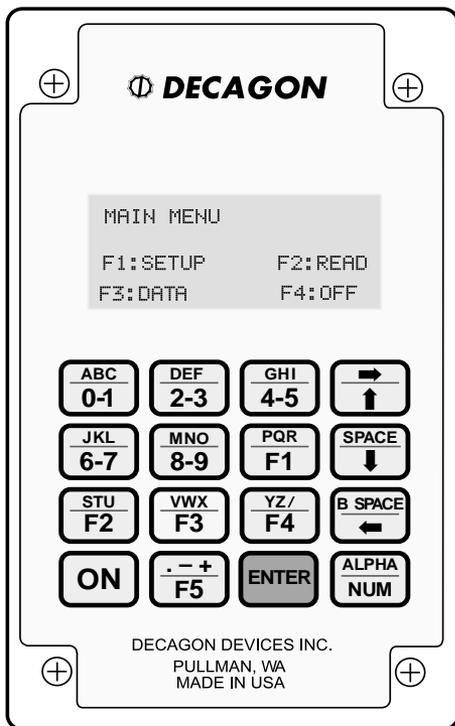


Figure 1: AccuPAR Keypad

The AccuPAR's keypad is a 16-key panel with full alphanumeric capability. Note that each key is divided in half, with the top half in green and the lower half in blue. The green half is activated when the instrument is in ALPHA mode, and the blue

section is active when in the NUM mode.

The ALPHA-NUM key

The ALPHA/NUM (alpha-numeric) key, located in the lower right corner, is a toggle switch to allow you to use both the Alpha and Numeric functions. When you are in a mode wherein you are entering information, there will be either a letter “N” or “A” in the bottom right corner of the screen, indicating either “number” or “alpha” mode. If you are in number mode, when you press any of the keys, the blue functions associated with that key will be entered (either numbers or F- keys). When you press the ALPHA/NUM button, it will toggle to “A,” indicating that it is now in alpha mode, allowing you to enter the green functions associated with the keys (letters, symbols, etc.). If you keep pressing the ALPHA/NUM button, it will toggle between the two modes.

Typing numbers and letters

Numbers are grouped two to a key. Push the key once for the first number, twice for the second. Keep pushing the key to toggle back and forth between the numbers. Similarly, letters are grouped in threes. Push once for the first letter, twice for the second, and three times for the third. If you push a fourth time, you will rotate back to the first letter. When you press a different key, the cursor will

move forward and you can select the next letter. If the number or word you are entering is such that two numbers or characters are next to each other consecutively and are represented by the same key, (e.g., the number 45, the word “bad,” etc.) you can move the cursor to the next space by pressing the ⇒ button.

Note: when typing in numbers, you will need to press the ALPHA/NUM key before using the ⇒ button.

Function Keys

The function keys (F1-F5) are used to select menu options. They can also be used as “macros” to designate preset comments (assigned in the Function Key option of the Setup/System menu).

Arrow Keys

↑ The up arrow is probably the most useful and most used of all the keys on the keypad. It allows you to move back to previous menus from your current screen, until you ultimately come to the main menu.

⇐ ⇒ The left and right directional arrows allow the cursor to move back and forth without having to overwrite what you have written.

↑ ↓ The up and down arrows allow you to scroll

through your saved data when you are in the VIEW DATA option of the VIEW menu.

The SPACE key allows you to move the cursor forward one position, and the B SPACE key backs up and erases one character.

4. Uses and Definitions

PAR Sampling

AccuPAR can sample intercepted PAR in any plant canopy. PAR (photosynthetically active radiation) is defined as the radiation in the 400 to 700 nanometer waveband. It represents the portion of the spectrum which plants use for photosynthesis (refer to Appendix A for spectral and cosine response information). AccuPAR offers various options for PAR sampling, including manual, unattended, or continuous modes. Intercepted PAR data can be used for determining important parameters of canopy structure and for the calculation of LAI, using inversion equations. 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 when performing gap fraction analysis.

Unattended

AccuPAR can be set up to collect PAR data unattended. This option is used to monitor the

amount of PAR available to a canopy over a period of time. It is also often used in canopies to determine how gap fraction changes as the sun's zenith angle changes. The gap fraction of a canopy refers to the fraction of the area under the canopy that is covered by sunflecks. Sunfleck or gap fraction measurements at several sun angles are helpful in determining other canopy characteristics. After gap fraction data has been collected, the gap fraction or canopy cover can be calculated for any sun angle or projection into the canopy.

Continuous

AccuPAR may be used in the continuous mode in order to constantly monitor the PAR condition of your canopy. This is useful in determining general trends in PAR variation within a canopy at different locations, and in monitoring how canopy light conditions change over a short period of time.

LAI Sampling

AccuPAR calculates Leaf Area Index in the field by using PAR samples. LAI is a very important canopy measurement; it is the area of leaves per unit area of soil surface. To determine LAI with the AccuPAR, you need the zenith angle, a fractional beam measurement, and a leaf area distribution parameter (also known as x .) AccuPAR automatically calculates the zenith angle, prompts you for the fractional

beam reading, and requires you to input a value for x . When you are in the LAI sampling mode, you have a great amount of flexibility in the ways a canopy can be measured. The instrument can be programmed to give you the average LAI of all your sample plots, as well as the LAI of each particular plot, enabling you to see the changes in LAI throughout the entire canopy.

External Sensor

An external PAR sensor can be used with the AccuPAR in order to give you simultaneous above and below canopy PAR measurements. This is very 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. AccuPAR can use sensors that provide either a voltage or a current output. To do so, however, it is important to set up the AccuPAR to read the output of your particular sensor, since each one has different calibration constants and requires different dip switch settings within the AccuPAR. Further information on this is given later in the manual. Figure 2 (below) shows the pinout on AccuPAR for connection with an external PAR sensor.

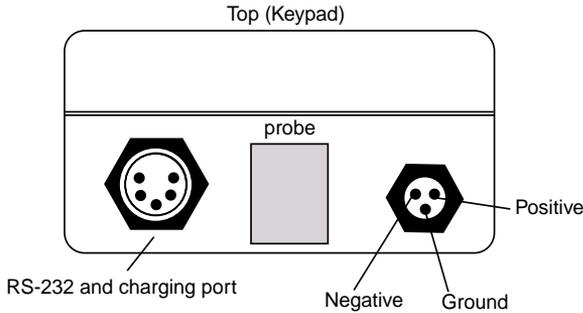


Figure 2: AccuPAR ports

Zenith Angle

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, or you can measure it directly and input it manually. When PAR sampling, you have the option of finding the zenith angle; when LAI sampling, a zenith angle value is required. AccuPAR allows you to enter zenith angle data manually, or it can automatically calculate it for you. AccuPAR can automatically calculate your zenith angle after you correctly set the longitude, latitude, date, and time of day in the setup menu. Once these variables have been

correctly put in, AccuPAR can automatically calculate the zenith angle without further input. If you wish to calculate the zenith angle manually, refer to Chapter 9 of this manual.

Fraction of Beam Radiation (F_b)

Fractional beam radiation is the amount of beam radiation coming directly from the sun, distinguished from ambient (diffuse) radiation. AccuPAR requires a fractional beam radiation measurement before any LAI sampling can be made. The instrument does this by comparing measurements of total available PAR with measurements of diffuse radiation. Directions on performing this function are given in Chapter 7.

Leaf Distribution Parameter (x)

Leaf Distribution Parameter (also known as Chi, or x) refers to the distribution and orientation of leaves within a canopy. The parameter x is the ratio of the length of the horizontal to the vertical axis of the spheroid described by the canopy. It can 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 x is 1.0, which assumes the canopy distribution to be spherical in nature. Onions are good example of a strongly vertical

crop. For onions, x would be about 0.7. On the other extreme, strawberries, a crop with a strongly horizontal nature, would have a x value of about 3.

x is a very important factor when calculating LAI, since it determines the amount of PAR which will be intercepted by a canopy at a given zenith angle. For example, when the zenith is small (around 0°), the strawberries will intercept PAR with all or most of their leaf area, whereas onions at the same zenith angle will intercept very little PAR. On the other hand, as the sun moves to greater zenith angles (80° , for example), the onions will intercept PAR with all or most of their leaf area, and the strawberries will intercept very little. This is most critical on sunny days, where most of the radiation is direct beam from the sun. The following table shows some typical x values for certain crops.

Tau (τ)

Tau is a variable in the LAI inversion equations. It is defined as the ratio of below canopy PAR measurements to the above canopy PAR value. It is measured automatically by the instrument, based upon the PAR readings you make. Further explanation of its significance is given in Chapter 9.

Table 1: typical x values

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

5. Menus

When you turn on the AccuPAR, you will always come to the following base menu:

MAIN MENU	
F1: SETUP	F2: READ
F3: DATA	F4: OFF

F1: SETUP

SETUP	
F1: SYSTEM	
F4: SENSOR	

The setup menu gives you two options: System and Sensor. “System” will allow you to set up your AccuPAR with the correct time and date. “Sensor” will allow you to set up the way you want the AccuPAR to sample, set up an external point sensor, or set up information for automatic calculation of zenith angle.

F2: READ

F1: LAI SAMPLING
F2: PAR SAMPLING
F3: UNATTENDED
F4: CONTINUOUS

The **READ** menu allows you to choose which type of sampling you want to make.

The **F1: LAI Sampling** option allows is used to measure the LAI of your canopy using PAR measurements. It also allows you to make the other necessary measurements in the field before you begin sampling.

The **F2: PAR Sampling** option allows you to make direct above and below canopy PAR measurements. These measurements can be done with or without an external point sensor.

The **F3: Unattended** option allows you to log PAR data unattended for an extended period of time. You can program the sampling interval, the number of samples to average and store, and when to turn on and turn off. It also has the option of a night-time shutdown/wake-up function, if you want it to sample over the period of a few days.

The **F4: Continuous** option reads and displays PAR continuously, giving you a real-time reading of the actual PAR conditions as you move to different parts of the plant canopy.

F3: DATA

DATA	40947
F1:	DOWNLOAD
F2:	CLEAR DATA
F3:	VIEW DATA

The **DATA** menu allows you to interface with your computer for downloading, and allows you to view or clear the stored data that you have in memory.

F4: OFF

This option will turn off the instrument. All data that has been stored inside AccuPAR's memory, including your AccuPAR's current sampling configuration, will be maintained while the power is off.

6. F1: SETUP



As mentioned before, this menu will allow you to set up and configure your AccuPAR. You have two options in this menu— F1: System and F4: Sensor.



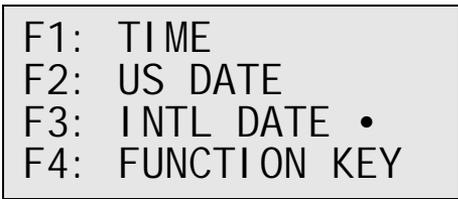
SETUP

F1: SYSTEM

F4: SENSOR

F1: System

This is a very important menu. In order to calculate zenith angle correctly, the time and date must be accurately entered for your area. When you press F1: SYSTEM, the following screen will appear:



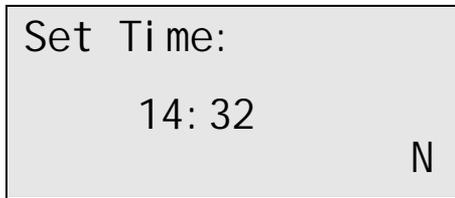
F1: TIME

F2: US DATE

F3: INTL DATE •

F4: FUNCTION KEY

Setting the Time: F1: TIME

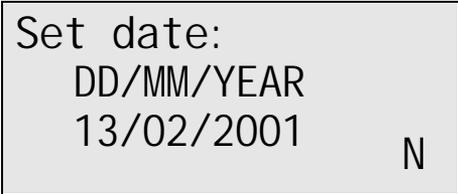


Use this option to set the instrument to your local solar time. Use the up and down arrows to change the number value, and the left arrow to change the position of the cursor between hours and minutes. Note that it is in 24-hour format (also known as military format), so make sure not to accidentally input 16:00 as 4:00 if you are accustomed to the a.m./p.m. format. Generally, time zones are 15° wide (+7.5 to -7.5 degrees wide on either side of a standard meridian), but this varies depending on such things as political boundaries and daylight savings time. In order for your AccuPAR to correctly determine solar zenith angle, time should be entered as determined from the standard meridian. Do not use time changes from daylight savings or political boundaries. If you are unsure, check an atlas to find your standard meridian.

When you have properly set the time, press ENTER to exit this menu.

Setting the Date: F2 and F3

You have two options in the setup menu for the date: US or international format. US Format allows you to enter your date in the month/day/year format. The international format allows you to enter your date in the day/month/year format.



```
Set date:
DD/MM/YEAR
13/02/2001      N
```

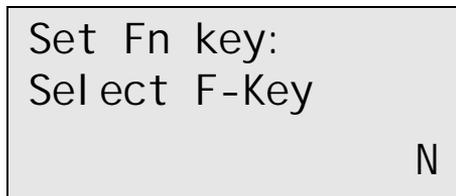
In this illustration, we have international format selected. Use the up and down arrows to change the number values, and the left arrow to move the cursor between the month, day, and year. When you have correctly entered the date, press ENTER to exit this menu. A bullet will appear next to the date mode you have selected.

Function Keys: F4

After each PAR sample you make, you have the option of adding comments, if desired. This is useful if you find yourself repeatedly using the same comment. You may wish to assign that comment to a function key, making it more convenient to comment.

For example, say you are sampling PAR in a certain plot (say “Plot one” and you would like each reading that you store to indicate this, but you don’t want to have to write “PLOT 1” after each measurement is stored. Therefore, you would go into the Function Keys option in the Setup/System menu, and you assign the words “Plot 1” to a function key (say F1, for example). Thereafter, all you would need to do is press the F1 button when the comment prompt appears in the PAR and LAI sampling menus.

To program the function key, press F4: Function Keys. The following screen will appear:



Set Fn key:
Select F-Key
N

At this point, enter the function that you wish to use as your macro. Any of the five function keys may be used. For this illustration we’ll use F1. The following

screen will then appear:

Set F1 Key: Enter Macro: —	A
----------------------------------	---

Type in your desired comment to associate with this function key and then press ENTER. Each comment may be up to 15 characters long. The key will be programmed and then it will take you back to the main menu. Remember that the keys are each assigned three alphabetical letters, so you must sometimes press the key assigned to the letter you want multiple times until the right letter comes up. Use the SPACE key to advance the cursor.

Caution!:

If you already have a comment assigned to this function key, it will not be displayed here. Therefore, if you don't wish to overwrite the current comment (if any) that is assigned to this key, use the ↑ key to escape this menu and use a different F-key.

F4: SENSOR

Use this menu to configure how you want AccuPAR to make PAR samples, to set up your zenith angle calculation, and to configure an external point

sensor for use with the AccuPAR.

```
F1: PAR GROUPS
F2: PAR SAMPLE
F3: EXT SENSOR
F4: ZENITH ANGLE
```

F1: PAR GROUPS

This menu will allow you to divide AccuPAR's probe into smaller groups or segments. When you select this option from the SENSOR menu, you will see the following:

```
ENTER NUMBER OF
PAR GROUPS
(80 MAXIMUM)
N=1 N
```

This menu prompts you to enter a value for the number of par groups, or segments, you want to create. The default setting is "1", meaning that all 80 sensors are grouped into one segment, but you may make up to 80 segments. If you change this number, the new value will remain until you change it again. After you have selected the number of groups that you desire, press ENTER and the following screen will

appear:

```
AUTO PARTITION  
OF ENTIRE PROBE?  
F1: YES      F4: NO
```

If you choose “yes,” AccuPAR will program the probe groups by dividing 80 by the number of segments you indicated in the earlier menu. If you have selected a number of segments that does not evenly divide into 80, AccuPAR will add the remaining sensors to the last group. After auto-partitioning the probe, you will be returned to the F4: SENSOR menu.

If you choose “no,” the following screen will appear:

```
ENTER SENSOR  
RANGE OF GROUP 1  
START: STOP  
1:          N
```

When you first enter this menu, the number below “START” will always be “1.” You will notice that the side of the probe is numbered according to the sensor number that corresponds to it. Use this as a guide to enter which sensors you want in each group. After you input the values for a sensor range,

press ENTER and the next sensor range menu will appear. This will continue until you reach the last sensor range, after which you will return to the F4: SENSOR menu. The values you enter here will be stored for future until you change them again.

Tips when manually entering the sensor range:

- Each time you enter the range for a sensor group, you will be brought to the prompt for the next sensor group. However, it is not necessary to start the next group with the next sensor. You can select any sensor as the first sensor in that range.
- When entering sensor ranges, the ranges cannot overlap. If you enter the same sensor number in one range as was input in a previous sensor range, you will get an error message.
- The ↑ arrow key can be used to move back to the SENSOR menu if you wish to exit the sensor range menu. Do this before pressing ENTER if you don't wish to save the configuration.

Why Partition the Probe?

A large source of error in methods for determining LAI comes from the assumption that canopy elements are randomly distributed. Canopies are never truly random in distribution and most exhibit

AccuPAR

F1: SETUP

some degree of clumping. By partitioning the probe into segments, you can better mimic the clumping effects of a canopy. Grouping the sensors along the probe provides a small sampling volume of those elements within a canopy which can be assumed to be randomly distributed. Accurate LAI is determined by collecting data on each group of sensors and then allowing the program to average all LAI results for active groups together.

F2: PAR SAMPLE

ENTER NUMBER OF SAMPLES PER READING: 1 (20 MAX) N

This option allows you to configure how many samples you wish the AccuPAR to make for each reading (each time you press the button). By configuring it to take multiple samples per reading, you enable yourself to take more below-canopy PAR readings without having to press the button each time. It also allows you to get a better value for average below-canopy PAR. Select the number of samples you wish and press ENTER. The

following screen will appear:

```
ENTER TIME DELAY  
BETWEEN SAMPLES.  
DELAY=000mSec  
(500 MAX)           N
```

The value it prompts you for is the length of time you wish for AccuPAR to wait between each sample in a PAR reading. For example, if you have your system configured to take 3 samples per reading, and at this screen you input 500mSec, it will wait 500mSec between each of the three samples when you press the button to read PAR. If you do not want to have any time delay between readings, leave this value as 0 and press ENTER.

F3: EXT SENSOR

Some researchers find it beneficial to use an external sensor to make simultaneous above and below canopy PAR measurements. This saves time, and is especially valuable when PAR sampling in variable light conditions. If you have an external point sensor that you wish to use with the AccuPAR, make sure you know what type it is and have the calibration constants before proceeding in this menu. When you select this option, the following

screen will appear:

```
EXT. POINT SENSOR  
SENSOR TYPE:  
F1:  CURRENT  
F2:  VOLTAGE
```

Select the option that corresponds to your sensor and press ENTER.

F1: CURRENT

```
ENTER SENSOR  
CALIBRATION:  
0.00uA/1000uM  N
```

Enter the calibration constant as calculated for 1000 μ mol of PAR. This value should have been provided by the manufacturer of the external sensor that you are using. The maximum allowable calibration constant is 20 μ A/1000 μ mol. The minimum allowable constant is 3.5 μ A/1000 μ Mols. After you have entered the proper calibration constant, press ENTER.

F2: VOLTAGE

```
ENTER SENSOR  
CALIBRATION:  
0.00mV/1000uM   N
```

Enter the calibration constant as calculated for 1000 μ Mols of PAR. This value should have been provided by the manufacturer of the external sensor that you are using. The maximum allowable calibration constant is 10mV/1000 μ Mols. The minimum allowable constant is 3mV/1000 μ Mols. After you have entered the proper calibration constant, press ENTER. The following menu will appear:

```
PROBE LIMITS ARE  
MAX  $\Delta$  PAR: 2384  
 $\Delta$  PAR RES: 0.59
```

or for a current-type sensor:

```
PROBE LIMITS ARE  
MAX  $\Delta$  PAR: 2520  
 $\Delta$ PAR RES: 0.64
```

The values shown above are arbitrary, and will be

different according to your specific sensor and calibration constant. The first value, MAX Δ PAR, is the maximum amount of PAR that the sensor will read. The second value, Δ PAR resolution, is the maximum PAR resolution. After this screen appears, press ENTER. The following screen will appear:

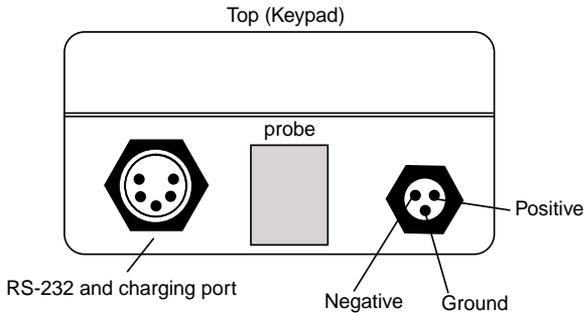
Configure DIP
n=ON f=OFF
DIP SW: 12345678
<ENTER> nnnnfnff

This is a prompt for you to change the DIP Switch settings inside your AccuPAR to match the settings displayed on the screen. To access the DIP Switch, unscrew the AccuPAR case and lift the upper case up and over. The DIP Switch will be a plastic component with eight numbered toggle switches on the face. Change the DIP switch settings by pushing each switch either up (ON) or down (OFF) according to the screen. The DIP switch settings are also located in Appendix C of this manual. After you have set them correctly, carefully screw the case back together and press ENTER. Your settings will become stored and then you will be returned to the SENSOR menu.

External Sensor Adapters

The most common external point sensor that is

used with the AccuPAR is LI-COR's Quantum Sensor. Because of this, we ship a BNC connector/adapter for use with the Quantum Sensor with every AccuPAR. If you have a different type of external sensor, this adapter may not work for you. Below is a pinout illustration for the AccuPAR's external sensor port. You can use this to make your own adapter, or contact Decagon for more assistance.



F4: ZENITH ANGLE

AccuPAR is designed to internally calculate your zenith angle based on your time of day and global location. When you are doing PAR sampling or LAI sampling, the zenith angle will be calculated and stored for each reading you save. When you select this option, the following screen will appear:

```
ZENITH ANGLE
ENTER SITE
LATITUDE
0.00°           N
```

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F1: SETUP

At this screen, enter your latitude in fractions of a degree. For example, if your location is 45° 30' N(45 degrees, 30 minutes North), you would input this as 45.5.

If you are in the Southern Hemisphere, Enter this value as a negative number. This is how AccuPAR is programmed to recognize North- and South-designated degrees. (To input the — symbol, press the ALPHA/NUM key once and press the F5 key).Once you have correctly input your latitude, press ENTER. The following screen will appear:

ZENITH ANGLE
ENTER SITE
LONGITUDE
0.00° N

At this screen, enter your longitude in fractions of a degree, as explained above, and as a value between 1 and 360, moving west from 0° (Greenwich, England). This only affects those located in the Eastern Hemisphere. For example, if your longitude is normally 16°E, you would input this as 344°. When you have correctly input your information, press ENTER and you will be returned to the SENSOR menu.

7. F2: READ

The READ menu allows you to perform your PAR and LAI sampling after you've set up your system correctly. When you select the READ option from the main menu, you will be brought to the following menu:

F1: LAI SAMPLING
F2: PAR SAMPLING
F3: UNATTENDED
F4: CONTINUOUS

F1: LAI SAMPLING

The LAI sampling option in the READ menu allows you to measure the Leaf Area Index of your plant canopy. Using this mode, you will perform the necessary measurements needed for your AccuPAR to make the LAI calculations in the field, and you will make PAR measurements. You can operate with or without an external point sensor, and you can save your data. When you select the LAI sampling

option, the following screen will appear:

```
LAI SAMPLING
SELECT OPTION
F1: FULL PROBE
F2: SEGMENTED
```

This screen asks you to choose between using the full probe, or using your probe in segmented mode, according to how you have it configured in the setup menu. If you choose F2: Segmented, the instrument's operating program will check to see if there are segments configured in the setup menu. If you have not configured any segments and try to use this option, an error message will appear. Choose the option you want, and the following screen will appear:

```
LAI SAMPLING
USE EXTERNAL
POINT SENSOR?
F1: YES      F4: NO
```

As mentioned earlier, AccuPAR can be used with or without an external point sensor. For more information on this, refer to the section titled "F3: EXT. SENSOR" in Chapter 6. Choose the option that

you want and the following screen will appear:

```
LAI SAMPLING
ZENITH ANGLE
F1: AUTO CALC
F4: MANUAL
```

If you have already input your time, date, longitude and latitude in the setup menu, you can press F1: AUTO CALC and AccuPAR will automatically calculate your zenith angle as you take PAR measurements. If you choose F4: MANUAL, you will be prompted to input your zenith angle at the end of each data set. When you have made your selection, the following screen will appear:

```
ENTER LEAF
DISTRIBUTION
PARAMETER
X=1.0
```

Leaf distribution parameter (x) refers to the distribution and orientation of leaves within a canopy. The default value for x is 1.0, which assumes the distribution to be spherical. For more detailed information on x , see the section titled “Leaf Distribution Parameter” in Chapter 4. Either keep the default value or input a separate value and

press ENTER. The following screen will appear:

```
FRAC BEAM CALC  
CLEAR SENSOR 01  
SHADE SENSOR 80  
F4: READ
```

This menu is prompting you to make a Fraction of Beam reading. Fraction of Beam (Fb) refers to the fraction of total radiation that is coming as direct beam from the sun, distinguished from diffuse radiation that is reflected from clouds, leaves, the ground, etc. This is an essential variable in LAI calculation. To perform this calculation, move the instrument to a clear, open location. Shade sensor 80 by placing a 10cm disk (or your hand) about 2 feet (60cm) away from the probe, in the path of the direct beam. If the weather is overcast, there will be no direct beam radiation, so there is no need to shade the sensor. Sensor 1 (the tip of the probe) should be fully exposed to the total available radiation while you are shading sensor 80. When the two sensors are respectively shaded and clear, press F4. If you are not using an external sensor, the

following menu will appear (the LAI CALC menu):

```
LAI PAR SAMPLING
F2: TOFF  F3: FBEAM
F4: PAR SAMPLING
F5: LAI CALC
```

If you are using an external sensor, the following LAI CALC menu will appear:

```
F1: MATCH SENSORS*
F2: TOFF  F3: FBEAM
F4: PAR SAMPLING
F5: LAI CALC
```

The LAI CALC Menu

F1: MATCH SENSORS

When using an external sensor, you want to ensure that the values being read by the point sensor match correctly with the AccuPAR when exposed to identical light levels. Therefore, F1: MATCH SENSORS is used to accomplish this. If you haven't yet matched your sensors before sampling, you will see an asterisk next to the MATCH SENSORS option to remind you. The AccuPAR will match both sensors to account for any variability in sensor response due to sensor calibration or spectral and cosine response that may exist between the two types of sensors. To minimize errors that may be caused by cosine response mismatch, the sensors

should be matched periodically throughout a lengthy sampling session, as the sun's zenith angle changes. When you select this option, the following screen will appear:

PLACE SENSOR 40
NEXT TO ABOVE
CANOPY SENSOR
PRESS F4

As the directions say, place the external sensor next to AccuPAR's sensor number 40, which is the sensor in the middle of the probe. When doing so, make sure they are parallel so they both receive the same amount of light. Press F4. The program will initialize the sensors and then tell you the sensors have been matched. At this point, it will return to the LAI CALC menu.

F2: TOFF

During the course of PAR data collection, you may want to temporarily shut down operation of your AccuPAR without leaving the current menu. This option lets you temporarily quit sampling for LAI and then return to the same data set when you turn your instrument back on. The next time you turn it on after using F2: TOFF, the LAI CALC menu will appear instead of the main menu.

F3: FBEAM

Sometimes while collecting data sets for LAI calculation, the radiation conditions may change, making it necessary to calculate a new value for fractional beam. Do this by choosing F3: FBEAM from the LAI CALC menu. If conditions change during PAR collection, you can recalculate this term at the end of each data set. The most recently-calculated fractional beam value will be used in LAI calculations. Keep in mind that the light conditions must remain stable during each session of PAR collection, or your LAI calculations may be inaccurate. Choosing the FBEAM option will give you the following menu:

```
FRAC BEAM CALC  
CLEAR SENSOR 01  
SHADE SENSOR 80  
F4: READ
```

Follow the directions mentioned earlier in this section on taking a fractional beam reading. Once this is done, you will return to the LAI PAR SAMPLING menu so you can continue.

F4: PAR SAMPLING

As mentioned earlier, AccuPAR requires PAR measurements to make LAI calculations. The size of the data set is affected by the number of probe

segments you have set up (if any), as well as the number of samples you store. If many readings are needed from a large plot or field, it may be better to divide the area into smaller sets to help in record-keeping. You can then enter comments pertaining to each plot. If the area to be measured is small, you may choose to develop only one data set. Regardless of the size of the area to be measured, AccuPAR will record all measurements of PAR and give the average LAI and the average intercepted ratio (τ) of above to below canopy intercepted PAR for all the data sets.

Above-canopy PAR readings are necessary in LAI computation since one of the necessary variables in the LAI equation, " τ ," is the ratio of average below-canopy PAR values to the average above-canopy PAR values. Above-canopy PAR measurements should be taken at the beginning of each data set, or at any time during the measurement process when the level of total available PAR changes. This PAR measurement will be the reference until another above-canopy PAR reading is taken. Above-canopy data can be collected again at any time without affecting previously-recorded data.

—Sampling with an external sensor

If you are using an external PAR sensor to aid you in your measurements, you should have already configured it (see "F3:EXT SENSOR" in Chapter 6)

and matched it for use with the AccuPAR. If it hasn't been set up and matched, and you try to begin PAR sampling, you will get an error message. If you have it properly set up, the following screen will appear when you select this option:

```
F4: PAR SAMPLE
ENTER: AVERAGE
△ XXXX  ▽XXXX #XX
```

To begin sampling, place the external sensor outside the canopy on a level surface. Position the probe where you want within the canopy, and press F4 to take a PAR sample. You may continue taking as many PAR samples as you wish by pressing F4.

—Sampling without an external sensor

If you are not using an external point sensor, when you select F4: PAR SAMPLE you will get the following screen:

```
F1: △ CANOPY PAR
F4: ▽ CANOPY PAR
ENTER: AVERAGE
△ XXXX  ▽XXXX #XX
```

The △ symbol signifies above canopy values, the ▽ symbol signifies below canopy values. The # indicates how many samples you've taken.

To sample, level the probe in a position outside or above the canopy, and press F1 to make an above-canopy PAR reading. You will notice that each time you press F4, the latest PAR values are displayed.

When you have taken sufficient PAR samples, press ENTER. The instrument will now average your PAR values and give you the following screen (the following values are arbitrary):

△	PAR=1750	τ =0.12
▽	PAR=210	L=0.65
F1:	SAVE	F4: COMNT
F2:	DISCARD	

The data is displayed for the data set you just finished. The average above and below PAR values are displayed to the left, and the τ and LAI are displayed on the right. At this point, you are given the choice of saving the data as it is, adding a comment to the data, or discarding it. If you select F1: SAVE, the data will be saved to memory, including the time, date, and zenith angle (if you previously selected auto-calculation), and you will be returned to the PAR SAMPLE menu. If you select F2: DISCARD, all the PAR data you've just taken will be discarded and you will return to the PAR SAMPLE menu. If you select F4: COMT, the

following screen will appear:

```

△ PAR=1750 τ=0. 12
▽ PAR=210 L=0. 65
COMMENT: <ENTER>
_ A
  
```

At the prompt, type in the comment you want and press ENTER. Remember that each key toggles between three letters, so you may need to press a button a few times to get the letter you want. Use the SPACE key to move the cursor to the next space. When you press ENTER, the PAR and LAI data will be saved, along with the time, date, any comments, and zenith angle, if you have selected auto calculation for zenith angle. If you chose manual calculation of zenith angle, the following screen will appear:

```

ENTER ZENITH
ANGLE IN DEGREES
(VERT IS 0 DEG)
ZA=_ ° N
  
```

F5: LAI CALC

At the end of each data set collected in the PAR SAMPLING mode of the LAI SAMPLING function, the following values will be determined and stored for each data set: LAI, τ , average above canopy PAR, average below canopy PAR, zenith angle (Θ),

and any comments you may have added. When you have collected all the data you desire and the above values have been calculated and saved to memory, the F5: LAI CALC function can be used. LAI CALC will store average LAI, average τ , time, date, and comments about the data sets. When you select this function, the following screen will appear (following values are arbitrary):

```
AVG LAI =X. XX
AVG  $\tau$ =X. XX
F1: SAVE      F4: COMT
F2: DI SCARD
```

At this point, you may choose to save the data with or without a comment, or discard the data. If you choose F1: SAVE, the data will be saved to memory and you will be returned to the LAI CALC menu. If you select F4: COMNT, the last two lines of the screen will be replaced by a cursor, and you can enter comments. You will then be returned to the LAI CALC menu. If you choose to discard the data, these values will be discarded and you will be returned to the LAI CALC menu.

F2: PAR SAMPLING

The PAR SAMPLING menu contains functions for collection and storage of PAR data. Each function option will be discussed in order of its appearance

on the display.

Choosing this option will give you the following menu:

```
PAR SAMPLING  
SELECT OPTION  
F1: FULL PROBE  
F4: SEGMENTED
```

This screen asks you to choose between using the full probe, or using your probe in segmented mode, according to how you have it configured in the setup menu. If you choose F2: Segmented, the instrument's operating program will check to see if there are segments configured in the setup menu. If you have not configured any segments and try to use this option, an error message will appear. Choose the option you want, and the following screen will appear:

```
PAR SAMPLING  
USE EXTERNAL  
POINT SENSOR?  
F1: YES    F4: NO
```

As mentioned earlier, AccuPAR can be used with or without an external point sensor. For more information on this, refer to the section titled "F3: EXT. SENSOR" in Chapter 6. If you're not using an

external sensor, the following screen (the PAR SAMPLING menu) will appear:

```
PAR SAMPLING
F2: FRACTION BEAM
F3: ZENITH ANGLE
F4: PAR SAMPLE
```

Or if you are using an external sensor:

```
F1: MATCH SENSORS*
F2: FRACTION BEAM
F3: ZENITH ANGLE
F4: PAR SAMPLE
```

Functions F2: Fraction Beam and F3: Zenith Angle are optional in this menu. Fraction Beam is discussed in detail in Chapters 5 and 8. If you are collecting PAR data over an extended period of time (several hours), the zenith angle will change. F3: Zenith Angle allows you to make zenith angle measurements throughout your sampling session, as the sun's zenith angle changes. If you do not wish to collect fractional beam data or the zenith angle, select F4: PAR SAMPLE.

F4: PAR SAMPLE

The size of each data set is affected by the number of probe segments you have set up (if any), as well as the number of samples you store. If many

readings are needed from a large plot or field, it may be better to divide the area into smaller sets to help in record-keeping. You can then enter notes pertaining to each plot. If the area to be measured is small, you may choose to develop only one data set. Regardless of the size of the area to be measured, AccuPAR will record all measurements of PAR and give the average above and below canopy intercepted PAR for all the data sets.

Sampling with an external sensor

If you are using an external PAR sensor to aid you in your measurements, you should have already configured it (see “F3: EXT SENSOR” in Chapter 6) When using an external sensor, you want to ensure that the values being read by the sensor match correctly with the AccuPAR when exposed to identical light levels. F1: MATCH SENSORS is used to accomplish this. It will match both the external sensor and the AccuPAR’s sensors to account for any variability in response, due to sensor calibration or spectral and cosine response that may exist between the two types of sensors. To minimize errors that may be caused by cosine response difference, the sensors should be matched periodically throughout a lengthy sampling session, as the sun’s zenith angle changes. When you select

this option, the following screen will appear:

```
PLACE SENSOR 40
NEXT TO ABOVE
CANOPY SENSOR
PRESS F4
```

As the directions say, place the external sensor next to AccuPAR's sensor number 40, which is the sensor in the middle of the probe. When doing so, make sure they are parallel so they are both at the same angle relative to the sun. Press F4. The program will initialize the sensors and then tell you the sensors have been matched. Once you have matched the sensors, the following screen will appear:

```
PAR SAMPLING
F4:  $\triangle$  $\nabla$  PAR
ENTER: AVERAGE
 $\triangle$  XXXX  $\nabla$  XXXX #XX
```

To begin sampling, place the external sample outside the canopy on a level surface. Position the probe where you want within the canopy, and press F4 to take a PAR sample. You may continue taking as many PAR samples as you wish by pressing F4. Each time you press F4, an above and below canopy reading will be made and displayed. The current number of samples taken will also be displayed.

Sampling without an external sensor

If you are not using an external point sensor, when you select F4: PAR SAMPLE you will get the following screen:

```
F1: Δ CANOPY PAR
F4: ∇ CANOPY PAR
ENTER: AVERAGE
Δ XXXX ∇ XXXX #XX
```

The Δ symbol signifies above canopy values, the ∇ symbol signifies below canopy values. The # indicates how many samples you've taken.

To sample, level the probe in a position outside or above the canopy, and press F1 to make an above-canopy PAR reading. Next, place the instrument underneath or inside the canopy, keeping the probe level, and press F4. Take several below canopy readings in different locations to get a good representation of the below canopy conditions. You will notice that each time you press F4, the latest PAR values are displayed on the screen.

ENTER: AVERAGE

When you have taken sufficient PAR samples, press ENTER. The instrument will now average your PAR values and give you the following screen (the

following values are arbitrary):

```
AVG ▽ PAR:    235.7
AVG △ PAR:    1769.4
F1: SAVE  F4: COMT
F2: DI SCARD
```

You may choose to save the data with or without comments, or discard the data. If you choose F1: SAVE, the data you've taken will be stored, along with the time and date, and you will return to the PAR SAMPLING menu. If you select F2: DISCARD, any data you have taken will be discarded and you will return to the PAR SAMPLING menu. If you select F4: COMNT, the following screen will appear:

```
AVG ▽ PAR:    235.7
AVG △ PAR:    1769.4
COMMENTS: <ENTER>
```

At the prompt, enter the desired comments and press ENTER. You will then return to the PAR SAMPLING menu.

F3: UNATTENDED

Many applications require an extended period of time to collect PAR data. For this reason, you can use AccuPAR's unattended mode. When you select

this option, the following menu will appear:

```
UNATTENDED PAR
SELECT OPTION
F1: FULL PROBE
F4: SEGMENTED
```

This screen asks you to choose between using the full probe, or using your probe in segmented mode, according to how you have it configured in the setup menu. If you choose F2: Segmented, the instrument's operating program will check to see if there are segments configured in the setup menu. If you have not configured any segments and try to use this option, an error message will appear. Choose the option you want, and the following screen will appear:

```
UNATTENDED PAR
USE EXTERNAL
POINT SENSOR?
F1: YES   F4: NO
```

AccuPAR can be used with an external PAR sensor in this mode, in order to collect simultaneous above and below canopy PAR data. To use an external PAR sensor with this program, it must first be configured in the SETUP menu. Refer to Chapter 6 for more information on this. After selecting your option, the

following screen will appear:

```
UNATTENDED PAR
AUTO CALCULATE
ZENITH ANGLE?
F1: YES   F4: NO
```

If measurement of zenith angle is necessary for your application, AccuPAR can be programmed to calculate and store the zenith angle at each measurement interval in the unattended mode. If selected, AccuPAR will calculate the zenith angle of the sun using the time, date and site location previously entered in the SETUP Menu. Choosing either option will produce the following menu:

```
ENTER START TIME

HR: MIN - 15:
                                     N
```

Using the ↑ and ↓ arrows, enter the time that you wish the unattended sampling session to start. Press ENTER to move to the minutes side. The current hour and minute is displayed as the default value. Keep in mind that time should be entered in 24-hour format, determined from your standard meridian, not necessarily your standard time zone. Time zones may be affected by political boundaries. Also, do not incorporate time changes such as

daylight savings (if applicable). After you enter the start time, press ENTER. A date line will appear below it, displaying the current date. If you wish to keep this date, press ENTER. If not, change the date by using the ↑ and ↓ arrows as above. Press ENTER. The following menu will appear:

```
ENTER STOP TIME  
  
HR: MI N - 0:  
  
N
```

Enter the unattended session's stop time in the same way. Again, a date line will appear below the time line for you to enter the date you wish to stop collecting PAR data. After entering the stop date, press ENTER. The following screen will appear:

```
ENTER SAMPLING  
INTERVAL:  
HR: MI N: SEC  
0 : 00: 00 N
```

Enter the length of time that you want the program to wait between each sample, and press ENTER. The minimum interval between samples that you can enter is 30 seconds. The following menu will

appear:

```
ENTER NUMBER OF  
SAMPLES AVERAGED  
IN DATA SET:  
N=1                N
```

At this screen, enter the number of samples that you want the instrument to average together and store at a time. For example, if you put “5” in at the prompt, it will take 5 readings, average them and store the value, take 5 more samples, average them, etc. If you have chosen to have the instrument calculate zenith angle automatically, it will be calculated at the time the samples are averaged and stored. Do not specify such a large number of samples that the time they encompass makes a zenith angle measurement erroneous. After you enter the number you want, press ENTER. The following menu will appear:

```
NIGHT-TIME  
SHUTDOWN?  
  
F1: YES    F4: NO
```

If you want to do unattended sampling over a period of a few days, but don't wish for your AccuPAR to take samples during the night, you will want to use the night-time shutdown function.

Select F1: Yes and the following screen will appear:

```
NI GHT SHUTDOWN
      HR: MIN
SLEEP: 0 :
WAKE  :   :      N
```

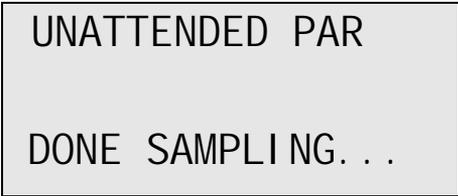
Enter the time you want it to shut down for the night, and when you want it to “wake up” and resume PAR sampling. Then press ENTER. Again, remember to enter the correct standard local time for these values. After you press ENTER, the AccuPAR will enter the unattended mode and will operate according how you set it up. The next screen will appear on the display for about 30 seconds and then the display will disappear. While the AccuPAR is sampling in unattended mode, you can check the status of the measurements by pressing the ON key. The display will come up and show the current time and number of samples taken, as shown:

```
UNATTENDED PAR
TIME: XX: XX: XX
F1:  TERMINATE
READINGS=XXX
```

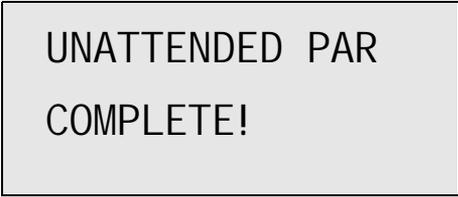
Note that at any time in the unattended sampling mode, you may terminate the session by pressing F1. If you do so, you will be brought back to the

main menu.

When measurements are complete according to how you programmed it, you will see the following screens when you check its status:



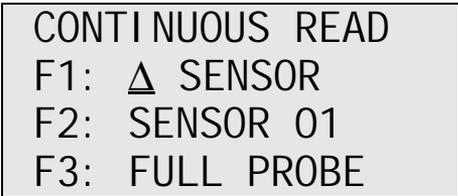
UNATTENDED PAR
DONE SAMPLING. . .



UNATTENDED PAR
COMPLETE!

F4: CONTINUOUS

The following screen will appear:



CONTINUOUS READ
F1: Δ SENSOR
F2: SENSOR 01
F3: FULL PROBE

You may choose to read your external sensor (if you have one), just the probe's end sensor, or the entire probe. Choosing any of the three options will

bring you to the next screen:

```
CONTINUOUS READ
PAR=749.3
FULL PROBE
F4: HOLD/STORE
```

PAR readings will be updated about every 500 milliseconds, and it will show the mode in which you are reading (full probe, external sensor, or end sensor). If you want to hold a reading, press F4. The following menu will appear:

```
CONTINUOUS READ
PAR=751.7
F1: SAVE F4: COMNT
F2: DISCARD
```

You may save this reading with or without a comment, or discard it.

8. F3: DATA

The data menu allows you to view your previously-stored data, download the data to your computer, or delete stored data. When you select F3: DATA from the MAIN MENU, the following screen will appear:

DATA	40947
F1: DOWNLOAD	
F2: CLEAR DATA	
F3: VIEW DATA	

Notice that in the top right corner of the screen, a number is displayed. This number indicates how much data space is left in memory. You can use this to gage how much memory you have left to sample with, or how much space a particular PAR sampling configuration takes up.

F1: DOWNLOAD

Use this menu to download your stored data to a computer. For instructions on how to download data from your AccuPAR to a computer via the RS-232 cable, refer to Chapter 12. When you have properly connected to your computer via the

Acculink program or your computer's terminal program, select F1: DOWNLOAD. The following screen will appear:

```
DATA
  
DOWNLOADING. . .
```

The data will be sent to your computer, and you will then return to the MAIN MENU. Your data is still stored in the AccuPAR, until you clear it.

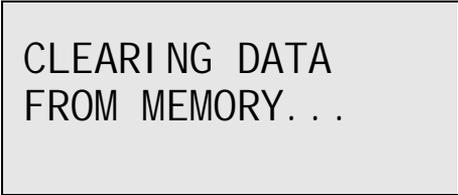
F2: CLEAR DATA

The CLEAR DATA option is used to clear data that you have stored in the AccuPAR's memory. When you choose this option, the following screen will appear:

```
CLEAR DATA
F1: CLEAR NOW
F2: ABORT
```

Choosing F2: ABORT returns you to the main menu, leaving all data still in memory. When you choose

F1: CLEAR NOW, the following screen will appear:



CLEARING DATA
FROM MEMORY. . .

After the data has been cleared, you will be returned to the MAIN MENU.

F3: VIEW DATA

The View Data option allows you to view the data that you've stored to memory.

Data is displayed in the order that it was stored, and is shown one data set at a time. Use the ↓ key or F4 to scroll through data sets, and press ENTER to return to the MAIN MENU.

When viewing data taken with a segmented probe, you can view each line with the ↓ key, or F4 to view the next data set. After scrolling through all the data, you will be returned to the MAIN MENU.

Following is an example of a data set as displayed in the VIEW function. The bracketed numbers next to the PAR values indicate that the reading was done when the probe was segmented, and the number is the segment number in that data set.

Δ PAR 1750.3 ∇ PAR 665.4	#1		Whole Probe as one segment
Δ PAR 1950.4 ∇ PAR 567.8	#2		Whole Probe as one segment
Δ PAR1527.8 ∇ PAR [1] 600.5	#3		Probe partitioned into 4 segments
Δ PAR1530.4 ∇ PAR [2] 598.7	#3		
Δ PAR1526.5 ∇ PAR [3] 599.8	#3		
Δ PAR1531.4 ∇ PAR [4] 566.4	#3		
Δ PAR1775.7 ∇ PAR [1] 467.3	#4		
Δ PAR1770.9 ∇ PAR [2] 463.8	#4		Probe partitioned into 3 segments
Δ PAR1773.8 ∇ PAR [3] 465.3	#4		
Δ PAR1996.8 ∇ PAR 598.4	#5		Whole probe as one segment

9. Measurement Theory

AccuPAR is useful for a number of applications, including the measurement of average and intercepted PAR. From these measurements, LAI can be calculated and other attributes of the canopy structure can be determined.

PAR (photosynthetically active radiation)

PAR is defined as 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.

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:

$$P = efS$$

(equation 1)

where P is the amount of dry matter produced, S is the flux density 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 f and S are monitored over the period of growth of a crop, and P is measured at harvest, e can be determined. The results of experimental treatments or the influence of genetics can be interpreted 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:

$$f = 1 - t - r + tr_s$$

(equation 2)

The last two terms are often ignored and fractional interception is approximated by:

$$f = 1 - t$$

(equation 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. 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

$$r = (1 - t)r_c + tr_s$$

(equation 4)

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

$$f = (1 - t)(1 - r_c)$$

(equation 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 AccuPAR's sensors are sensitive only to radiation in the PAR waveband, equation 3 will generally be accurate for making measurements of intercepted radiation. However, measurement of the other terms needed for equation 2 is simple and will also be explained.

Sampling for Fractional Interception

The functions needed to perform these calculations are available in the PAR SAMPLING mode of the READ Menu. The measurements needed for fractional interception are those from which t , r , and r_s are calculated. 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 from:

$$t = T/S$$

(equation 6)

$$r = R/S$$

(equation 7)

$$r_s = U/T$$

(equation 8)

Assume only t needs to be known. Measure S above the crop canopy. Level AccuPAR above the canopy and select F4:PAR SAMPLE from the PAR SAMPLING Menu. Details concerning this function can be found in chapter 7. The reading you obtain will be the value for S .

Measure T by placing AccuPAR below the plant canopy, being careful to place it below all of the leaves. Try to keep the instrument level. 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, 10 readings and computing the coefficient of variation from:

$$CV = \frac{[(\sum(x_i - x)^2)/(n - 1)]^{\frac{1}{2}}}{S}$$

(equation 9)

where n is the number of samples taken. Any error

in the measurement of t will be CV divided by the square root of the number of samples. Usually, about 10 samples should suffice. Again, use the F4: PAR SAMPLE option available in the PAR SAMPLING Menu to collect this data.

Once you have taken several below PAR readings, you will press ENTER: AVERAGE. The average below canopy PAR value displayed is the T value. The fractional transmission for the canopy, t , can now be calculated from equation 6.

This calculation would normally be generated by a computer program after the data from all of the samples have been sent to the computer. However, it is important to set up some kind of sampling scheme beforehand or keep detailed notes of sampled areas of the field plot or treatment so that they can be compared to stored readings. AccuPAR allows you to enter comments concerning the data collected as it is saved.

To find r , invert AccuPAR at a height of 1-2 meters above the crop canopy. Leveling is not critical for this measurement since the radiation reaching the sensor is not directional. Select F4: PAR SAMPLE from the PAR SAMPLING Menu. The reading you obtain will be the R value. Multiple readings are not necessary since R is not usually variable. Calculate r

from equation 7 using the previously recorded S value.

To find r_s , invert 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 is occurring in the canopy.

Using PAR to determine Leaf Area Index

Some AccuPAR users may want to use sunfleck measurements to determine plant canopy parameters such as leaf area index and leaf angle

distribution. The theory for obtaining LAI and leaf angle distribution from these measurements is widely published. However, the theory is incomplete in some respects and this affects the accuracy of canopy parameters predicted from sunfleck measurements. Errors are greatest when LAI is high and/or when the canopy is tall. The sunfleck inversion fails completely when the sky is overcast and there are no sunflecks.

Our research has shown that an inversion using transmitted PAR is much more reliable under almost all conditions than an inversion using sunfleck fraction. We recommend that this PAR inversion be used instead of the inversion based on sunfleck fraction.

The PAR measured by 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.

The Norman-Jarvis model was used to test and fit two simpler models which are more easily inverted. Equation 10 is a simple light scattering model suggested by Goudriaan (1988). It 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

$$= f_b \exp(-\sqrt{aKL}) + (1 - f_b) \exp(-0.87\sqrt{aL})$$

(equation 10)

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. Assuming an ellipsoidal angle distribution function (Campbell 1986), then

$$K = \frac{(x^2 + \tan^2 \Theta)^{1/2}}{x + 1.744(x + 1.182)^{-0.733}}$$

(equation 11)

where θ is the zenith angle of the sun and x is a leaf angle distribution parameter. When $x=1$, the angle distribution is spherical, and K simplifies to

$$K = \frac{1}{2 \cos \Theta}$$

(equation 12)

John Norman suggested a different equation for

predicting scattered and transmitted PAR.

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

(equation 13)

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 10 is slightly more accurate, but equation 13 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 equation 13 will be used to determine LAI. Inverting equation 13 gives the following:

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

(equation 14)

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 AccuPAR automatically

calculates LAI in the field.

PAR was measured above a barley canopy of 391 μmol ($\mu\text{mol m}^{-2}\text{s}^{-2}$) on an overcast day. The average of several measurements below the canopy was 62 μmol . 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 14, $L = -\ln(0.159)/0.86 = 2.14$. Because the measurement was made 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 μmol was measured above a pea canopy and 80 μmol under the canopy. The fraction of PAR transmitted by the canopy was therefore $\tau = 80/1614 = 0.05$. The solar zenith angle was 30° . The fraction of diffuse radiation was measured by configuring AccuPAR to measure a single end sensor in full sun using the CONTINUOUS function available from the READ Menu. Another reading was taken with the end sensor shaded by a hand one meter from the probe in the path of the direct solar beam. The ratio of the shaded to unshaded readings was 0.119, which is the diffuse PAR fraction. The beam fraction was

$f_b = 1 - f_d = 0.881$. The A value for equation 14 is again 0.86. “x” for the canopy is unknown, but unless leaves have obvious horizontal or vertical tendencies, a spherical distribution can be assumed and x be set equal to 1. (The AccuPAR default value for leaf distribution parameter is 1.0, which is accurate 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 Leaf Area Index. AccuPAR prompts you to enter zenith angle, fractional beam, and leaf angle distribution parameters, and then couples these parameters with collected intercepted PAR data to determine LAI.

Gap Fraction

The sun approximates a point source of radiation which can be utilized on clear days with AccuPAR to obtain information about canopy cover and canopy geometry. The information needed to determine these canopy properties is the fraction of the area under the canopy which is covered by sunflecks, or the gap fraction of the canopy. Gap fraction data can be used to compute LAI in full or single isolated canopies.

Gap fraction data can be evaluated by reviewing PAR data collected with a fully segmented probe which includes measurement data on 80 individual sensors. This configuration can be accomplished through the SETUP Menu. After taking a PAR reading using the functions available in the PAR SAMPLING Menu, the 80 individual sensor readings can be loaded into a spreadsheet for further analysis. This allows you to set a PAR value for threshold that determines which readings are true sunflecks and which readings are attenuated by other canopy elements.

Gap fraction is convenient for determining how PAR interception changes spatially within a canopy, including the size, shape and frequency of sunflecks.

To find gap fraction percentage, the following equation should be used:

$$\text{Gap Fraction} = \frac{\# \text{ of sunflecks}}{80 \text{ total sensors}}(100)=\%$$

(equation 15)

Theory of Sunflecks and Canopy Structure

If 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 sunfleck fraction, which is the beam transmission coefficient, $t(\theta)$, for the canopy. The parameter, θ , is the zenith angle (angle measured from the vertical) of the probe or solar beam. t usually varies with zenith angle. The transmission coefficient for a canopy of randomly placed elements is:

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

(equation 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. τ is sunflecks/100

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:

$$K = \frac{(x^2 + \tan^2 \Theta)^{1/2}}{x + 1.744(x + 1.182)^{-0.733}}$$

(equation 17)

The parameter, x , 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.

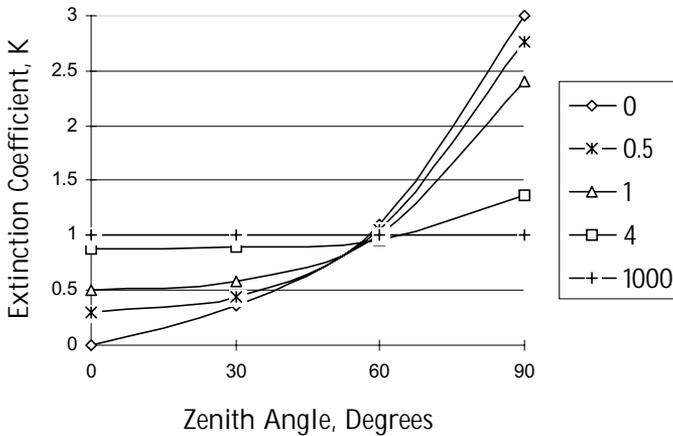


Figure 4: Extinction Coefficient vs. Zenith Angle

Figure 4 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 x), the extinction coefficient, K , is unity for all elevation angles, but as x 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:

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

(equation 18)

If a sunfleck 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 $y = \cos \Theta \ln \tau \Theta$. These are regressed on Θ (in radians), giving

a slope, B and intercept, A . The leaf area index is given by:

$$L = 2(A + B)$$

(equation 19)

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

Example: Sunfleck readings were obtained as follows:

Table 2: Sunfleck 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:

$$A = 1.21$$

$$B = 0.12$$

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

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

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

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

(equation 20)

subject to the constraint, $x > 0$, 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.

Correction of Sunfleck and PAR for Sun Angle

Sunfleck fraction, τ , measured at one zenith angle, can be used to predict sunfleck fraction 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:

$$\frac{\ln \tau_1}{\ln \tau_2} = \frac{K_1}{K_2} = p$$

(equation 21)

so:

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

(equation 22)

We can calculate p from equation 17:

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

(equation 23)

If $\Theta_1 = 0$,

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

If x is not known, assume $x=1$.

Example: From the measurements in the previous example, find the canopy cover. Take $\Theta = 35^\circ$, $\tau = 0.21$. The x value is 0.9.

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

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

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

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

$$f = 1 - \tau_d$$

(equation 24)

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

$$-\ln \tau_d = uL^v$$

(equation 25)

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

$$u = 1 - 0.33 \exp(-0.57x)$$

(equation 26)

$$v = 1 - 0.33 \exp(-0.97x)$$

(equation 27)

The next table shows typical values.

Table 3: values of u and v for equation 25

x	u	v
0.1	0.69	0.73
0.5	0.75	0.82

Table 3: values of u and v for equation 25

x	u	v
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:

$$\tau d = \tau(\Theta)^q$$

(equation 28)

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

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

$$u = 1 - 0.33 \exp(-0.57 \times 0.9) = 0.80$$

$$v = 1 - 0.33 \exp(-0.97 \times 0.9) = 0.87$$

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

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

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

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

Zenith Angle

AccuPAR calculates zenith angle automatically or allows you to enter it manually. AccuPAR's automatic zenith angle calculation is accurate and convenient, and determines zenith angle with no action required from you. However, this function requires that you have entered the latitude and longitude of your site location in the SETUP>SENSOR>ZENITH ANGLE menu. If you do not know this information, you should calculate zenith angle and enter it manually.

Manual Method of Calculation

Zenith angle of the sun is required for inversion of canopy light transmission data to determine leaf area index. Zenith angle can either be calculated from time of day or measured directly.

The zenith angle is the angle the sun makes with respect to a line perpendicular to the earth's surface. For zenith angle, the point directly overhead would be defined as 0° and the horizon defined as 90°. For elevation angle, however, the point directly overhead would be defined as 90°

and the horizon 0° . The simplest method for measuring zenith angle is to construct a device as shown in Figure 5 from two pieces of wood placed at right angles to each other. The top edge of the vertical piece should be 10 centimeters above the top surface of the horizontal piece, and the horizontal piece should be 20 to 30 centimeters long. Mount a bubble level and a ruler on the horizontal piece. To measure zenith angle, level the horizontal piece with the vertical piece perpendicular to the sun azimuth and measure the length of the shadow on the horizontal ruler.

The zenith angle is calculated from:

$$\theta = \arctan(x/10)$$

(equation 29)

where x is the shadow length (cm) and 10 is the height of the vertical piece.

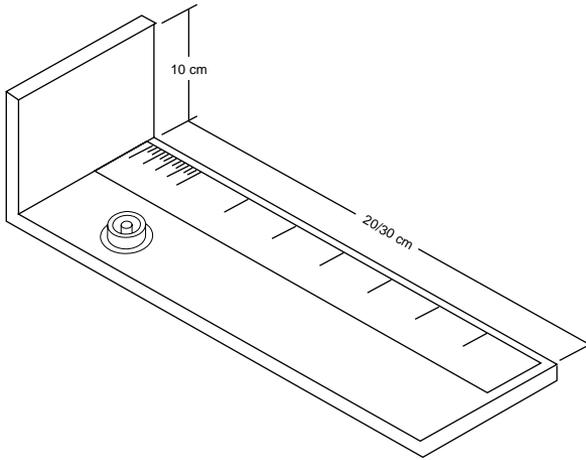


Figure 5: Board/Scale zenith angle device.

Another simple method is to attach a protractor to a small board, mount a bubble level on the board to the level of the protractor, and attach the end of a soda straw with a pin to the center of the protractor so that the straw can pivot across the face of the protractor. To take a reading, level the board with the protractor parallel with the sun azimuth, and adjust the soda straw, watching its shadow on a surface below its end. When light shines through the straw onto the surface, read the angle from the protractor.

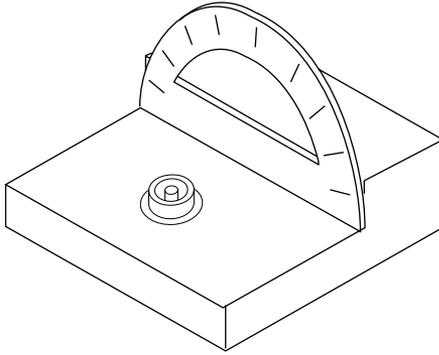


Figure 6: Protractor/Straw zenith angle device.

The formulas for calculating elevation angle are relatively straightforward. The zenith angle is calculated from:

$$\theta = \arccos(\sin L \sin D + \cos L \cos D \cos 0.2618(t - t_o))$$

(equation 30)

where L is the latitude, D is the solar declination, t is the time, and t_o 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 site is easily found in an atlas. Users in the Southern hemisphere should enter latitude as a negative number. Solar declination ranges from +0.409 radians (+23.45°) at summer solstice to -0.409 radians (-23.45°) at winter solstice. It can be

calculated from:

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

(equation 31)

where J is the day of the year. Some values are given in Table 1. The time of solar noon is calculated from:

$$t_o = 12 - LC - ET$$

(equation 32)

where 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° ... 345° . Note that longitude is not given as degrees east or west of 0° , but as fractions of 360° , moving west from 0° . 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.

The Equation of Time is a 15 to 20 minute correction which depends on the day of the year. It

can be calculated from:

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

(equation 33)

where $\phi = (279.575 + 0.986 J)\pi/180$. 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 33 or Table 4, $ET = -0.06$ hours.

Equation 32 then gives $t_o = 12 - 0.19 - (-0.06) = 11.87$.

Declination from Table 4 or Equation 31 is 0.4 radians.

Substituting these values into Equation 30 gives:

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

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

Table 4: Solar Declination and Equation of Time

Date	Day of Year	D in radians	ET hour
Jun 19	200	0.366	-0.103
Jun 29	210	0.331	-0.107
Aug 8	220	0.286	-0.097
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

AccuPAR automatically determines zenith angle using the same theory described in the manual calculation section. To do so, you need to enter the site latitude and longitude as well as time and date in the SETUP Menu. Once these values are entered, AccuPAR determines zenith angle without further

input.

Before PAR sampling or LAI sampling, you will be asked to either select manual or automatic calculation of zenith angle. If you have set it up to do so, AccuPAR will calculate the zenith angle of the sun using the time of day and site location entered in this menu. The sun's zenith angle will then be calculated at the end of each data set and stored.

10. Measurement Tips

Above Canopy (External) Sensor

AccuPAR is equipped with an external sensor port for connection to an above canopy sensor (like Li-Cor's quantum sensor, for example). This 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 an external point sensor to AccuPAR. This insures an accurate measurement of intercepted PAR, especially on days where radiation levels vary rapidly.

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

1. Use a separate datalogger with an attached PAR sensor such as a quantum point 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.

Note: If LAI data for tall canopies is desired, use the intercepted PAR inversions and not the gap fraction theory. Intercepted PAR inversions may be found in Chapter 9.

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.

Clumping in Canopies

When evaluating discontinuous canopies or canopies with definite clumping, AccuPAR can be configured such that its view is restricted to a small

area. This is accomplished by segmenting the probe into unique PAR groups whose size is chosen to match general trends in canopy structure changes. In this way you can gather information that better describes the changes in canopy structure with regard to location. This is done in the Sensor option of the Setup Menu. Refer to chapter 7 for more information on segmenting the probe.

Gap Fraction Analysis

When using AccuPAR for evaluating canopy gap fraction over a variety of zenith angles, the unattended mode of measurement should be used. This ensures that the placement of the instrument does not vary between measurements. Also, make sure to segment the probe into 80 segments. This will give you individual values for each of the probe's 80 sensors, rather than an average of all of them. For information on segmenting the probe, refer to the "Sensor" section of chapter 6.

Beam Fraction Value

When using the LAI sampling mode, it is important to update the fractional beam value when there are changes in cloud cover or radiation levels. Keep in mind that as the sun's zenith angle changes throughout the day, the level of available PAR diminishes as well. Therefore, on a completely sunny day, you may want to make update this

reading every two hours or so. LAI theory depends on an accurate measurement of the diffuse and beam components of PAR.

11. Interfacing with a Computer

AccuPAR transmits and receives data using a Duplex RS-232 serial protocol. The instrument is designed to be used with any commercial serial terminal program. A terminal program allows a personal computer to interact with another serial device, and allows you to collect and transmit data with AccuPAR. Your instrument was shipped with its own terminal program called DecaLink. DecaLink allows you to upload the operating system to and download data from your AccuPAR more easily than other programs, as it is configured to work with AccuPAR directly.

shorting block on one pin

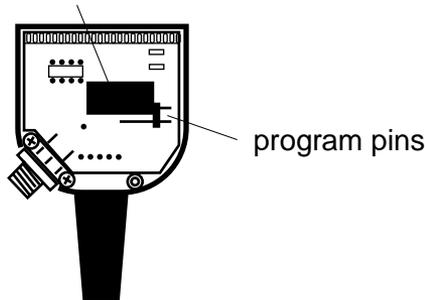


figure 7: Shorting block position

The Shorting Block

Before configuring AccuPAR to receive or transmit data, the shorting block on the RS-232 circuit board must be in the proper place. To check this, open the cover on the cable. You will see a black connector and two pins. This black connector is the shorting block. To download data to a computer and during normal use, the shorting block must be on one pin only. To install the operating program, this shorting block must be on both pins. Having the shorting block on two pins locks the programming function. To move the shorting block, slide it up and then put it back on in the desired position (see figure 7).

Downloading Data to a PC

You can use any terminal program to download AccuPAR's data to your computer. The AccuLink program provided is a simple terminal program that also allows you the ability to easily install the operating software to your AccuPAR, should you ever need to do so. Here are instructions on downloading using some common terminal programs, as well as AccuLink.

Using Terminal for Windows 3.0 and 3.11

1. Connect the RS-232 cable between the AccuPAR and your computer. Remember which COM port

- you are using, and make sure the shorting block is not on both program pins.
2. Double-click on the Accessories icon in Program Manager. Open the icon labeled "Terminal."
 3. Select "Communications" from the Settings menu. Set the baud rate to 9600, and make sure the other settings are as follows: 8 data bits, 1 stop bit, no parity. Select the COM port that you will be using. Click OK.
 4. Select "Receive text file" from the Transfers menu. A pop-up window will appear. Type in a name for this terminal session and click OK.
 5. From the Main Menu of the AccuPAR, select F3: DATA and then press F1: DOWNLOAD. The data will then appear on the computer screen.
 6. When it has finished downloading, click on the "Stop" button on the bottom left corner of the screen. Terminal will save your data to the file-name you indicated earlier.
 7. If you wish, you can open this file in a spreadsheet program and analyze the data further.

Using Hyperterminal for Windows 95

1. Press the Start button and select Programs > Accessories > Hyperterminal and click the Hyperterminal icon.
-

2. At the prompt, choose a name for this program (AccuPAR is a good one) and choose an arbitrary icon above to represent it. In future downloads, you will be able to click on this icon in have it already set up for you to download. Click the OK button.
3. A pop-up menu labeled “Connect To” will appear. Click on the scroll bar on the bottom of the screen labeled “Connect Using” and select the COM Port your RS-232 cable is connected to.
4. A pop-up menu labeled “COM Properties” will appear, showing the port settings for the COM port you selected. Make sure the settings are the following: Bits per second, 9600; 8 databits, no parity, 1 stop bit, and flow control set to hardware. Click OK.
5. Plug your RS-232 cable to the COM port you selected and connect it to your AccuPAR. Make sure the shorting block is not on both program pins in the RS-232’s connector.
6. From the Main Menu of the AccuPAR, select F3: DATA and then press F1: DOWNLOAD. The data will then appear on the computer screen.
7. When it has finished downloading, you can print the data in the terminal session, or save it.

Using DecaLink

Install the DecaLink communications software shipped with your AccuPAR to your hard drive.

1. Click on the Start Menu, then select Programs>DecaLink.
2. DecaLink will ask which COM port you wish to use. Your COM ports will be one or more serial ports located on the back of your computer, typically a 9-pin or 25-pin connector into which you will plug the instrument's RS-232 cable. Select a COM Port that is not currently in use and click OK. You can change the COM Port selected at any time by clicking on the Utility menu and selecting "Connection."
3. Click on the Device Menu and select "AccuPAR."
4. Plug one end of the instrument's cable to the instrument, and the other to the COM port you selected from the Utility>Connection menu. You may need to use the 25-9 pin adapter that was shipped with your instrument, depending on whether your COM port has a 25- or 9-pin configuration. The cable's shorting block should be on only one program pin (the shorting block and program pins are on the cable's serial port circuit board are located at the 25-pin end of the cable, and can be accessed by lifting up on the two tabs that fasten the plastic enclosure and

opening it up (see fig. 7 above). Make sure your cable is connected to the correct COM port.

5. From the Main Menu of your AccuPAR, select F3: DATA and then press F1: DOWNLOAD. All data stored in your instrument's memory is downloaded to the DecaLink terminal screen.
6. To save the data, click on the File Menu and select "Save". When the dialog box appears, name the file and save it as a text file (filename.txt) in a directory of your choice. You can then open this file in a program like Microsoft Excel for further analysis.
7. When you are finished downloading, click on the File Menu and select "Exit."

Before you clear the data from your AccuPAR's memory, check the file you just downloaded. You may want to import the data file to a spreadsheet or text program before you clear AccuPAR's memory.

The format of this file is comma delimited, so you can have the spreadsheet sort it with that delimitation type. If directly printed, the file looks like this:

```
"ABOVE CANOPY PAR",2336.3  
"BELOW CANOPY PAR",2363.2  
"HOURS:MINUTES:SECONDS", "10:40:46"  
"MONTH:DAY:YEAR", "06:03:1995"
```

“COMMENT”, ””

“ABOVE CANOPY PAR”,2336.3

“BELOW CANOPY PAR”,2363.2

“HOURS:MINUTES:SECONDS”,”10:41:32”

“MONTH:DAY:YEAR”,106:03:1995”

“COMMENT”, “HELLO”

“END OF SESSION”

“ABOVE CANOPY PAR”,2336.3

“SEGMENTED PAR”

“BELOW PAR SEGMENT [1]”,2336.3

“BELOW PAR SEGMENT [2]”,2424.0

“BELOW PAR SEGMENT [3]”,2353.5

“BELOW PAR SEGMENT [4]”,2474.3

“BELOW PAR SEGMENT [76]”,2338.3

“BELOW PAR SEGMENT [77]”,2324.3

“BELOW PAR SEGMENT [78]”,2272.2

“BELOW PAR SEGMENT [79]”,2296.7

“BELOW PAR SEGMENT [80]”,2336.3

Headings read across the top. Then data is listed in rows. If this file is imported into a spreadsheet, the data will align in columns under the proper headings.

Installing the Firmware

You can load your AccuPAR's operating system (firmware) to the instrument when updated code

revisions are made available, or if your current firmware installation becomes corrupted for some reason. You can check which version of code your instrument is using by turning on the instrument and looking at the boot-up screens. The newest versions of code for your instrument are available on our website at <http://www.decagon.com/instruments/agdownload.html>, or at our ftp site at <ftp://ftp.decagon.com/firmware/>

****NOTE:** You must complete the full firmware uploading procedures for your instrument to work correctly. If you interrupt the following procedure at any time, your instrument will not function until you restart and completely finished this procedure. You can restart this procedure at any time without damaging the instrument.*

***CAUTION!:** Be aware that installing firmware clears all memory and resets the instrument completely.*

There are two ways to load the firmware. One is by using the DecaLink software program included on the disks that came with your system. The other is by means of a terminal program. Following are directions for both methods of loading the firmware.

Using DecaLink to load Firmware

**NOTE: Before beginning this process make sure you have your product's registration code on hand. Once the upload is finished, it will prompt you for this, and you will not be able to use the instrument until you enter this code. If you don't have the registration code or have lost it, contact Decagon at 1-800-755-2751 or via email at support@decagon.com, and we will give it to you.*

To load the firmware follow these directions:

1. Connect the PC to the instrument with the RS-232 cable. The cable's shorting block should be on both program pins (shorting block and program pins are on the cable's serial port circuit board; see fig. 7).
2. Click on the Device menu and select the AccuPAR.
3. Press the ON button, even if the screen is already on. If the AccuPAR was previously turned off before connecting it to the computer, you will not see the screen appear. This is normal. The processor will still be running.
4. Click on the Utility menu and select "Upload Firmware." You should see a series of commands appear on the screen. If you receive an error message that says, "The AccuPAR is not

responding. Please check the connection, turn it on and try again," press the "ON" button again and then select "Upload Firmware" again from the Utility menu. If the warning appears again, make sure you have selected the COM port that your cable is plugged to, and that the RS232 is connected as described above. Press the ON button and try again. You should see the following commands appear in the terminal window on your computer:

```
DS5001 LOADER VERSION 0.1 COPYRIGHT (C)  
1991 DALLAS SEMICONDUCTOR>
```

```
U  
W MCON FA  
W RPCTL 8B  
F 0 0 FFFF  
W MSL 0  
F 0 0 FFFF  
W MSL 1  
L
```

5. It will now ask for the Cal file, which is located on the diskette sent with your instrument.
**NOTE: Your instrument's cal file is unique to your instrument. If you have more than one AccuPAR, make sure you are using the cal file for that particular instrument, or your data will be incorrect. The cal file's name corresponds to your*

instrument's serial number. The AccuPAR's cal file will begin with AP (e.g. AP1476.hex). Select the correct file and click OK. The cal file will now be uploaded.

6. Next, a dialog box will appear, asking you for the Operating System file. This file is also located on the diskette that was sent with your instrument. As of this writing, it is "REL4_5.hex."
7. Select the correct file and click OK.

The following commands will now appear:

W CRC F1

I

W CRC 00

Z

E

8. Disconnect the RS-232 from the AccuPAR. It should now begin booting up. It will come to the registration screen. Enter the registration code, then you will be brought to the main menu. You are now ready to use your instrument.
9. When you are finished uploading to your instrument, exit the DecaLink program by clicking on the File menu and selecting "Exit." Move the cable's shorting block back to only one pin on the circuit board to allow for future data down-

loads.

Installing Firmware using a Terminal program

If you choose to use a terminal program such as the one in Windows 3.11 or Hyperterminal, follow these directions:

1. Connect the RS-232 cable to the AccuPAR and your computer. Make sure the program pins are shorted with the shorting block.
2. Set the terminal program to the correct COM Port that you are using. Set the terminal program for the highest baud rate possible (38400, 19200, 9600, 2400, or 1200). These baud rates are all supported by AccuPAR. Set the remaining communication parameters as follows: no parity, 8 data bits, and 1 stop bit.
3. Press the AccuPAR's ON key. This is a necessary action to activate the AccuPAR processor. It is possible for the LCD display to be on while the processor is off. Pressing the ON key will start the processor.
4. Move to the computer keyboard and press Enter a few times. The following message should appear on the computer monitor:

```
DS5001 LOADER VERSION 0.1 COPYRIGHT (C)  
1991 DALLAS SEMICONDUCTOR>
```

If this message does not appear, disconnect the RS-232 cable and check to make sure that the shorting block is seated correctly, and that all the correct communication settings are correct. Then reconnect the cable and turn AccuPAR on again.

At the prompt, type the following commands:

```
"U" <ENTER>
"W MCON FA" <ENTER>
"W RPCTL 8B" <ENTER>
"F 0 0 FFFF" <ENTER>
"W MSL 1" <ENTER>
"L" <ENTER>
```

Give the terminal program the command to send an ASCII file (usually located in the program's "Transfer" menu under "Send text file"). Send the file AP**.HEX, (This file's name should correspond to your serial number, like AP1474.hex) This is located on the AccuPAR firmware diskette.

When the file has finished downloading, type the "L" command again and send the .hex file prefixed by "REL," located on the AccuPAR firmware diskette.

Now type the following commands:

```
"W CRC F1" <ENTER>
```

"I" <ENTER>
"W CRC 00" <ENTER>
"Z" <ENTER>
"E" <ENTER>

Remove the RS-232 cable. AccuPAR will reboot and ask for your registration number. Input your registration code and you will be returned to the Main Menu. If you have trouble finding your registration code, refer to Chapter 1 for more information

New Firmware Updates

As mentioned earlier, Decagon may send out new firmware upgrades, which may include changes and enhancements to the AccuPAR program. The current firmware is always posted on our website at www.decagon.com/instruments/agdownload.html. You can also contact us directly in order to receive the latest version via email or mail.

12. Care and Maintenance

Batteries

AccuPAR uses five standard 1.2 volt NiCad batteries. These batteries are economical and convenient, and can be charged and discharged many times before replacement. AccuPAR can also be operated with four AA alkaline batteries; in this instance the fifth position in the battery holder must be replaced with a dummy cell (available at most electronics stores).

Note: Avoid using 5 alkaline batteries in your instrument! It will provide more voltage than the instrument is designed for, and may cause components to fail!

Recharging Batteries

When AccuPAR runs low on battery power, the display will begin to go dim and a message will appear, announcing that the battery power is low. The instrument is provided with a 12VDC regulated, 200mA (outside positive, inside negative) AC adapter for quick recharge of the batteries. Connect the AC adapter plug to the jack on the serial interface cable. The jack is located on one side of

the 25-pin housing. Connect the 5-pin housing of the cable to the five-pin connector on top of the AccuPAR case and then plug the AC adapter into any standard outlet (see figure 8). A full charge requires approximately 10 hours. We recommend that the instrument be charged overnight. To maintain the life of the NiCad batteries, avoid charging them longer than 16 hours. If the batteries will no longer hold a charge, contact Decagon for replacements.

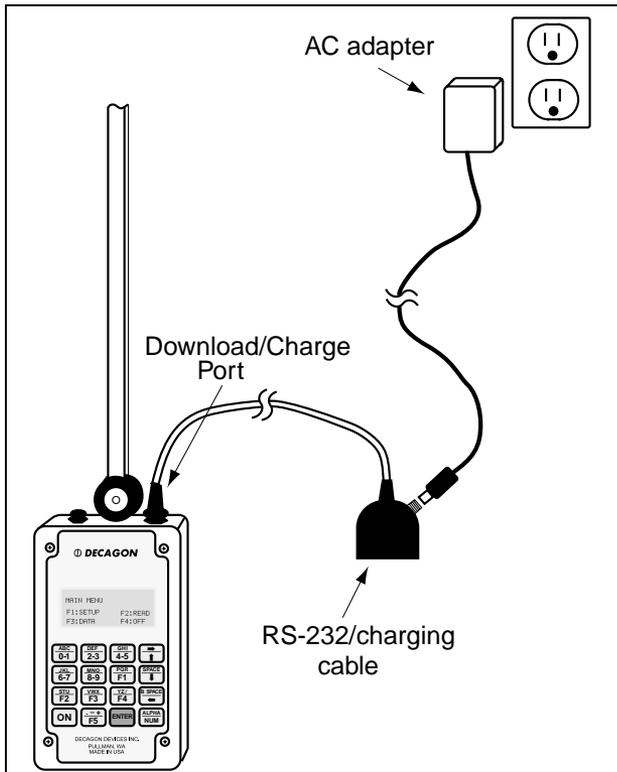


Figure 8: Recharging the batteries

Replacing Batteries

If the NiCad batteries require replacement, remove the four screws in the cover of AccuPAR and lift the cover carefully. Turn the cover over gently to locate and replace the batteries. Be sure to orient them properly; placing them the wrong way in the battery holder can damage the batteries. The battery holders indicate which direction they should be placed.

Note: Data will not be lost when the batteries are replaced. The memory and program sections of AccuPAR are backed up with lithium cells which provide approximately ten years of life. If these cells ever need to be replaced, contact Decagon for service.

Desiccant

When AccuPAR is exposed to fluctuating temperatures, condensation may form inside the instrument. For this reason, desiccant is placed beneath the circuit board inside the microcontroller, and acts as an absorbing agent for any trapped moisture. An indicator card is located in the bottom of the enclosure with the desiccant. Blue indicates that the desiccant is still good, whereas pink indicates that the desiccant needs to be renewed or replaced.

To renew desiccant

- Remove the four screws that secure the cover of the instrument. Gently lift the cover up to expose the packets of desiccant located beneath the circuit board.
- Remove the desiccant packets. Replace them with new packets or renew them by placing them in an oven at 220°F (104°C) for 16 hours.
- Replace the cover and the screws. The humidity indicator card will return to blue after a period of time.

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. Many tissues made from wood fiber will scratch the surface.

Re-calibration

The AccuPAR comes to you factory calibrated. However, as is the case with all electronic components, shifts in sensitivity will occur over time. As a result, we recommend that you periodically send your AccuPAR 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 re-calibration every 2 to 3 years should be adequate. Before sending the instrument in, make sure to contact Decagon via phone or email so we can prepare for its arrival.

General Precautions

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

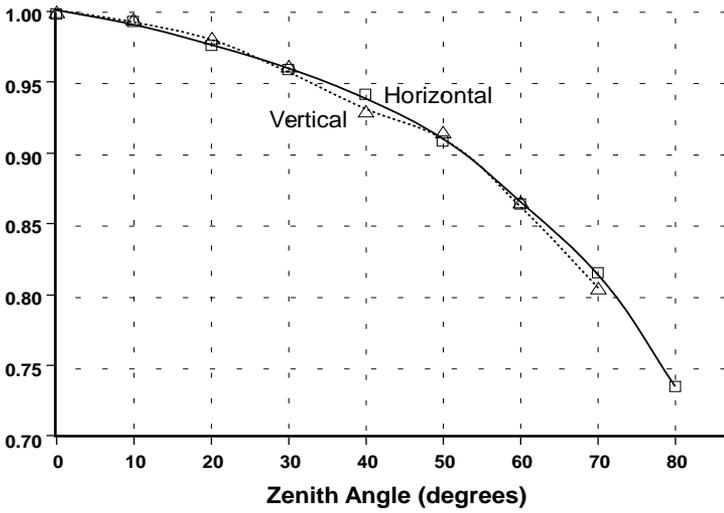
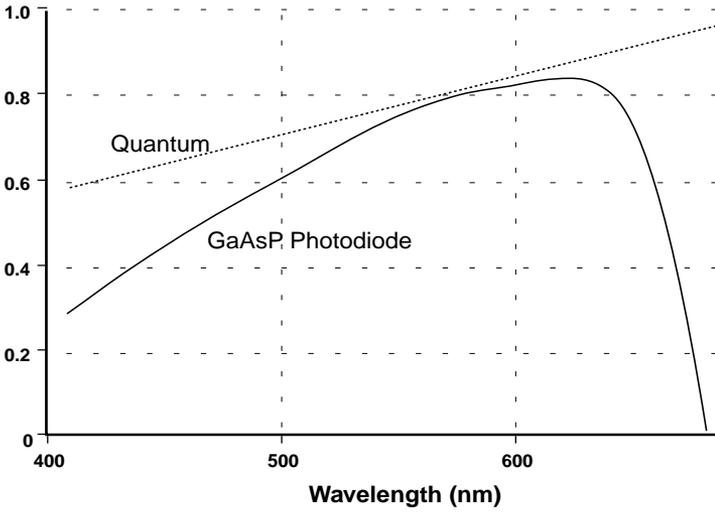
- Keep the probe clean. The accuracy of readings may decline if there is any debris on the probe which prevents light from entering the sensors.
- When taking readings, make sure the instrument is level. This ensures accurate PAR readings.
- Although AccuPAR is splash-proof, don't leave the instrument in water for long periods of time.

Appendix A: Spectral and Cosine Response

AccuPAR is limited in ideal PAR response because of its deficiencies in the blue spectrum. These deficiencies are insignificant when working with normal plant canopy environments and solar radiation. However, AccuPAR should not be used as an absolute PAR sensor when the environment being studied has a significant blue emphasis in its radiation composition. Examples of this blue component would include the measurement of blue skies while the sensors are shaded from direct beam radiation or artificial lighting that contains a strong blue component like metal halide.

The first graph indicates that the spectral response of the photodiodes lies almost entirely within the PAR waveband. The response approximates an ideal quantum response, but drops to zero at about 680 nm rather than 700 nm, and is somewhat low in the blue region. If the radiation is entirely blue skylight, the GaAsP photodiode reads about 20% lower than the PAR sensor, but under normal sun and light,

cloudy skies, or in crop canopies, errors due to limited spectral response are negligible.

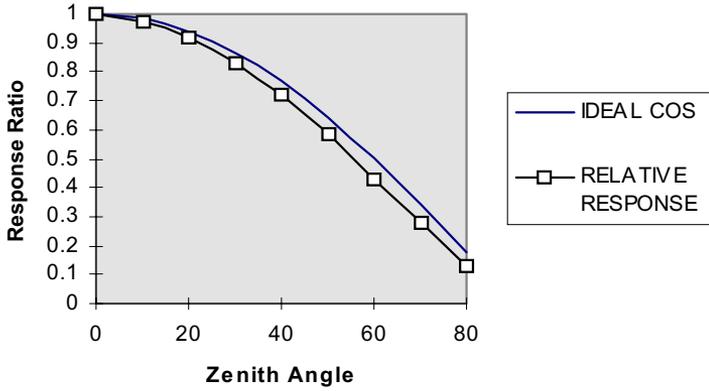


The second graph indicates the response ratio of the sensors as zenith angle changes. The two lines reflect the orientation of the probe with regard to the sun's beam direction (vertical and horizontal). An ideal cosine-corrected sensor would give you the same value as could be calculated using Lambert's cosine law, which is defined as:

$$\phi = \phi_o \cos \theta$$

where ϕ = radiation measured on a horizontal surface, ϕ_o = radiation measured on a surface perpendicular to the sun's rays, and θ = zenith angle. The graph indicates that at a given zenith angle, you can divide the value that the AccuPAR is reading by the sensors' response ratio at that angle, and you should get the ideal cosine response. Upon analysis, the difference is relatively minimal to that of a cosine-corrected sensor:

AccuPAR Probe Characteristics



Appendix B: LAI measurements and Non-Random Distribution

There has been much discussion concerning inversion methods to obtain leaf area index. Since all inversion methods rely on the assumption that elements of a canopy are randomly dispersed in space, errors in the measurement of leaf area index 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's deviation from this random dispersion assumption.

In past studies, LAI has been used 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, was related 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:

$$L_e = \Omega L$$

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 this equation, L_e refers to the actual canopy element orientation. For example, in a randomly dispersed canopy, L would be equal to L_e (figure 1), in an under-dispersed canopy (clumped), L would be greater than L_e (figure 2), and in an over-dispersed canopy, L would be less than L_e (figure 3). 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 interested in the interception of PAR within a canopy, the result of

the inversions given in this manual will be correct in reaching L_e . The leaf or plant area index that is calculated through inversion will be an accurate portrayal of the canopy's 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. Clumping effects can be minimized segmenting AccuPAR's probe in small groups such that the area sampled by group is relatively random. This can also be done by measuring only at certain times of day or at positions within the canopy that directly minimize the clumping effects.

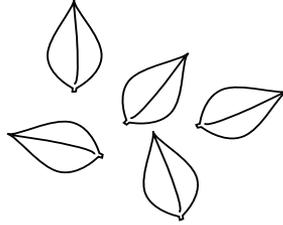
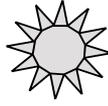


Figure 1: Randomly Dispersed
 $L = L_e$

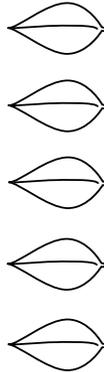


Figure 2: Underdispersed
 $L > L_e$

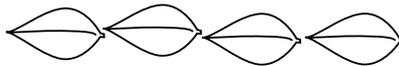


Figure 3: Overdispersed
 $L < L_e$

Appendix C: Dip Switch Settings

The following table shows the correct dip switch settings for various types of external sensors:

Table 5: Dip Switch Settings

External Sensor Type and Scale	1	2	3	4	5	6	7
Current Low Gain 20 μ A/ 1000 μ mol	on	off	off	off	on	off	on
Current High Gain (LiCor) 10mA/ 1000 μ mol	off	off	off	off	on	off	on
Voltage Low Gain 10mV/ 1000 μ mol	on	on	on	on	off	on	off

Table 5: Dip Switch Settings

External Sensor Type and Scale	1	2	3	4	5	6	7
Voltage High Gain 5mV/ 1000 μ mol s	on	off	off	on	off	on	off

Appendix D: Further Readings

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

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Menu Tree



The following page is a fold-out menu tree. It is a quick reference for the AccuPAR's menus and can be helpful in finding which menus accomplish the tasks you're looking for.