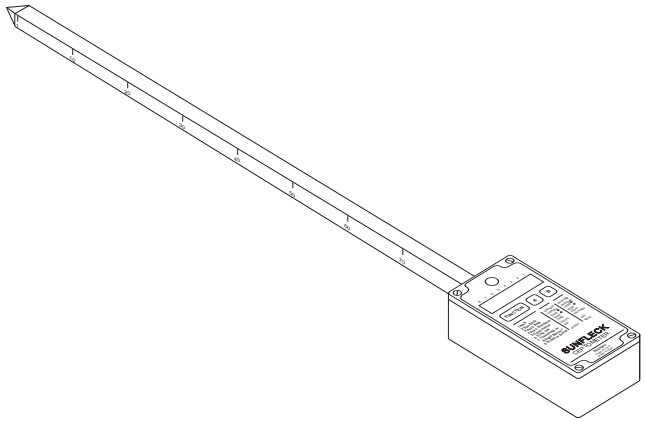


# Sunfleck PAR Ceptometer



Operator's Manual

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## 1. Introduction

The Sunfleck Ceptometer is a battery-operated PAR sensor used for data collection in plant and forestry canopy research. It will enable the user to collect and store radiation data in the 400-700 nm PAR region. The Ceptometer is easy to use and will give accurate results when properly maintained.

### **About This Guide**

Included in this manual are instructions for operation and calibration of the Ceptometer along with guidelines to help you maintain and care for your instrument. Please read all of these instructions before operating the Ceptometer to insure that the instrument performs to its full potential.

### **Warranty**

The Ceptometer has a 30 day satisfaction guarantee and a one year warranty on parts and labor. To validate your warranty, please complete and return the warranty card included in this manual. It is necessary for Decagon to have your current mailing address and telephone number in case we need to send updated product information to you.

### **Customer Service Information**

If you ever have questions concerning the Ceptometer or need assistance regarding your instrument, please call our toll free customer service number between 8 a.m. and 5 p.m. Monday through Friday, Pacific Time.

**1-800-755-2751**

## 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 not to be considered 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 Seller shall not be liable to Buyer for loss, damage or injuries to persons (including death), or to property or things 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.

## 2. About the Ceptometer

The Sunfleck PAR Ceptometer is a battery-operated PAR sensor used for data collection in plant and forestry canopy research. Model SF-80 has 80 independent sensors located in a weather-proof enclosure at one centimeter intervals along a sensor probe. Model SF-40 has 40 sensors located in the same manner. The datalogger is capable of either hand-held push button operation or stand alone measurements of light in plant canopies.

The sensors measure PAR (Photosynthetically Active Radiation) in the 400 to 700 nanometer waveband. Units of measurement for the instrument are  $\mu\text{mol m}^{-2}\text{s}^{-1}$ . The Ceptometer has two main modes of operation. In the first, the average photon flux density of PAR on the probe is measured. In the second, the fraction of the probe in sunflecks is measured and reported. Other modes allow continuous display of readings on a single sensor and stand alone data collection in both modes. The datalogger averages and stores measurements, and dumps them to a computer when field measurements are complete.

The biggest problem with making reliable measurements of light in plant canopies is the extreme light level variation of the measurements. In the PAR waveband, irradiances can vary from full sun to almost zero over the space of a few centimeters, and a reliable measurement of average PAR requires many samples at many locations under the plant canopy. The Ceptometer provides an easy way of obtaining the necessary number of samples for light measurement.

The instrument's 80 sensor probe is inserted into the canopy, and a microprocessor scans the sensors. In the sample mode, the Ceptometer displays a reading ( an average of the readings of all sensors) each time the sample button is pushed, and the user discerns when to average the accumulated readings and store them in memory. In the auto mode, the unattended Ceptometer takes readings every minute, then averages and stores accumulated readings every 30 minutes.

The Sunfleck application of the Ceptometer is an added bonus. Sunflecks are the bright areas under the canopy where direct beam solar radiation penetrates without attenuation by the canopy. The fraction of the ground covered by sunflecks is a useful measurement for determining canopy cover. Sunfleck fraction measurements can also be used with inverse methods to determine important characteristics of canopy structure. These will be discussed later in the manual. Sampling, averaging, and auto mode operation features for the sunfleck fraction mode are similar to those in the PAR mode.

The Ceptometer can be operated in environments with temperatures from  $-30^{\circ}$  to  $50^{\circ}$ C, and relative humidities up to 100%. The instrument comes with a standard RS-232 interface cable for easy connection to a user-provided computer. The Sunfleck provides fast reading and averaging data, and stores over 1,000 data sets. Each stored data set includes time, PAR, and sunfleck percentage regardless of the operating mode.

Biomass production in plant communities is directly related to PAR interception. The Ceptometer provides the user with the measurements needed to interpret field experiments.

Leaf area index and canopy cover can be estimated from measurements of intercepted PAR. The Ceptometer may also aid the user in understanding the importance of sunflecks in the photosynthesis and growth of forest understory plants and crops by recording their occurrence. Other Ceptometer applications include water stress studies, crop and canopy modeling, plant disease and environmental research, and fertilizer and pesticide efficacy studies.



### 3. Getting Started

There are a few things to consider before beginning measurements with the Ceptometer. These consist of installing the batteries, calibrating the instrument, and finding the zenith angle of the sun.

#### **Installing the Batteries**

The Ceptometer's batteries are shipped separate of the instrument and must be installed before operation. To install the batteries, remove the four screws in the corners of the instrument's cover and lift the cover carefully. The battery clips will be visible as the cover is lifted. Place the batteries in the battery clips, making sure to orient them correctly as indicated by the diagrams on the battery clip. Replace the cover and the four screws.

**Note:** When shipping the Ceptometer, always remove the batteries to prevent damage to the battery clips.

When using the Ceptometer in the field, the user may wish to download data to a portable personal computer; rough terrain may cause the batteries to shift and data may be lost.

## Calibration

Each time the batteries are replaced or installed for the first time, the Ceptometer's sensors must be recalibrated. Calibration must be performed in bright, even sunlight on a cloudless day. Shift to function seven by pressing the function key until the display pointer is stationed at function7. Hold down buttons A and B simultaneously and press the function key. The letter "PLL" will appear on the left side of the display. This indicates that the probe has been correctly calibrated. If these letters do not appear, refer to the troubleshooting section of this manual.

**Note:** Be sure to recalibrate the Ceptometer in the H -- mode of function seven and not the ELE mode. If the ELE mode is used, the instrument will not function properly and will need to be recalibrated.

## **Finding the Zenith Angle of the Sun**

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. This section suggests methods for finding the zenith angle of the sun.

### **Direct Measurement**

The zenith angle is the angle the sun makes with respect to a line vertical to the earth's surface. For zenith angle, the point directly overhead would be defined as  $0^\circ$  and the horizon defined as  $90^\circ$ . For elevation angle, the point directly overhead would be defined as  $90^\circ$  and the horizon  $0^\circ$ . The simplest method for measuring zenith angle is to construct a device as shown in Figure 1 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

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

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

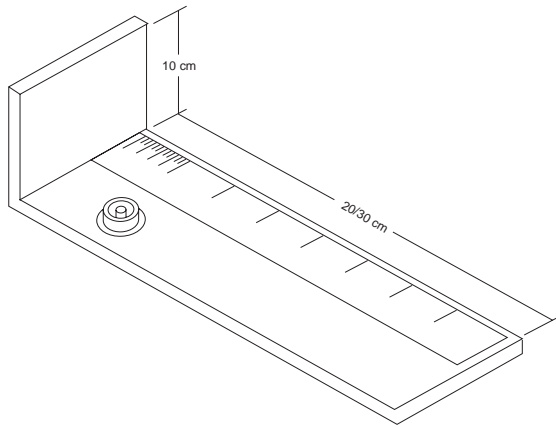


Figure 1. Board/Scale zenith angle device.

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.

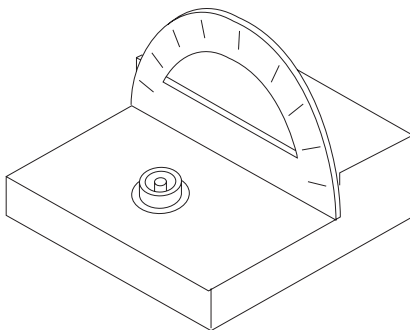


Figure 2. Protractor/Straw zenith angle device.

## Calculation

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

$$\theta = \arccos(\sin L \sin D + \cos L \cos D \cos 0.2618(t-t_0)) \quad (1)$$

where L is the latitude, D is the solar declination, t is the time, and  $t_0$  is the time of solar noon. The earth turns at a rate of 0.2618 radians per hour, so the 0.2618 factor converts hours to radians. Time, t, is in hours (standard local time), ranging from 0 to 24. Latitude of site is easily found in an atlas. Solar declination ranges from +0.409 radians (+23.45 degrees) at summer solstice to -0.409 radians (-23.45 degrees) at winter solstice. It can be calculated from:

$$D = \arcsin\{0.39785 \sin[4.869 + 0.0172 J + 0.03345 \sin(6.224 + 0.0172 J)]\} \quad (2)$$

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

$$t_0 = 12 - LC - ET \quad (3)$$

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 degrees. Generally, time zones run approximately +7.5 to -7.5 degrees either side of a standard meridian, but this varies depending on political boundaries so check an atlas to 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:

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

where  $f = (279.575 + 0.986 J)p/180$ . Some values for ET are given in Table 1.

### 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 degrees or 0.816 radians, and longitude is 117.2 degrees.

The standard meridian is 120 degrees.

The local meridian is 2.8 degrees east of the standard meridian, so  $LC = 2.8/15 = 0.19$  hours.

From equation 4 or Table 1,  $ET = -0.06$  hours.

Equation 3 then gives  $t_0 = 12 - 0.19 - (-0.06) = 11.87$ .

Declination from Table 1 or equation 3 is 0.4 radians.

Substituting these values into equation 1 gives:

$$\begin{aligned} \theta &= \arccos\{\sin(0.816) \sin(0.4) + \cos(0.816) \cos(0.4) \\ &\quad \cos[0.2618(9.75 - 11.87)]\} \\ &= 0.61 \text{ radians or } 34.9 \text{ degrees.} \end{aligned}$$

Table 1. Solar Declination and Equation of Time.

<u>Date</u>	<u>DOY</u>	<u>D-rad</u>	<u>ET-hour</u>
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	-0.170
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
Jul 19	200	0.366	-0.103
Jul 29	210	0.331	-0.107
Aug 8	220	0.286	-0.094
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	0.273
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

## 4. Keyboard Operation

This section is designed to familiarize the user with the Ceptometer's function keys. More in depth discussion of the methods described briefly here can be found later in this chapter.

### Overview of Functions

Function 1:	PAR Measurement; A is the sample button and B averages the readings and sends them to memory.
Function 2:	Sunfleck Measurement; A is the sample button and B averages the readings and sends them to memory.
Function 3:	Views previously stored PAR readings and reads PAR and sunflecks unattended.
Function 4:	Views previously stored sunfleck readings and reads sunflecks and PAR unattended.
Function 5:	Continuously samples PAR and sunflecks and displays readings.
Function 6:	Sets the Sunfleck to the correct time. The A key controls the hours and the B key controls the minutes.
Function 7:	Sets single element mode for point sensor use and sets the sunfleck threshold.
Function 8:	Downloads and erases memory.



The Ceptometer is controlled by the three keys on the cover, located just below the display. The key on the left is the function key and is used to switch functions. Keys A and B, located in the middle and right of the cover respectively, affect the Ceptometer's mode of operation within a function. All of the Ceptometer's modes are mapped out on the keyboard.

When the batteries are installed, the Ceptometer's microprocessor is always on to update the clock, check the keyboard, and maintain the memory, but the display closes after 7 minutes without keyboard operation. Any button may be pressed to activate the display.

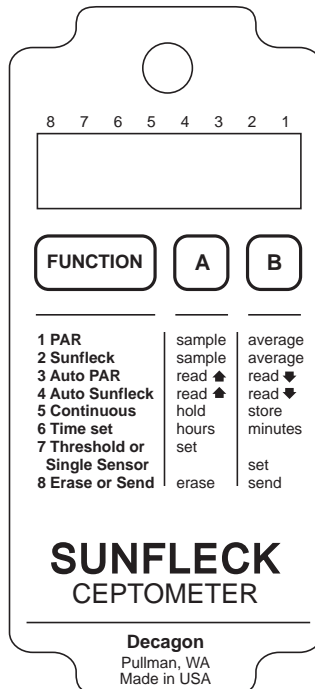


Figure 3. Cover of the Sunfleck Ceptometer.

Any of the eight functions of the Ceptometer may be selected by pressing the function key. A small arrow above the display corresponding indicates the selected function.

**Note:** Regardless of the mode, both Sunfleck and PAR readings are stored in final memory. The functions only alter the displayed readings.

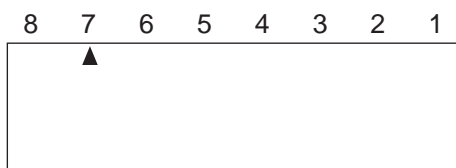


Figure 4. Function Indicator Arrow.

## Function 1: PAR Measurement

Press the function key until the display arrow is pointing to number one. In this mode, the A key is the sample key. Each time this key is pressed, the Ceptometer will take a new PAR reading. The previous readings will be saved in a short-term memory until an average is taken. The sample number is shown on the left side of the display and the PAR measurement is shown on the right.

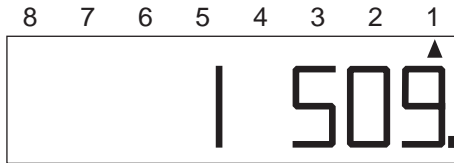


Figure 5. Sample Number and PAR Measurement.

When the B key is pressed, all the accumulated readings will be averaged and the average PAR will be displayed.

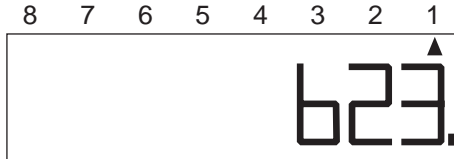


Figure 6. Average PAR.

Pressing the B key a second time will store the average reading in memory. Pressing the A key clears all readings and resets the sample counter. If the A key is pressed before the average reading is stored in memory, the average will be erased.

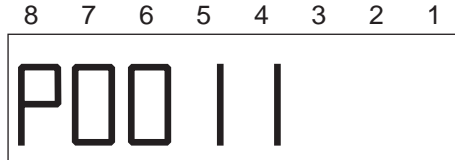


Figure 7. Memory Indicator: Indicates 11 readings stored in memory.

## Function 2: Sunfleck Measurement

Function two is similar to function one, but the number appearing on the right side of the display is the sunfleck fraction. Sunfleck fraction is given as a percentage of the sensors exposed to a radiation level greater than the set threshold. For a more detailed discussion of sunfleck fraction, please refer to page 43 of this manual. The A key is the sample key. The B key averages the readings and sends the averaged reading to memory. Before making sunfleck fraction measurements, a threshold will need to be set. Refer to function seven.

**Function 3: Unattended PAR Measurement and Display of PAR Memory.**

This function displays previously stored PAR readings and measures PAR unattended. Stored readings can be read by pressing either the A or B keys. The A key displays progressively earlier readings while the B key displays progressively later readings. The readings are shown on the right of the display and the time of sampling is displayed on the left.

To begin the unattended reading mode, press the A and B keys simultaneously. The Ceptometer will display the auto mode indicator. (Refer to Figure 9). Every minute, the instrument will automatically sample PAR and sunflecks, but the display will only show PAR. Function 4 is identical to function 3 and will only show sunflecks. Each half hour, the thirty samples will be averaged and stored in memory. The Ceptometer will remain in automatic mode until either the A or B key is pressed.

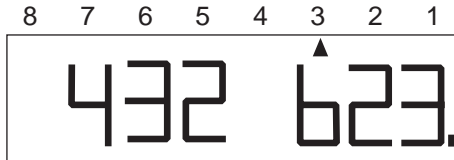


Figure 8. Time and Stored Reading.

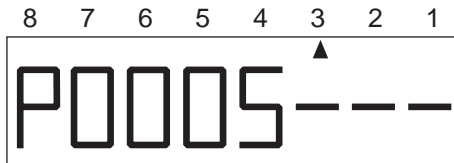


Figure 9. Unattended PAR Indicator.

**Function 4: Unattended Sunfleck Measurement and Display of Sunfleck Memory**

Function four displays previously stored sunfleck readings and measures sunflecks unattended. This function is similar to function three and the keys are used in the same way. As in function two, a threshold should be set before sunfleck measurements are taken. Refer to function seven.

**Function 5: Continuous Sunfleck and PAR Readings**

Function five continuously samples both PAR and Sunfleck and displays the readings. The PAR measurement is shown on the right of the display and the sunfleck measurement is shown on the left. As measurement conditions change, so will the readings, but they may be held by pressing the A key. Pressing the A key again will release the values. Held values can be sent to memory by pressing the B key and stored values can then be viewed by using functions three and four.

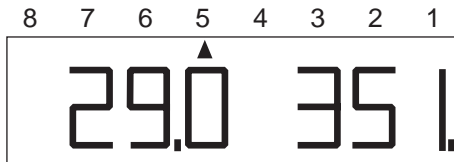


Figure 10. Continuous Sunfleck and PAR measurements.

## Function 6: Setting the Time

When a measurement is stored in memory, the time in hours and minutes will be stored along with it. Function six can be used to set the Ceptometer to the correct time. The A key controls the hour value and the B key controls the minutes. The clock can be set by either moving one hour or minute at a time by pressing the key once, or moving rapidly by holding down the key.

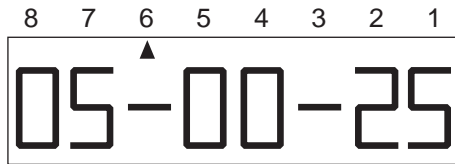


Figure 11. Time Setting.

## Function 7: Setting the Threshold

Function seven is used to set the threshold and determine whether one or all of the sensors will be sampled. For applications of the threshold and line vs. single sensor operation, refer to chapter six beginning on page 31 of this manual.

Threshold refers to the lowest PAR value in  $\mu\text{moles}$  that will be sampled. Any number below the chosen value will not be counted in the measurement. Pressing the A key sets the threshold manually; it will be set equal to half of the highest reading of any sensor on the probe. The letter "H" is shown on the display to indicate a threshold function along with the threshold setting in  $\mu\text{mol m}^{-2}\text{s}^{-1}$ .

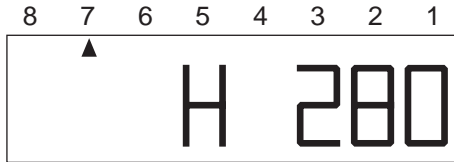


Figure 12. Threshold Indicator and Setting.

The B key is used for both automatic threshold and single sensor setting. In the automatic threshold mode, the Ceptometer will find the highest light reading on the probe and set the threshold at half of that value. If there is a difference in light along the probe, the sunfleck reading will be displayed as a percentage less than 100 if the lower value falls below the threshold. If the light on the probe is even, the reading will be 100 percent, regardless of the strength of the light and assuming the reading is greater than the set threshold.



In the single sensor mode, only one sensor at the tip of the probe will respond to light. This allows the instrument to be used as a point sensor. In this mode, the readings in functions one through five will be single sensor readings. The sunfleck reading will be either "1" or "0," indicating that the reading is above or below the manually set threshold.

Pressing the B key shifts between automatic threshold and single sensor settings. The automatic threshold is indicated by an "H" followed by two dashes on the display. When the single sensor setting is chosen, the display will read "ELE."

**NOTE:** The automatic threshold cannot be used in the single sensor mode. The threshold must be manually set before using this option.

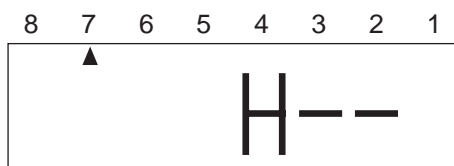


Figure 13. Automatic Threshold Indicator.

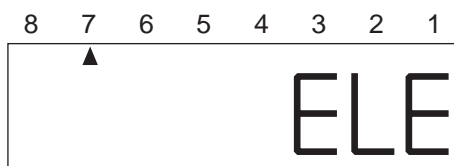


Figure 14. Single Sensor Indicator.

### Function 8: Send/Erase Memory and Individual Sensor Dump

Function eight is used to send stored readings to an external device or to erase the memory. Pressing the B key sends the data via an RS-232 interface cable to the external device. The sample numbers on the display will continually update until the transaction is complete. This transaction can be interrupted at any time by pressing the A key. To erase the memory, hold down the A key and press the B key.

If the memory is empty, individual sensor PAR readings may be sent to an external device. **This option will not work if any data is stored in the memory.** To send these readings, select function five. Choose desired values by pressing the A key to hold them. Return to function eight. **This move must be direct; if function eight is passed, the reading will be lost and must be made again.** Prepare the computer or other external device to receive the data. Press the B key to send the individual sensor readings to the prepared file. Refer to chapter nine for more information about interfacing with a computer.



Figure 15: Sending Memory to an External Device.

## 5. Measurement Tips

- ❑ When measuring with the Ceptometer, the instrument should be kept fairly level. This is less critical below the canopy; however, it should be followed as closely as possible as some of the radiation below the canopy may be direct beam.
  
- ❑ Since light below a canopy is extremely variable, several samples are necessary for reliable averages.
  
- ❑ When using sunfleck inversion methods, the instrument should be left in the same position. If the instrument is moved, errors may result in data collection.
  
- ❑ In canopies with clumped or row structures, it is important to take samples that show no favoring of within-row or between-row areas. In these cases, it is best to sample with the probe of the Ceptometer placed perpendicular to the row. If row spacing is different from the probe length, the probe can be placed diagonally to get a representative sample.
  
- ❑ In tall canopies and canopies having small leaves, overlapping penumbra make measurements of sunfleck fraction unreliable. Inversion to obtain leaf area index must therefore be performed using measurements of transmitted PAR.

### **Discussion of the Effects of Non-Random Distribution of Canopy Elements on LAI Measurements in situ**

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. Chen et. al. (1991) have proposed another 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  $L$  represents the actual leaf area index (equal to a harvested leaf area measurement) and  $\Omega$  refers to a clumping index resulting from the non-random distribution of canopy elements.

When a canopy displays random dispersion,  $\Omega$  is unity; however, when a canopy is clumped,  $\Omega$  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 underdispersed canopy (clumping),  $L$  would be greater than  $L_e$  (figure 2), and conversely, in an overdispersed canopy,  $L$  would be less than  $L_e$  (figure 3). Refer to page 30 for illustrations.

The purpose of this discussion is to expose the user to possible errors that may occur when making LAI measurements in situ. When setting up an experiment, the user should carefully examine the desired end result. If one is 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 the user is 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. This can be accomplished by modeling the clumping factors of the canopy or by measuring only at certain times of day or at positions within the canopy that directly minimize the clumping effects.

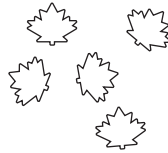
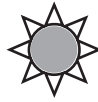


Figure 1: Randomly Dispersed  
 $L = L_e$



Figure 2: Underdispersed  
 $L > L_e$



Figure 3: Overdispersed  
 $L < L_e$

## 6. Applications

The Sunfleck Ceptometer is useful for a number of applications including the measurement of average and intercepted PAR and the recording of sunfleck occurrences. From these measurements, canopy structure can be estimated.

### **PAR**

PAR (photosynthetically active radiation) is generally considered to be the radiation in the 400 to 700 nanometer waveband. It represents the portion of the spectrum that plants can use for photosynthesis. In the PAR waveband, irradiances can vary from full sun to almost zero over the space of a few centimeters and reliable measurement of PAR requires many samples at many locations under the canopy.

### **Measuring 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:

$$P = efS$$

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 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:

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

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

$$f = 1 - t \quad (2)$$

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

$$r=(1-t)r_c+tr_s \quad (3)$$

where  $r_c$  is the reflectance of the vegetation. The first equation becomes:

$$f = (1 - t)(1 - r_c) \quad (4)$$

The error resulting from using the second equation is approximately equal to  $r_c$ , which is typically less than 0.05 in the PAR waveband. Since the Ceptometer's sensors are sensitive only to radiation in the PAR waveband, equation 2 will generally be accurate for making measurements of intercepted radiation. However, measurement of the other terms needed for equation 1 is simple and will also be explained.

### **Sampling for Fractional Interception**

Select function one. For specific instructions concerning function one, refer to page 18 of this manual. 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 Ceptometer above the plant canopy,  $R$  is the reflected PAR above the canopy (inverted Ceptometer above the crop),  $T$  is the upward-facing Ceptometer below the plant canopy, and  $U$  is the reflected PAR from the soil surface, then  $t$ ,  $r$ , and  $r_s$  can be calculated from:

$$t = T/S \quad (5)$$

$$r = R/S \quad (6)$$

$$r_s = U/T \quad (7)$$

Assume only  $t$  needs to be known. Measure  $S$  above the crop canopy. Level the Ceptometer above the canopy using the bubble level and then press the A key. The reading appearing on the right of the display is  $S$ . This value can be stored in memory by pressing the B key twice. Press the A key again to clear the display.

Measure  $T$  by placing the Ceptometer 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:

$$CV = [\sum(x_i - \bar{x})^2 / (n - 1)]^{1/2} / S \quad (8)$$

where  $n$  is the number of samples taken. The error in any measurement of  $t$  will be  $CV$  divided by the square root of the number of samples. Usually, a number around 10 should suffice. Press the A key to take a reading. Each of the readings will appear on the left of the display.

In canopies with a clumped or row structure, it is important that samples show no favor of between-row or within-row areas. It is best to sample with the probe perpendicular to the row. If the row spacing is different from the probe length, the probe can be placed diagonally to get a representative sample. The readings taken can be averaged by pressing the B key. This reading is the  $T$  value. Pressing the B key a second time stores the reading in memory. The fractional transmission for the canopy,  $t$ , can now be calculated from equation 5.

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 the readings stored in the instrument's memory.

To find  $r$ , invert the Ceptometer 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. Clear the display by pressing the A key. Press the A key a second time to take a reading. The display shows the R value. Multiple readings are not necessary since R is not usually variable. Press the B key twice to store the reading in memory. Calculate  $r$  from equation 6 using the previously recorded S value.

To find  $r_s$ , invert the Ceptometer 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 7 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.

## **Unattended Recording of Transmitted PAR**

The value of  $f$  in equation 1 can vary with sun elevation, since  $t$  depends on elevation angle. Fractional interception should be an integrated value averaged over the growing season. While the reading obtained at a particular time is closely related to this average value, readings need to be taken over a full day to find the true integrated value of  $t$ . Two measurements are needed;  $T$  at various times of the day, and  $S$  integrated over these same times.

We recommend that the data for  $S$  be obtained by recording the output of another Ceptometer or a SunLink PAR Probe. Both instruments have identical spectral and cosine responses. A PAR point sensor may also be used, or the data may be obtained by calculating PAR from incident solar radiation. To do so, multiply the total short- wave flux density ( $W\ m^{-2}$ ) by 2.1 to convert to  $\mu mol\ m^{-2}s^{-1}$ . This calculation can be verified by comparing these estimates to spot measurements with the Ceptometer placed above the plant canopy.

To obtain data for  $T$ , support the Ceptometer in the canopy, select function three, and press the A and B keys simultaneously. Readings will be taken automatically every minute, and then averaged and stored in memory every 30 minutes. Press either the A key or the B key to stop logging. Readings can be reviewed by pressing the A and B keys to move back and forth through the memory.

## **Survey Sampling of Average Line PAR**

Select function five. The value appearing to the right of the display is the average PAR over the length of the probe. The value will be updated continuously until the A key is pressed to hold the present reading. This reading may be stored in memory by pressing the B key, or the user may return to the continuous readings by pressing the A key again.

## **Using PAR to Determine Leaf Area Index**

Ceptometer 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 the Ceptometer 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 1 is a simple light scattering model suggested by Goudriaan (1988). It gives the fraction of transmitted PAR,  $t$  (ratio of PAR measured below the canopy to PAR above the canopy), below a canopy of LAI,  $L$ , as

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

Here  $f_b$  is the fraction of incident PAR which is beam,  $a$  is the leaf absorptivity in the PAR band (typically around 0.9), 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

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

where  $\theta$  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

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

John Norman suggested a different equation for predicting scattered and transmitted PAR.

$$\tau = \exp \left\{ \frac{A(1 - 0.47f_b)L}{\left(1 - \frac{1}{2K}\right)f_b - 1} \right\} \quad (3)$$

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 1 is slightly more accurate, but equation 3 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 3 will be used to determine LAI. Inverting equation 3 gives:

$$L = \frac{\left[ \left( 1 - \frac{1}{2K} \right) f_b - 1 \right] \ln \tau}{A(1 - 0.47f_b)} \quad (4)$$

## Applications and Examples

PAR was measured above a barley canopy of  $391 \mu\text{mol m}^{-2}\text{s}^{-1}$  on an overcast day. The average of several measurements below the canopy was  $62 \mu\text{mol m}^{-2}\text{s}^{-1}$ . The transmission,  $\tau$ , is therefore  $62/391 = 0.159$ . Since the day was overcast,  $f_b = 0$ . If  $a = 0.9$ , then  $A = 0.86$ . From equation 4,  $L = -\ln(0.159)/0.86 = 2.14$ . 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.  $1614 \mu\text{mol m}^{-2}\text{s}^{-1}$  was measured above a pea canopy and  $80 \mu\text{mol m}^{-2}\text{s}^{-1}$  under the canopy. The fraction of PAR transmitted by the canopy was therefore  $\tau = 80/1614 = 0.05$ . The solar zenith angle was  $30^\circ$ .

The fraction of diffuse radiation was measured by switching the Ceptometer to single sensor mode and taking a reading with the leveled probe in full sun and another reading with the sensor at the tip of the probe shaded by a 10 centimeter diameter shade at a distance of about 1 meter. 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 4 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. For a zenith angle of 30 degrees, this gives  $K = 0.577$ . Substituting these values into equation 4 results in  $L = 5.2$ .



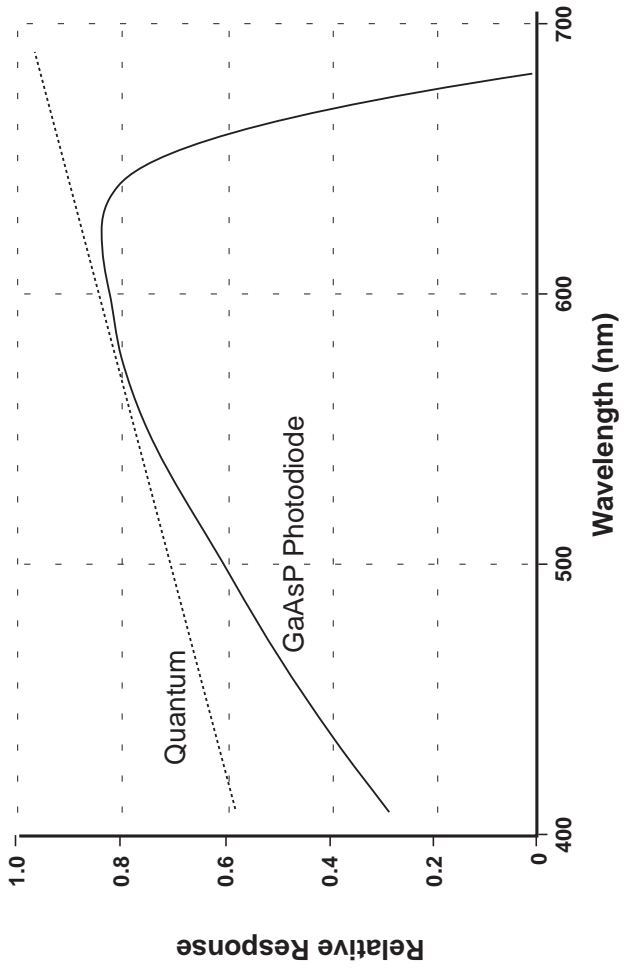
## **Final Comments**

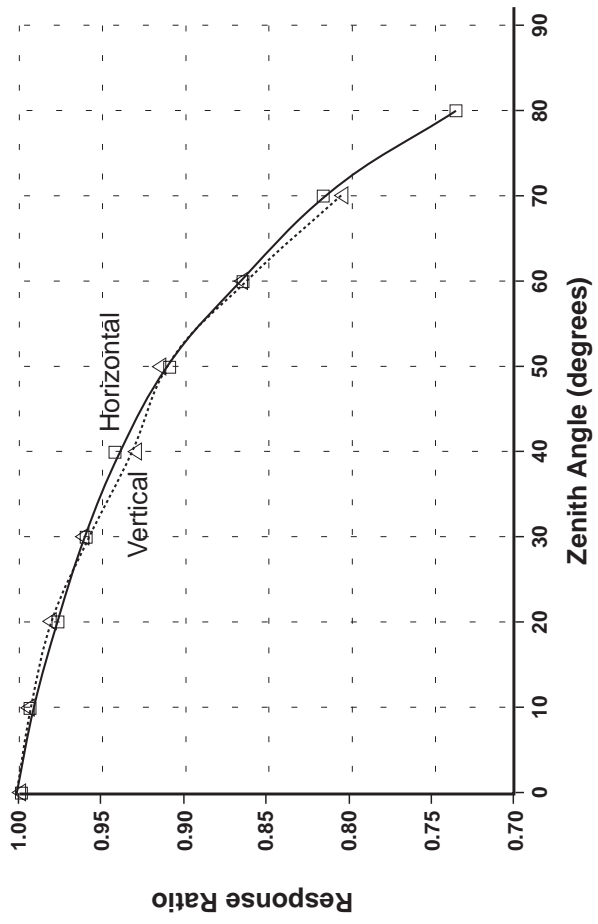
While leaf area estimates can be made under either clear or overcast skies, the clear sky estimate requires that you guess a value for  $x$ . The overcast sky measurement may therefore be more reliable. Spatial variability is a big problem in canopies, and measurements at several locations should always be used to determine LAI.

## **Spectral and Cosine Response**

The Ceptometer 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, the Ceptometer 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 two graphs on the following pages show the responses of the Ceptometer sensors. 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.





## 7. Sunflecks

Sunflecks refer to the bright areas under the canopy where direct beam solar radiation penetrates without dissipation by the canopy. The size, shape, duration, and peak photon flux of a sunfleck depends on the height and precise arrangement of vegetation within the canopy as well as the position of the sun in the sky. Fraction measurements of a ground covered by sunflecks can be used with inverse methods to determine important characteristics of canopy structure.

The sun approximates a point source of radiation which can be used on clear days to probe the canopy and obtain information on 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. For canopy cover, only measurements at high sun angles are needed since cover is the fraction of the ground covered by a vertical projection of the canopy onto it. Sunfleck measurements at several sun angles are needed to determine other canopy characteristics.

**Note:** When using sunflecks for inversions, it is critical that the instrument be placed in exactly the same location for each reading. It is therefore strongly recommended the unattended mode of data collection be used.

The sunfleck measurement can also be used to determine intercepted radiation for a canopy.

The sunfleck measurement is faster than the PAR measurement since the sunfleck measurement does not require finding the ratio of measurements below the canopy to measurements above it. It also has advantages on days where incoming radiation varies over short time periods, since light levels needed for making calculations are all measured at one time. The method cannot be used on overcast days or in canopies with overlapping penumbra since it relies on distinct shadows to make the measurement. (Penumbra are the partial shadows which surround the shadows of objects illuminated by the sun or any other source of finite size, and are the result of the sun not being a point source of light).

### **Setting the Threshold**

A proper threshold level must be established before accurate sunfleck measurements can be made. At each sunfleck measurement, the sensors in the probe are scanned by the microprocessor, and the reading of each sensor is compared to the established threshold. The microprocessor counts the number of sensors above the threshold, divides this value by the total number of sensors in the probe, and then displays the reading as a percentage. Two types of threshold settings are possible. When a sample is taken by the instrument in the automatic threshold setting, the microprocessor scans the set of readings, finds the highest one and sets the threshold at half of this value. If the highest light value on the probe changes as different samples are taken, the threshold will also change. As long as the sunflecks are large enough for at least one sensor to be in full sun the automatic threshold setting is the simplest and most reliable setting to use. It also measures the correct size of sunflecks with penumbra, as long as they do not overlap.

The manually set threshold must be used for dense canopies when there is a possibility that not even one sensor will be in full sun during a scan. Select function seven and press the A key. The probe is scanned and the threshold is set at half of the value of the highest sensor reading. The threshold value is displayed in  $\mu\text{mol m}^{-2}\text{s}^{-1}$ . If a different threshold level is desired, select the location of the probe when the A key is pressed.

The manually set threshold will remain until it is reset.

The user should experiment with the manual threshold mode before taking serious data, as it may take some time to learn to use this setting effectively. Measurements of low sunfleck fraction which cause the Ceptometer to register a high value are an indication that this mode may need to be used. The instrument reads 100.0 in full sun, but it also reads 100.0 in full shade, since it determines the percentages by comparing the highest reading on the probe. It is only when there is variation along the probe that it can detect sunflecks.

### **Sampling for Sunfleck Fraction**

Sampling for sunfleck fraction is similar to sampling PAR under the canopy. Select function two. Place the probe under the canopy and press the A key. Many samples are needed because of the large spatial variation in sunfleck fraction. Leveling is not important for sunfleck measurements, and it is sometimes desirable to tip the probe in the direction of the sun when sun angles are low so that a larger reading is obtained. The sunfleck fraction is shown on the right of the display and the number of samples taken is shown on the left. After 10 to 20 samples are taken, press the B key to average and display the reading.

The number of samples needed for a given precision can be estimated using equation 8 on page 34. To store the reading, press the B key again. In the sampling modes of functions one through five, both PAR and sunfleck fraction are read, averaged, and stored, but only one reading (PAR in function one and three, and sunfleck fraction in function two and four) is displayed.

### **Unattended Recording of Sunfleck Fraction**

To record sunfleck fraction unattended, select function four. Press the A and B keys simultaneously to begin readings. Readings will be taken every minute automatically and stored in memory every 30 minutes. The display will show time on the left and the sunfleck fraction on the right. To stop data collection, press either the A or B key. The readings can be reviewed by pressing the A and B keys to move backward and forward through the memory.

### **Survey Sampling of Sunfleck Fraction**

Select function five. A continuous sunfleck fraction is shown on the left of the display. Press the A key to hold the reading and the B key to store the reading in memory. This mode is often used to check a canopy's variability or to determine which threshold mode to use.

## 8. The 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,  $\tau(\Theta)$ , for the canopy. The parameter,  $\Theta$ , is the zenith angle of the probe or solar beam.  $\tau$  usually varies with zenith angle. The transmission coefficient for a canopy of randomly placed elements is:

$$\tau(\Theta) = \exp(-KL) \quad (1)$$

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.  $\tau$  is sunflecks/100.

Zenith angle refers to the angle the sun makes with respect to a line vertical to the earth's surface. A full description of zenith angle and how to measure it begins on page 11.

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:

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

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. Extinction coefficient is plotted as a function of zenith angle for various values of  $x$ . (See figure 16). At a zenith angle of about 57 degrees, 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 1 can be used in various ways to determine the leaf area index, and possibly also the leaf angle distribution function for a canopy. The simplest application is that of Bonhomme et al. (1974). Since  $K=1$  for zenith angles near 57 degrees, the inversion of equation 1 is simple and gives:

$$L = -\ln(\tau_{57}) \quad (3)$$

If a sunfleck measurement is made when the zenith angle is about 57 degrees, equation 3 can be used directly to find  $L$ .

If measurements of the transmission coefficient,  $\tau$ , are made at several elevation angles, a simple method from Lang (1987) can be used.

The measurements of  $\tau$  are used to compute  $y = \cos \Theta \ln \tau_{\Theta}$ . These are regressed on  $\Theta$  (in radians), giving a slope, B, and an intercept, A. The leaf area index is given by:

$$L = 2(A+B) \quad (4)$$

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

**Example:** Sunfleck readings were obtained as follows:

<u><math>\Theta</math>-degree</u>	<u><math>\Theta</math>-radian</u>	<u><math>\tau</math></u>	<u><math>-\cos\Theta \ln \tau</math></u>
35	0.61	0.21	1.28
41	0.72	0.18	1.29
55	.096	0.10	1.32

Linear Regression gives:

$$A = 1.21$$

$$B = 0.12$$

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

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

**Note:**  $\Theta$  can be measured by placing a stick of length, y, vertically in the ground and measuring the shadow length, x, on a horizontal surface.  
 $\tan Q = x/y$  so  $\Theta = \tan^{-1}(x/y)$ .

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

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

subject to the constraint,  $x > 0$ , where  $\tau_i$  are transmission coefficients measured at several zenith angles, and  $K_i$  are the extinction coefficients for the corresponding angles. A BASIC computer program which finds  $L$  and  $x$  from measured sunfleck fraction data is outlined on the following page.

## A Computer Program to Find LAI and LAD from Sunfleck Fraction Measurements

```

10 REM ***** ELLIPSOIDAL EXTINCTION COEFFICIENT
20 DEF FNK(Z,X)=SQR(X*X+Z*Z)/(x + 1.774*(x + 1.182)^(-0.733))
35 REM ***** Z IS TAN(ZENITH ANGLE)
30 REM *****
40 PI=3.14159:DX=0.1
50 INPUT "NUMBER OF ZENITH ANGLES";NZ
60 DIM Z(NZ),T(NZ)
70 FOR I=1 TO NZ
80   PRINT "ZENITH ANGLE";I;" - DEGREES";:INPUT Z(I)
90   PRINT "TRANSMISSION AT ";Z(I);"DEG";: INPUT T(I)
100  Z(I)=TAN(Z(I)*PI/180):T(I)=LOG(T(I))
110 NEXT
120 REM ***** FIND X USING BISECTION METHOD
130 XMAX=10:XMIN=.1:X=1
140 S1=0:S2=0:S3=0:S4=0
150 FOR J=1 TO NZ:TZ=Z(J)
160   KB=FNK(TZ,X):DK=(FNK(TZ,X+DX)-KB)
170   S1=S1+KB*T(J):S2=S2+KB*KB:S3=S3+KB*DK:S4=S4+DK*T(J)
180 NEXT
190 F=S2*S4-S1*S3 :PRINT X,F
200 IF F<0 THEN XMIN=X ELSE XMAX=X
210 X=(XMAX+XMIN)/2
220 IF (XMAX-XMIN)>.01 THEN GOTO 140
230 REM ***** FIND LAI AND PRINT RESULTS
240 L=-S1/S2:PRINT "LEAF AREA INDEX=";L
250 PRINT "RATIO OF VERTICAL TO HORIZONTAL
    PROJECTIONS=";X
260 PRINT
270 PRINT "ZENITH ANG.", "MEASURED T", "PREDICTED T"
280 FOR J=1 TO NZ
290   PRINT ATN(Z(J))*180/PI,EXP(T(J)),EXP(-FNK(Z(J),X)*L)
300 NEXT

```

## Correction of Sunfleck and Intercepted Radiation for Sun Angle

Sunfleck fraction,  $\tau$ , 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 1,

$$\ln \tau_1 / \ln \tau_2 = K_1 / K_2 = p \quad (5)$$

so

$$\tau(\Theta_1) = \tau(\Theta_2)^p \quad (6)$$

Calculate p from equation 2

$$p = [(x^2 + \tan^2 \Theta_1) / (x^2 + \tan^2 \Theta_2)]^{1/2} \quad (7)$$

$$\text{If } \Theta_1 = 0, p = [x^2 / (x^2 + \tan^2 \Theta_2)]^{1/2}.$$

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

**Example:** From the previous measurements, find the canopy cover. Take  $\Theta = 35^\circ$ ,  $\tau = 0.21$ , and  $x = 0.9$ .

$$p = [(0.9^2) / (0.9^2 + \tan^2 35)] = 0.79$$

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

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

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

$$f = 1 - \tau_d \quad (8)$$

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

$$-\ln \tau_d = uL^v \quad (9)$$

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

$$u = 1 - 0.33 \exp(-0.57x) \quad (10)$$

$$v = 1 - 0.3 \exp(0.97x) \quad (11)$$

The following table shows typical values of  $u$  and  $v$ .

$v$	$u$	$v$
0.1	0.699	0.728
0.5	0.745	0.818
1.0	0.816	0.892
2.0	0.903	0.951
4.0	0.963	0.982
8.0	0.989	0.995

Table 2. Values for  $u$  and  $v$  for equation 9.

Combining equations 1 and 9 gives:

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

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

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

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

$$v = 1 - 0.3 \exp(-0.97 \times 0.9) = 0.87$$

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

$$\tau = \frac{0.80 \times 2.64^{-0.13}}{0.59} = 1.2$$

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

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

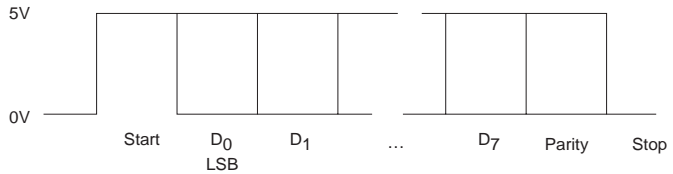
## 9. Interfacing with a Computer

Data collected and stored in the Ceptometer's memory can be downloaded to a disk file using the SunView software included with your instrument or the BASIC program outlined in this chapter.

The Ceptometer's communication protocol is:

- Baud Rate: 1200
- Parity: even
- Data Bits: 7
- Stop Bits: 1

Ceptometer data is output as comma separated values. The output signal is as follows:





**Connections for the 9 pin connector are:**

1. 5V	6. 5V
2. Ground	7. NC
3. NC	8. NC
4. NC	9. Data Out
5. NC	

**BASIC Program**

```
5 INPUT "NAME OF DATE FILE";DF$
10 OPEN"COM1:1200,,,,CS,DS,CD" AS 1
20 OPEN DF$ FOR OUTPUT AS 2
40 T$ = INPUT$(1,#1)
45 ON ERROR GOTO 85
50 IF T$ = CHR$(127) THEN T$ = CHR$(63)
60 PRINT T$;
70 PRINT #2,T$;
80 GOTO 40
85 RESUME
```

## **Notes on the BASIC Program**

Line 1: Prompts the program to go to line 85 if an error occurs during the execution of the program.

Line 5: Displays "NAME OF DATA FILE?", and assigns it to the variable DF\$.

Line 10: Opens communication device 1 as file number 1. The baud rate is 1200, parity is set to the default value, the number of data bits is set to the default value, the stop bit is set to the default value, the request to send is suppressed, and CS (clear to send), DS (data set ready), and CD (carrier detect) are set so as not to allow them to time out.

Line 20: Opens DF\$ and creates a file number 2 to receive data.

Line 40: Inputs one character at a time from the file numbered 1 to the file or variable t.

Line 50: Checks the contents of t. If it is equal to 127, it is changed to 63.

Line 60: Prints the contents of t to the screen.

Line 70: Prints the contents of t to the file numbered 2.

Line 80: Prompts the program to go to line 40.

Line 85: Prompts the program to resume running on the line where an error was detected.

## Executing the BASIC Program

Write and save the BASIC program to disk, then execute it in the following way to avoid any communication/buffer overflow problems:

If the program were called Sunread, type "gwbasic sunread \C:15000" at the prompt.

This allocates 15,000 bytes to the RS-232 receiver buffers and allows enough room for a full interface with the Ceptometer's memory.

**Note:** When running the program and saving data to disk, check to see that there is at least 40K left on the disk. A full interface of 1200 data points requires 22K of disk space.

## Sunfleck SunView Software

### **Backing Up and Running SunView from Floppy Disk**

Before using the SunView program from a floppy disk, make a backup copy.

- Insert a blank formatted disk into drive A.
- Place the SunView disk in drive B.
- Type COPY B: SUNVIEW.EXE A:

### **To run SunView from a floppy disk:**

- Place the floppy disk in drive A.
- Type A:SUNVIEW.

**Note:** Put the original SunView disk in a safe place. Always run the program from a backup copy.

## Installing SunView to the Hard Drive

- ❑ Place the SunView disk in drive A.
- ❑ Move to your hard drive and make a SunView directory by typing MD SUNVIEW.
- ❑ Move to the SunView directory (CD\SunView) and type COPY A:SUNVIEW.EXE.
- ❑ Put the original SunView disk in a safe place.
- ❑ To run the SunView program, type CD\SUNVIEW then SUNVIEW.

## Connecting the RS-232 Cable

An optically isolated RS-232 cable is included with each Ceptometer. This cable is specifically designed for use with the instrument and should be used whenever the operator wishes to download data to a computer. Other cables will not provide correct data output.

One end of the RS-232 cable houses a 9 pin connector. Secure this connector to the 9 pin receptacle on the Ceptometer. The other end of the cable houses a 25 pin connector which needs to be connected to the serial port of the computer at COM1. If you are unsure which port is COM1, see your computer operator's manual.

**Note:** You may use a 25-to-9 pin adapter to interface with your computer if needed; however, the 9 pin end of the RS-232 cable must be connected to the Ceptometer for correct operation.

## **Downloading Memory to a Computer**

Prepare your computer to receive data with the SunView software or the BASIC program described earlier. Press the function key until the display pointer is stationed at function 8, then press the B key to send the data to the computer. The sample numbers on the display will continually update until the transaction is complete. This transaction can be interrupted at any time by pressing the A key.

## **Running SunView Software**

The SunView program displays data under four headings: Index, Time, PAR, and Sunfleck %. The Index column refers to the data set number as it was stored in the Ceptometer's memory.

After the required data has been sent, press F2 to save. Press F1 to exit. If printing is a necessary application, data sets will need to be copied to a user-provided spreadsheet. Some instructions for importing to these spreadsheets are listed below.

Microsoft Excel: To export data to Excel, include a .CSV extension when naming a file. You can load the file into Excel by selecting File-Open.

Lotus 123: To export data to Lotus 123, include a .PRN extension when naming a file. You can load the file into Lotus 123 by selecting File-Import-Numbers.

Borland's Quattro: To export data to Quattro, include a .PRN extension when naming a file. You can load the file into Quattro by selecting Tools-Import. Then select Comma & "" delimited ascii for the file format.

## 10. Maintenance

### Changing the Batteries

The Ceptometer does not have a power switch. The microprocessor is always on to maintain the memory and update the clock, but the display closes after 7 minutes without keyboard activity.

The instrument uses 5 AA-type batteries. When the batteries are low, an indicator will appear when the Ceptometer is activated (the letters "LO" to the left of the display). Press any button to clear the display. The instrument may be used and although it will continue its normal function, the batteries should be replaced as soon as possible.

To replace the batteries, remove the four screws in the cover of the Ceptometer and lift the cover carefully. The batteries will be exposed and can be replaced. Be sure to orient the batteries correctly. The battery clips indicate the direction in which the batteries should be placed.

The switch to the side of the batteries controls power to the Ceptometer. The switch will be closed when the cover is on the instrument and power will be on to maintain the memory and update the clock. When the cover is removed, the switch opens and the instrument is reset. **Data will be lost whenever the instrument is reset.** Only one sensor of the Ceptometer has an absolute calibration; the others are calibrated against that sensor by the microprocessor and stored in memory. Memory is usually lost when the batteries are replaced and the sensors must be recalibrated.

## **Recalibrating the Sensors**

The sensors should only need recalibration when the batteries are replaced. Calibration must be performed in bright, even sunlight on a cloudless day. Select function seven. The display should read H - -. Hold down the A and B keys simultaneously and press the function key. The letters "PLL" will appear on the left of the display, indicating that the sensors have been recalibrated.

**Note:** Be sure to recalibrate the Ceptometer in the H - - mode of function seven and not the ELE mode. If the ELE mode is used, the instrument will not function properly and will need to be recalibrated.

## **Cleaning the Probe**

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



## 11. Return and Repair

Should anything ever go wrong with the Ceptometer, Decagon will repair it. Just follow the instructions below for returning the instrument.

- Before returning the Ceptometer, call our offices for a Return Materials Authorization Number (RMA#). Include this number on all correspondence regarding the repair of your instrument.
- With your return, please include your RMA#, a complete return address, the name and department of the person responsible for the Ceptometer, a repair budget for non-warranty instruments, and a purchase order number.
- Pack the Ceptometer carefully and mail to:

Decagon Devices, Inc.  
NE 1525 Merman Drive  
Pullman, WA 99163

To avoid damage during shipping, return the instrument in the case in which it was shipped or place adequate padding around it. **NEVER SHIP THE CEPTOMETER WITH THE BATTERIES INSTALLED.**

## 12. Questions and Answers

- When should I remove the batteries from my instrument?
- Always remove the batteries before shipping or traveling with the Ceptometer. If the batteries are shifted during transit, data will be lost and cannot be retrieved. Damage to the battery clips is also a possibility if the batteries are shifted.
- Can the data I gather with the Ceptometer be saved to an external device?
- Yes. Data collected and stored in the Ceptometer memory can be downloaded to a disk file using a BASIC program or the SunView software included with the instrument. Please refer to page 63 of this manual for instructions on downloading the Ceptometer.
- Can I send individual PAR readings to an external device?
- Yes. However, this option will not work if any data is stored in memory. Please refer to page 26 of this manual for instructions on this option.

- ❑ Can I use the automatic threshold setting in the single sensor mode?
  - No. The automatic threshold setting cannot be used in the single sensor mode. The threshold must be manually set before using this option. Please refer to page 25 of this manual for more details.
  
- ❑ "PLL" does not appear on the display after I have calibrated. What should I do?
  - First try your calibration technique again. Remember to hold the keys down simultaneously to avoid any errors. Refer to page 10 of this manual for detailed instructions on calibration. If this does not work, contact Decagon for technical assistance.
  
- ❑ I accidentally recalibrated my instrument in the ELE mode instead of the H - - mode. What should I do?
  - Recalibrate the Ceptometer making sure to calibrate in the H - - mode. Refer to page 65 of this manual for instructions on recalibration. Calibrating in the ELE mode will not damage the instrument, but will put it in the single sensor mode, meaning that only one sensor at the probe tip will respond to light. Future readings in this mode will not be accurate.
  
- ❑ The display is reading "LO." What does this mean?
  - A "LO" reading indicates that the batteries are running low. Press any key to clear the display. The instrument may be used as normal; however, the batteries should be replaced as soon as possible.

- ❑ Pressing keys on the keypad does not activate the display. What should I do?
- Reset the batteries in the battery pack. Refer to page 64 of this manual for instructions. If this does not solve the problem, the instrument will need to be sent for repair. Refer to chapter 11 for return and repair instructions.

The following is a list of problems that may indicate other complications with the Ceptometer. If any of these problems should occur, the instrument may need to be returned for repair. Please contact Decagon first for technical assistance.

- ❑ The instrument powers up but seems to stick when trying to scroll through functions.
- ❑ The instrument powers up but the display fades and flickers.
- ❑ After calibration, the instrument reads low light readings, but will not read above low light readings.

## Appendix A: Additional Information

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

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