LI-COR Biosciences

Measuring Change in a Changing World

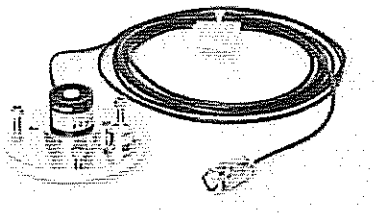
LI-200 Pyranometer Sensor

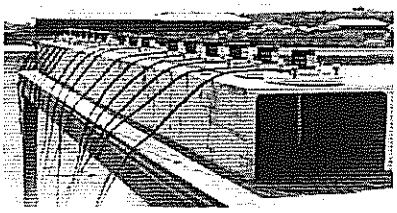
Measures Total Solar Radiation

Description
Specifications
Ordering
Brochures
Publications
Manuals

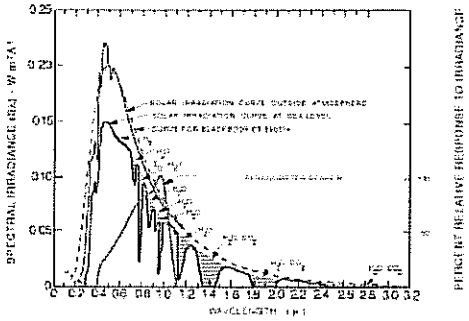
The LI-200 Pyranometer is designed for field measurement of global solar radiation in agricultural, meteorological, and solar energy studies. In clear, unobstructed daylight conditions, the LI-COR pyranometer compares favorably with first class thermopile-type pyranometers (1, 4), but is priced at a fraction of the cost.

Patterned after the work of Kerr, Thurtell and Tanner (2), the LI-200 features a silicon photovoltaic detector mounted in a fully cosine-corrected miniature head. Current output, which is directly proportional to solar radiation, is calibrated against an Eppley Precision Spectral Pyranometer (PSP) under natural daylight conditions in units of watts per square meter (W m^{-2}). Under most conditions of natural daylight, the error is < 5% (2).





The spectral response of the LI-200 does not include the entire solar spectrum, so it must be used in the same lighting conditions as those under which it was calibrated. Therefore, the LI-200 should only be used to measure unobstructed daylight. It should not be used under vegetation, artificial lights, in a greenhouse, or for reflected solar radiation.



The LI-200 Pyranometer spectral response is illustrated along with the energy distribution in the solar spectrum (3).

References

1. Biggs, W.W., A.R. Edison, J.D. Easton, K.W. Brown, J.W. Maranville and M.D. Clegg. 1971. Photosynthesis light sensor and meter. Ecology 52:125-131.
2. De Wit, C. T. 1965. Photosynthesis of leaf canopies. Agric. Res. Rep. No. 663. Institute for Bio. and Chem. Res. on Field Crops and Herbage. Wageningen, The Netherlands.
3. Federer, C.A. and C.B. Tanner. 1966. Sensors for measuring light available for photosynthesis. Ecology 47:654-657.
4. Hesketh, J., and D. Baker. 1967. Light and carbon assimilation by plant communities. Crop Sci. 7:285-293.

LI-COR Biosciences

Biotechnology
4647 Superior St
Lincoln, NE 68504
Toll-Free: 800-645-4267
Email: biohelp@licor.com

Environmental
4421 Superior Street
Lincoln, NE 68504
Toll-Free: 800-447-3576
Email: envsales@licor.com

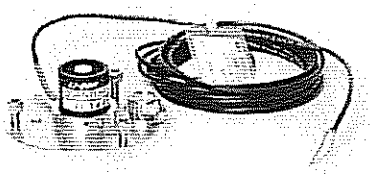
LI-COR Biosciences

Measuring Change in a Changing World

LI-190 Quantum Sensor

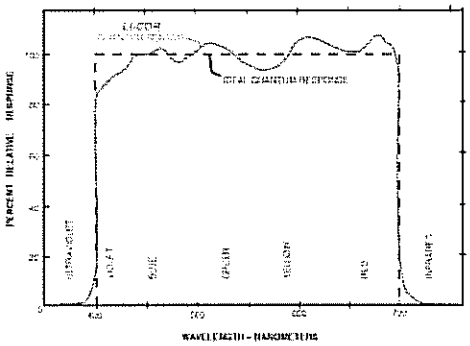
Measure Photosynthetically Active Radiation

During photosynthesis, plants use energy in the region of the electromagnetic spectrum from 400-700 nm. The radiation in this range, referred to as Photosynthetically Active Radiation (PAR), can be measured in energy units (watts m^{-2}) or as Photosynthetic Photon Flux Density (PPFD), which has units of quanta (photons) per unit time per unit surface area. The units most commonly used are micromoles of quanta per second per square meter (mmol s-1 m^{-2}). Plant scientists, horticulturists, ecologists, and other environmental scientists use the LI-190 Quantum Sensor to accurately measure this variable.



Accurate measurements are obtained under all natural and artificial lighting conditions because of the computer-tailored spectral response of the LI-190. Colored glass filters are used to tailor the silicon photodiode response to the desired quantum response. An interference filter provides a sharp cutoff at 700 nm, which is critical for measurements under vegetation where the ratio of infrared to visible light may be high. A small response in the infrared region can cause an appreciable measurement error. This sensor, developed from earlier work (1), was pioneered by LI-COR and has become the standard for PPFD measurement in most photosynthesis-related studies.

The LI-190 is also used in oceanography, limnology, and marine science as a reference sensor for comparison to underwater PAR measured by the LI-192 Underwater Quantum Sensor and LI-193 Spherical Underwater Quantum Sensor.



Typical spectral response of LI-COR Quantum Sensors vs. Wavelength and the Ideal Quantum Response (equal response to all photons in the 400-700 nm waveband).

References

1. Biggs, W.W., A.R. Edison, J.D. Easton, K.W. Brown, J.W. Maranville and M.D. Clegg. 1971. Photosynthesis light sensor and meter. Ecology 52:125-131.

2. Federer, C.A. and C.B. Tanner. 1966. Sensors for measuring light available for photosynthesis. Ecology 47:654-657.

3. McCree, K.J. 1972. Test of current definitions of photosynthetically active radiation against leaf photosynthesis data. Agric. Meteorol. 10:443-453.

LI-COR Biosciences

Biotechnology
4647 Superior St
Lincoln, NE 68504
Toll-Free: 800-645-4267
Email: biohelp@licor.com

Environmental
4421 Superior Street
Lincoln, NE 68504
Toll-Free: 800-447-3576
Email: envsales@licor.com

LI-COR Biosciences

Measuring Change in a Changing World

LI-191 Line Quantum Sensor

Measure Photosynthetically Active Radiation in Plant Canopies

Description
Specifications
Ordering
Brochures
Publications
Manuals

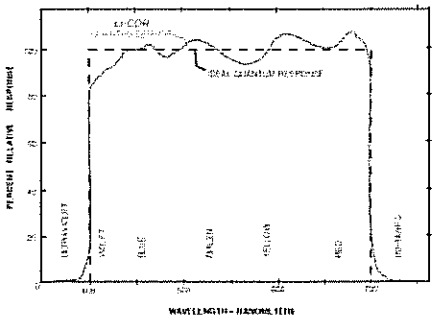
The LI-191 Line Quantum Sensor spatially averages PPFD over its one-meter length.

During photosynthesis, plants use energy in the region of the electromagnetic spectrum from 400-700 nm (1, 2). The radiation in this range, referred to as Photosynthetically Active Radiation (PAR), can be measured in energy units (watts m^{-2}) or as Photosynthetic Photon Flux Density (PPFD), which has units of quanta (photons) per unit time per unit surface area. The scaled units most commonly used are micromoles of quanta per second per square meter ($\mu mol\ s^{-1}\ m^{-2}$).

Measuring PAR within a plant canopy can be very difficult because of the non-uniformity of the light field. When PAR is measured with a small diameter quantum sensor such as the LI-190 Quantum Sensor, intensity can vary 10-fold between sunflecks and shadows, requiring a large number of readings to get an accurate average. The LI-191 Line quantum Sensor reduces the number of individual readings required because it effectively averages PPFD over its one-meter length. One person can quickly make plant canopy PPFD measurements in many plots in a short period of time.

Rather than using multiple detectors linearly arranged over its one-meter length, the LI-191 uses a one-meter-long quartz rod under a diffuser to conduct light to a single, high-quality quantum sensor. Its response is shown below.

There are two advantages to this design. First, the sensor has a very good quantum response, unlike sensors using inexpensive gallium arsenide detectors with only an approximation of the ideal quantum response. Second, it is much easier to maintain calibration on a single quantum sensor than on multiple (up to 60) individual gallium arsenide detectors.



Typical spectral response of LI-COR Quantum Sensors vs. Wavelength and the Ideal Quantum Response (equal response to all photons in the 400-700 nm waveband).

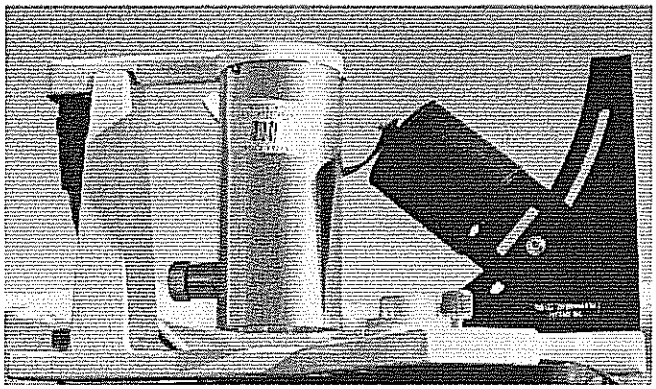
LI-COR Biosciences

Biotechnology
4647 Superior St
Lincoln, NE 68504
Toll-Free: 800-645-4267
Email: biohelp@licor.com

Environmental
4421 Superior Street
Lincoln, NE 68504
Toll-Free: 800-447-3576
Email: envsales@licor.com

USDA UV-B Monitoring and Research Program

Program Overview
Stations/Data
Research
Instrumentation
Intercomparisons
Publications
Image Gallery
UV Links
Ag. Impact
What's New
Contact Us
UV-B Site Map
UV-B Home



The Ultraviolet Multi-Filter Rotating Shadowband Radiometer

The Yankee Environmental Systems UV Multifilter Rotating Shadowband Radiometer (UV-MFRSR) uses 7 independent interference filter photodiode detector combinations to make total horizontal solar irradiance measurements at 300, 305.5, 311.4, 317.6, 325.4, 332.4 and 368 nm (nominal 2 nm FWHM bandwidth) through a single Lambertian detector. A computer-controlled, automatic rotating shadow band permits the near simultaneous determination of total horizontal, direct normal and diffuse radiation at each filtered passband.

Measurements are made sequentially at each wavelength every 20 seconds and integrated into 3-minute averages by an on-board computer. The computer also serves as the data logger for the UV-MFRSR. The UV-MFRSR is polled daily via a dedicated telephone line.

As with other multifilter rotating shadowband radiometers the choice of wavelengths permits a Langley analysis for the direct determination of optical depth. The 332.4nm wavelength serves as a reference to Dobson instruments and the 311.5 is designed to be a reference point to a relatively unstructured (flat) portion of the UV spectra.

Lamp Calibrations are performed by the NOAA Central UV Calibrations Facility(CUCF).

- **Representativeness**
- **Bias**
- **Precision**
- **Comparability**
- **Additional Manufacturer's Specifications**
- Overall Radiometric Accuracy: 2-3% with angle corrections
- **References**

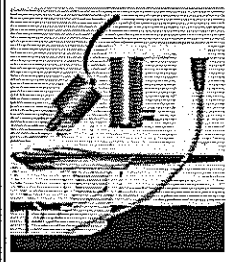
Harrison, L., J. Michalsky, J. Bernt, Automated multi-filter rotating shadow-band radiometer: an instrument for optical depth and radiation measurements, *Appl. Opt.* 33 (22) 1994.

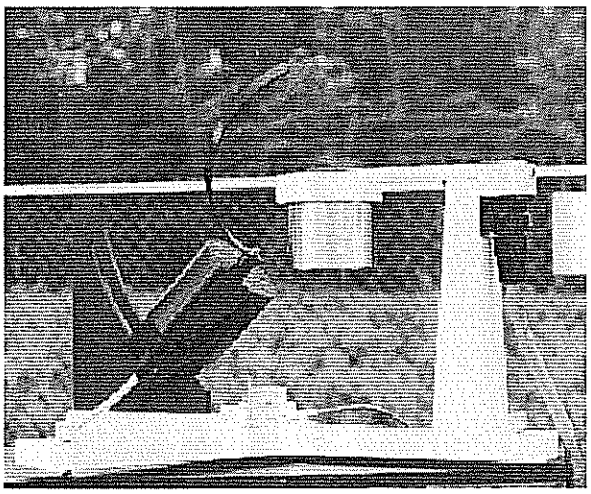
Bigelow, D.S. and J.R. Slusser, 1999, Establishing the Stability of Multi-filter UV Rotating Shadowband Radiometers, *J. Geophys. Res.* (In press).

Slusser, J.R., J.H. Gibson, D.S. Bigelow, D. Kolinski, P. Disterhoft, K. Lantz and A. Beaubien, 1999, Langley Method of Calibrating UV Filter Radiometers, *J. Geophys. Res.* (In press).

USDA UV-B Monitoring and Research Program

Program Overview
Stations/Data
Research
Instrumentation
Intercomparisons
Publications
Image Gallery
UV Links
Ag. Impact
What's New
Contact Us
UV-B Site Map
UV-B Home





The Multi-Filter Rotating Shadowband Radiometer

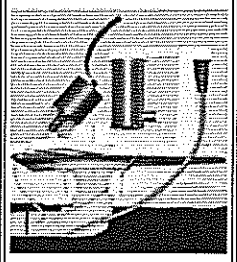
The Yankee Environmental Systems seven channel Multi-Filter Rotating Shadow-Band Radiometer(MFRSR) uses 6 independent interference filter photodiode detector combinations to make total horizontal solar irradiance measurements at 415, 500, 610, 665, 862 and 940 nm (nominal 10 nm FWHM bandwidth) through a single Lambertian detector. The seventh channel is an unfiltered broadband silicon diode detector. A computer-controlled, automatic rotating shadow band permits the near simultaneous determination of total horizontal, direct normal and diffuse radiation at each filtered wavelength. The wavelengths (except the 940 nm water-vapor band) were chosen to permit a Langley analysis for the direct determination of optical depth. Measurements are made sequentially at each wavelength every 15 seconds and integrated into 3-minute averages by an on-board computer. The computer also serves as a data logger for ancillary instrumentation that is connected to it. The MFRSR is polled daily via a dedicated telephone line.

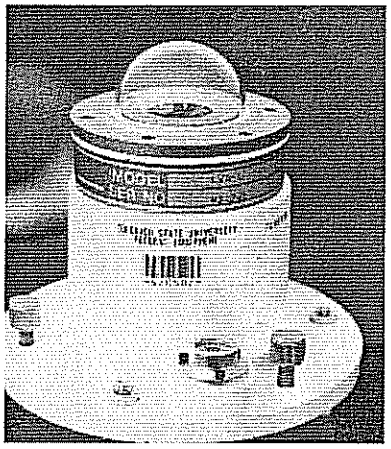
- Plan (SOP)
- Representativeness
- Bias
- Precision
- Comparability
- References

Harrison, L., J. Michalsky, J. Bernt, Automated multi-filter rotating shadow-band radiometer: an instrument for optical depth and radiation measurements, *Appl. Opt.*, 33(22) 1994.

USDA UV-B Monitoring and Research Program

Program Overview
Stations/Data
Research
Instrumentation
Intercomparisons
Publications
Image Gallery
UV Links
Ag. Impact
What's New
Contact Us
UV-B Site Map
UV-B Home





The Broadband UVB-1 Pyranometer

The Yankee Environmental Systems UVB-1 Pyranometer measures global irradiance in the UVB spectral range of 280-330 nm. The measurement technique employs a combination of colored glass optical filters to block the sun's visible spectra and a UV sensitive flourescent phosphor to convert the UVB light to visible light. The converted light is then measured with a solid-state photodiode. Signal output is 0-5 volts DC, low Z, corresponding to 0-9.84 Watts/meter^2 of effective UVB irradiance.

Broadband Measurement Plan

The USDA UV-B Monitoring and Research Program recognizes the importance of instrument stability in establishing a long-term climatological record. The network documents the stability of its broadband instruments through annual calibrations and annual re-characterizations of each instrument's spectral response. Initial instrument characterizations were first established by submitting each of the network's initial broadband meters to the National Institute of Standards and Technology (NIST) for an evaluation of their cosine and spectral response. Plots of the NIST characterizations are available.

Representativeness

Spectral Response

The spectral response of a broadband meter is a measure of the instrument's response to light at specific wavelengths - typically generated with a high resolution scanning monochrometer and xenon arc source. Two important quality attributes of the instrument can be determined and tracked through this characterization; the instrument's central wavelength stability and stability of its characteristic shape. Because of the importance of documenting uniformity in these parameters over the life of the USDA's monitoring program, spectral characterizations are remeasured approximately annually when each instrument is returned to the manufacturer for re-calibration.

Bias

Cosine Response

The cosine response of a broadband meter is a measure of the departure of the angular response of the instrument from that of Lambert's cosine law. This law states that the response of an ideal detector to constant and uniform light source should decrease in proportion to the cosine of the angle of incidence of the light. In practice the response is a function of the design geometry and manufacturing of the meter. It is anticipated that once determined, the cosine response characteristic of an individual instrument will not change unless the instrument becomes damaged. In field applications the stability of cosine response, once characterized, should only be dependent upon maintaining it in a level plane. In the USDA monitoring program this is checked and adjusted annually.

Calibration

Calibration of the USDA broadband meters follows the theory of Grainger, et al., 1993. That is, a calibration constant for a selected broadband meter was derived from a regression of the integrated spectral response of a spectroradiometer against the signal produced by the selected meter. This meter serves as the primary reference for the network. Results of the regression yielded a relationship of 1.866 +/- 0.11 (Watts per meter-squared)/Volt. The relationship represents the irradiance integrated over the range of 280 - 320nm. It should be noted that integrating over other spectral ranges will result in a different relationship (constant).

Annual calibrations follow ASTM E_824 methodology ending with the adjustment of each test meter's signal to the signal of a reference instrument maintained according to ASTM method E_816 by the calibration facility. The merits of this approach are discussed by Deluisi et al. (1992). Presently, the calibration facility is located at Yankee Environmental Systems, Inc. in Turners Falls, MA.

Precision

Comparability

Traceability to NIST

1994 Boulder Intercomparison

1995 Boulder Intercomparison

See Spectral and Cosine Response (above)

Additional Information

Manufacturer's Specifications

Instrument Response Time: approximately 100 ms.

Cosine Response: Better than +/- 5% for 0-60 degrees zenith angle

Active Sensor Area: approximately 2.54 cm lin diameter.

Operating Temperature: -40 to +40 degrees C.

From the Surface Radiation Research Branch of NOAA

References

American Society for Testing Materials, 1994. ASTM Method E_824. Standard Test Method for Transfer of Calibration From Reference to Field Radiometers. West Conshohocken, PA 19428.

American Society for Testing Materials, 1995. ASTM Method E_816. Standard Test Method for Calibration of Pyrheliometers by Comparison to Reference Pyrheliometers. West Conshohocken, PA 19428.

Deluisi, J., Wendell, J., Kreiner, F. 1992. An Examination of the Spectral Response Characteristics of Seven Robertson-Berger Meters After Long-Term Field Use. Photochemistry and Photobiology 56(1) pp115-122.

Grainger, R.G., R.E. Basher, R.L. McKenzie 1993. UV-B Robertson-Berger meter characterization and field calibration. Applied Optics, 32(3) pp343-349.

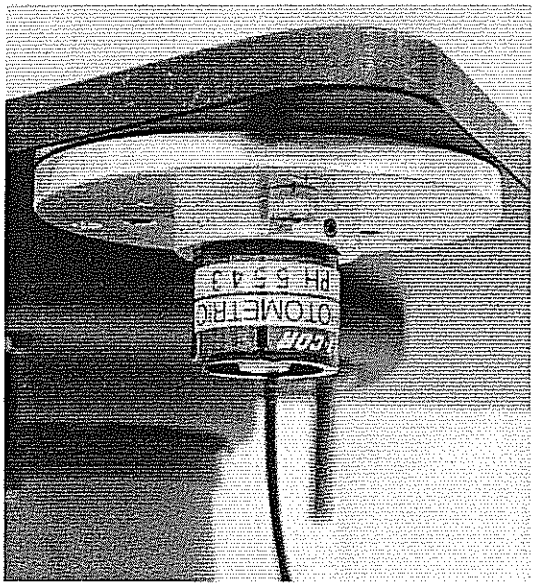
Green, A.E.S., Cross, K.R., Smith, L.A. 1980. Improved Analytic Characterization of Ultraviolet Sky. Photochemistry and Photobiology 31, pp59-65.

Yankee Environmental Systems, Inc. Bulletin UVB-1S. PO Box 746, Montague Industrial Park, Turners Falls, MA. 01376 USA.

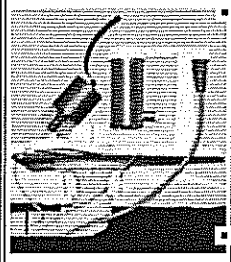
Yankee Environmental Systems, Inc. 1995. UVB-1 Ultraviolet Pyranometer Installation and User Guide, Turners Falls, MA 01376

UV-B Monitoring and Research Program

Program Overview
Stations/Data
Research
Instrumentation
Intercomparisons
Publications
Image Gallery
UV Links
Ag. Impact
What's New
Contact Us
UV-B Site Map
UV-B Home



Downward looking LI-COR 210SZ radiation sensor



Use in the USDA UVB Monitoring Network

The model 210SZ LI-COR photometer is used in the USDA's UVB monitoring program as a simple indicator of surface reflectance. The photometer is pointed downward, instead of skyward and therefore responds to illumination reflected from the seasonal ground cover just below and around the network's instrument array. The importance of this measurement is in determining the presence of snow cover.

Calibration

Because of the photometer's use within the network and its unconventional orientation, the network has chosen to apply a single, constant calibration conversion (30.69 mA/ 100K lux) to all of its meters rather than specific constants for each meter as furnished by the manufacturer. Since the stated calibration constants for the network's LI-COR photometers range from 27.86 - 33.51mA per 100K lux, this introduces an additional uncertainty in the reported measurements of approximately 7%. This uncertainty, however, is more than acceptable for the instrument's intended use. To further differentiate the network's photometric results from other LI-COR photometer results, the network reports the meter's output in units of Watts/Meter-squared rather than *lux* as is suggested by the manufacturer. This unit conversion has been made using the 1 Watt = 683 lumens as recommended by the manufacturer.

Quality Assurance

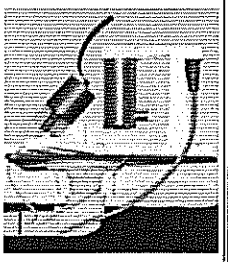
The simple use to which the photometer is applied does not warrant any specific quality assurance procedures other than checks to ensure that the photometer is operating. The network does not intend to maintain current photometer calibrations.

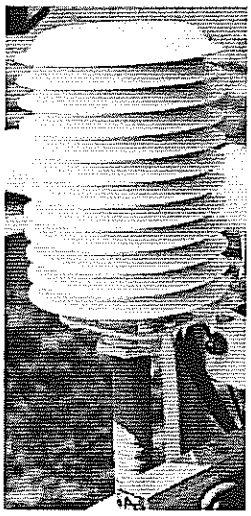
Manufacturer's Information

LI-COR Inc.

USDA UV-B Monitoring and Research Program

Program Overview
Stations/Data
Research
Instrumentation
Intercomparisons
Publications
Image Gallery
UV Links
Ag. Impact
What's New
Contact Us
UV-B Site Map
UV-B Home



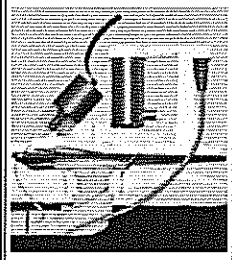


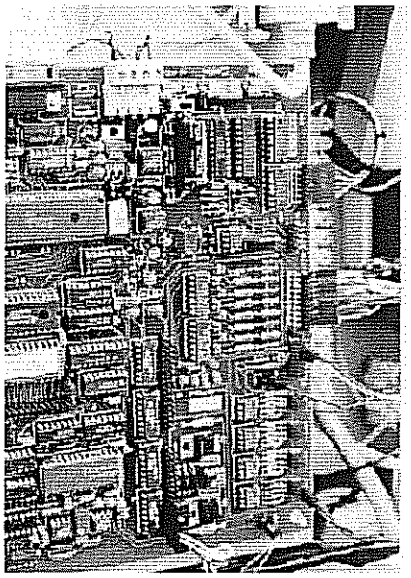
Temperature and Humidity Probe

Temperature and humidity are measured at each site with a Vaisala HMP 35A probe. The temperture range is -20 to +60 degrees C. Humidity range is 0-100%.

USDA UV-B Monitoring and Research Program

Program Overview
Stations/Data
Research
Instrumentation
Intercomparisons
Publications
Image Gallery
UV Links
Ag. Impact
What's New
Contact Us
UV-B Site Map
UV-B Home





On-board data logger

CR1000

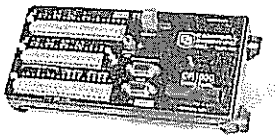
Datalogger for Measurement and Control

Add to Quick Quote

The CR1000 datalogger builds on the foundation of our CR10 and CR10X dataloggers. The CR1000 retains the versatility of the earlier loggers with a detachable wiring panel, separate power supply, and optional keyboard display. It features increased memory, more measurement channels, and an RS-232 port for communication than previous dataloggers in this series.

When used as part of a data acquisition system, the CR1000 datalogger provides the measurement and control functions. A complete system would include a power supply, weatherproof enclosure, sensors, programming/communications software, and communications peripherals.

Features



- Designed for unattended network applications
- Consists of a measurement and control module and the CR1000WP, a detachable wiring panel
- 4 MB SRAM for data storage, program storage and CPU usage
- Additional data storage using CFM100 Module with a CompactFlash® card
- Data stored in table format
- Operating system: PakBus®
- Software support offered in LoggerNet 3.x, PC400 1.2, or ShortCut 2.2
- Detachable keyboard/display, the CR1000KD, can be carried to multiple stations.

Specifications

- Analog inputs: 16 single-ended or 8 differential, individually configured
- Pulse counters: 2
- Switched voltage excitations: 3
- Control/digital ports: 8
- RS-232 port: 1
- CS I/O port: 1
- Scan rate: 100 Hz
- Burst mode: 1500 Hz
- Analog volt. resolution: to 0.33 uV
- A/D bits: 13
- Programming: CRBasic
- Data Storage: Table
- Telecommunications: PakBus

Resources

Ask Our Expert

FAQs

Downloads

Documents

Brochure Specs PakBus Guide

more

Related Products

CR1000KD Keyboard/Displa...

PS100 12 Vdc Power Suppl...

BPALK 12 V Alkaline Batt...

NL115 Ethernet Interface...

CFM100 CompactFlash Modu...

Events

CR1000/LoggerNet Training
February 11-14, 2008

Related Systems

RAWS-F Remote Automated W...

Custom Weather Station

Eddy Covariance Measure w...

CS110 Electric Field Meter

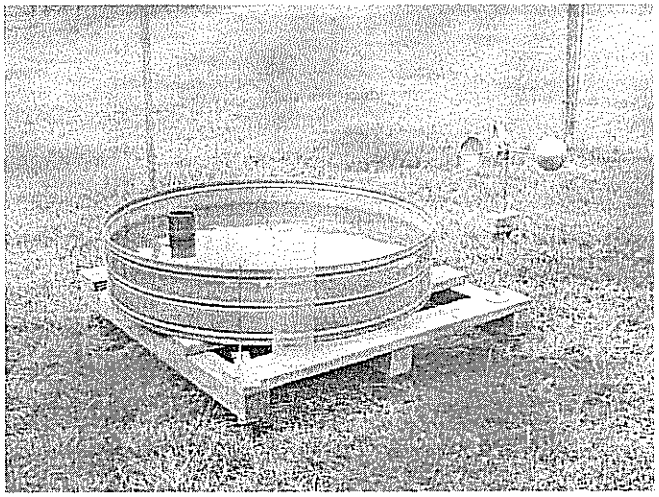
RAWS-P Remote Automated W...

TGA100A Trace Gas Analyze...

ET107 ETo Monitoring Stat...

more

Class A evaporation pan



In the United States, the National Weather Service has standardized its measurements on the **Class A evaporation pan**, a cylindrical with a diameter of 47.5 in (120.7 cm) has a depth of 10 in (25 cm). The pan rests on a carefully leveled, wooden base and is often enclosed by a chain link fence to prevent animals drinking from it. Evaporation is measured daily as the depth of water (in inches) evaporates from the pan. The measurement day begins with the pan filled to exactly two inches (5 cm) from the pan top. At the end of 24 hours, the amount of water to refill the pan to exactly two inches from its top is measured.

If precipitation occurs in the 24-hour period, it is taken into account in calculating the evaporation. Sometimes precipitation is greater than evaporation, and measured increments of water must be dipped from the pan. Evaporation cannot be measured in a Class A pan when the pan's water surface is frozen.

The Class A Evaporation Pan is of limited use on days with rainfall events of >30mm (203mm rain gauge) unless it is emptied more than once per 24hours. Analysis of the daily rainfall and evaporation readings in areas with regular heavy rainfall events shows that almost without fail, on days with rainfall in excess of 30mm (203mm Rain Gauge) the daily evaporation is spuriously higher than other days in the same month where conditions more receptive to evaporation prevailed.

The most common and obvious error is in daily rainfall events of >55mm (203mm rain gauge) where the Class A Evaporation pan will likely overflow. The less obvious, and therefore more concerning, is the influence of heavy or intense rainfall causing spuriously high daily evaporation totals without obvious overflow.

16. J. H. Davies, D. J. Stevenson, *J. Geophys. Res.* **97**, 2037 (1992).
17. Hydrated basalt contains amphiboles and chlorite, which also fail by dehydration embrittlement (*23–25*).
18. T. Seno, Y. Yamanaka, *Geophys. Monogr. Am. Geophys. Union 96* (American Geophysical Union, Washington, DC, 1996), pp. 347–355.
19. S. M. Peacock, *Geology* **29**, 299 (2000).
20. S. H. Kirby, E. R. Engdahl, R. Denlinger, *Geophys. Monogr. Am. Geophys. Union 96* (American Geophysical Union, Washington, DC, 1996), pp. 195–214.
21. W. Jiao, P. G. Silver, Y. Fei, C. T. Prewitt, *J. Geophys. Res.* **105**, 28125 (2000).
22. R. Tibi, G. Bock, C. H. Estabrook, *J. Geophys. Res.* **107**, ESE1-1 (2002).
23. K. Obara, *Science* **296**, 1679 (2002).
24. B. R. Hacker, J. M. Christie, *Geophys. Monogr. Am. Geophys. Union 56* (American Geophysical Union, Washington, DC, 1990), pp. 127–147.
25. S. A. F. Murrell, I. A. H. Ismail, *Tectonophysics* **31**, 207 (1976).
26. C. Meade, R. Jeanloz, *Science* **252**, 68 (1991).
27. D.P.D. is grateful for his Alexander von Humboldt Fellowship. Experiments were performed at the Bayerisches Geoinstitut under the EU "IHP to Research Infrastructures" Programme (contract no. HPRI-1999-CT-004 to D. C. Rubie).

19 August 2002; accepted 7 October 2002

The Cause of Decreased Pan Evaporation over the Past 50 Years

Michael L. Roderick and Graham D. Farquhar*

Changes in the global water cycle can cause major environmental and socioeconomic impacts. As the average global temperature increases, it is generally expected that the air will become drier and that evaporation from terrestrial water bodies will increase. Paradoxically, terrestrial observations over the past 50 years show the reverse. Here, we show that the decrease in evaporation is consistent with what one would expect from the observed large and widespread decreases in sunlight resulting from increasing cloud coverage and aerosol concentration.

It is now well established that the surface of Earth has, on average, warmed ~0.15°C decade^{-1} over the past 50 years (*1*). One expected consequence of this warming is that the air near the surface should be drier, which should result in an increase in the rate of evaporation from terrestrial open water bodies. However, despite the observed increases in average temperature, observations from the Northern Hemisphere show that the rate of evaporation from open pans of water has been steadily decreasing over the past 50 years (*2*). This trend is general (*3*, *4*) but not universal (*5*). The contrast between expectation and observation is called the pan evaporation paradox. It is important to understand why pan evaporation has decreased despite the increases in average temperature in order to make more robust predictions about future changes in the hydrological cycle.

Two proposals for the decline in pan evaporation have been advanced: the first invokes changes in the humidity regime over the pans (*6*), whereas the second invokes reductions in solar irradiance resulting from more clouds and/or aerosols (*5*, *7*) and is generally consistent with the independent suggestion that increased pollution would weaken the hydrological cycle (*8*). The first proposal is that pan evaporation has decreased because evaporation from the environment surrounding the pan has increased (*6*). The explanation is that in water-limited environments, when the evaporation from the adjacent environment is high, the air over the pan tends to be cooler and more humid, thereby reducing evaporation from the pan. A subsequent analysis of rainfall and streamflow data from water-limited environments in both the former Soviet Union and the United States does apparently show an increase in evaporation from the environment (*9*, *10*). However, this explanation for decreasing pan evaporation is unsatisfactory for two reasons. First, it only predicts changes in pan evaporation in water-limited environments. The problem is that some areas are not water-limited, and in wet environments the evaporation from pans and the surrounding environment have both declined (*9*). Further, if the proposed mechanism was the important one, then the vapor pressure deficit should have decreased. However, data from the United States show that its average has remained virtually constant over the past 50 years (*10*). This implies that the second proposal, based on the decrease in solar irradiance, should be further investigated.

Any explanation of the decrease in pan evaporation must accommodate the following: (i) the widespread decrease in pan evaporation has occurred in both dry and wet environments, and (ii) the average vapor pressure deficit (D, measured in Pa) has remained more or less constant despite increases in the average temperature. Decreases in solar irradiance would be consistent with (i), and here we specifically address the second item.

The key question is: How could D remain nearly constant despite increases in average temperature? We note that D is defined by

$$D = e_s(T) - e_s(T_d), \qquad (1)$$

where e_s (measured in Pa) denotes the saturation vapor pressure at the temperature (T) and dew point (T_d) of the air. To first order, the change in D is given by

$$\delta D = s\delta T - s_d\delta T_d, \qquad (2)$$

where s and s_d are the slopes of the saturation vapor pressure–temperature relationship at T and T_d, respectively. T is larger than T_d, and s is larger than s_d. δD would be zero if $\delta T_d/\delta T$ were equal to s/s_d. Averaged over a day, s/s_d depends on both the average T and the diurnal temperature range (DTR). This ratio is typically a little greater than 2 for a sunny day with a large DTR but a little less than 2 on cloudy days with a lower DTR (Table 1). Taking a typical value of s/s_d as 2 (Table 1), it follows that δD would be zero provided that δT_d is double δT. That is important, because globally averaged measurements over the past 50 years show that while the average T has been increasing (~0.15°C decade^{-1}), the average minimum T generally has been increasing twice as fast (~0.2°C decade^{-1}) as the average maximum T (~0.1°C decade^{-1}) (*1*). When above the freezing point, the dew point will in general set a lower limit on the minimum T. Thus, the observed increase in minimum T implies that the dew point must also be increasing faster than the average T.

Table 1. Variation in the ratio s/s_d as a function of T assuming three different T_d (T_d = 5°, 15°, 25°C).

T (°C)	s/s_d
T_d = 5°C s_d = 61 Pa K^{-1}	
10	1.36
15	1.80
20	2.38
25	3.10
T_d = 15°C s_d = 110 Pa K^{-1}	
20	1.32
25	1.72
30	2.22
35	2.84
T_d = 25°C s_d = 189 Pa K^{-1}	
30	1.29
35	1.65
40	2.08
45	2.61

Cooperative Research Centre for Greenhouse Accounting, Research School of Biological Sciences, Institute of Advanced Studies, Australian National University, Canberra ACT 0200, Australia.

*To whom correspondence should be sent. E-mail: farquhar@rsbs.anu.edu.au

That conclusion is consistent with data from the United States that show that the average dew point has generally increased much faster (~0.3°C decade^{-1} or a little greater in some parts of the United States) than the average T (*11, 12*). Consequently, over the United States at least, δD should be very close to zero because $\delta T_d/\delta T$ is about the same as s/s_d. This would explain why the average D has remained virtually constant in the United States over the past 50 years. More generally, the widespread observed decline in the DTR (*13, 14*), when combined with the above analysis, suggests that the changes in D should be very small in many places.

Pan evaporation is generally much more sensitive to variations in net irradiance and D than to variations in wind speed (*15–17*). Thus, with δD being small, a change in pan evaporation must result from a change in net irradiance. To estimate the magnitude of this change resulting from a change in solar irradiance, we use

$$(0.7)\,\lambda E_{\text{pan}} \approx 1.26\left(\frac{s}{s+\gamma}\right)R_n \qquad (3)$$

where the right-hand side of Eq. 3 is the well-known Priestley-Taylor expression for evaporation from a wet surface (*18*), and we have used the usual coefficient (0.7) to account for evaporation pans having a greater surface area for energy transfer than for mass transfer (*17*). In Eq. 3, λ (~2.4 MJ kg^{-1}) is the latent heat of vaporization of water; E_{pan} (kg m^{-2} s^{-1}), the pan evaporation; R_n (J m^{-2} s^{-1}), the net irradiance; and γ (~ 67 Pa K^{-1}), the psychrometric constant. The ratio $s/(s + \gamma)$ is calculated at the mean T and varies from 0.48 at 5°C to 0.82 at 35°C. Ignoring the change in that ratio resulting from the very small observed change in mean temperature, the change in pan evaporation resulting from a change in net irradiance can be approximated as:

$$\lambda\delta E_{\text{pan}} \approx \frac{1.26}{0.70}\left(\frac{s}{s+\gamma}\right)\delta R_n \qquad (4)$$

For an evaporation pan, R_n is nearly linearly related to the global solar irradiance (R_s, J m^{-2} s^{-1}), so that in differential form we have

$$\delta R_n \approx c\,\delta R_s \qquad (5)$$

where c is ~0.8 (*16, 17*). Thus, the change in pan evaporation resulting from a change in global solar irradiance can be approximated as:

$$\lambda\delta E_{\text{pan}} \approx 1.44\left(\frac{s}{s+\gamma}\right)\delta R_s \qquad (6)$$

In general, measurements of global solar irradiance are not as readily available as measurements of pan evaporation. However, much of the original work reporting the decrease in pan evaporation was from the northwest of the former Soviet Union (49° to 67°N) (*2, 9*), fortunately one of the few regions of the world where such regional measurements are available for the same period (*19*). Here we use those data, along with Eq. 6, to calculate the expected change in annual pan evaporation over a 30-year period (1960 to 1990), which is then compared with the observed change. In the region of interest, R_s decreased by 2 to 4% per decade from 1960 to 1990, and a typical annual total R_s in that region is in the range of 3000 to 4000 MJ m^{-2} per year (a^{-1}) (*19*). Assuming that R_s is 3500 MJ m^{-2} a^{-1} and is declining at a rate of 3% per decade over the 30-year period of interest, then δR_s would be −315 MJ m^{-2} a^{-1}. With $s/(s + \gamma)$ in the range of 0.48 to 0.82, the reduction in latent heat loss would be in the range (~1.44 × 0.48 × 315 to 1.44 × 0.82 × 315) of ~217 to 372 MJ m^{-2} a^{-1}, which is equivalent to a decrease in annual pan evaporation of ~90 to 155 mm a^{-1}. The observed pan evaporation at seven sites in the region show a rate of decrease ranging from 1.5 mm a^{-2} to 6.7 mm a^{-2}, and the average rate of decrease is 3.7 mm a^{-2} (*9*). Over the 30-year period of interest, this equates to a decrease in annual pan evaporation of 110 mm a^{-1}, consistent with our estimate of ~ 90-155 mm a^{-1}.

We have encountered considerable scepticism about the large reported declines in global solar irradiance. The issue is that most climate models as yet do not include the 10 to 20% reductions observed in many places over the past 50 years (*7, 20*). However, we have a further independent check. A substantial decline in global solar irradiance as a consequence of increased cloud coverage and/or aerosol concentration should result in a decrease in the DTR, because increases in clouds and/or aerosols dampen the diurnal cycle by reducing the incident sunlight and also by reducing the net loss of long-wave irradiance from the surface at night (*8, 21*). This was recently highlighted by the marked increase in DTR over parts of the United States from 11 September to 14 September 2001 when aircraft were grounded (*22*). Thus, the widespread longer-term decreases in DTR (*1, 13, 14*) are qualitatively consistent with the widespread observed decreases in global solar irradiance (*7, 20*). Quantifying that, we estimated the expected decrease in DTR with the use of an approximate relation between the transmission of solar irradiance through the atmosphere and the DTR (*23*). Over the same part of the former Soviet Union, the change in DTR computed from the observed change in solar irradiance is ~−0.2°C decade^{-1} (see SOM Text) and is consistent with the observed changes of ~−0.1° to −0.3°C decade^{-1} in the DTR (*1, 14*).

We conclude that the observed decrease in pan evaporation is not a paradox after all. Instead, the decrease is to be expected given the decreases in solar irradiance and the associated changes in DTR and vapor pressure deficit that have been observed. Further, the observed decrease in the DTR is itself qualitatively and quantitatively consistent with the observed decrease in global solar irradiance. These results highlight the fundamental importance of evaluating the direction and magnitude of changes in the surface energy balance resulting from greenhouse forcing as opposed to the direction and magnitude of changes resulting from aerosol loading (*8*). Such an evaluation is also important when estimating the biological and ecological impacts of changes in climate, because clouds and aerosols scatter light and thereby reduce the shade within vegetation canopies, markedly affecting the structure and productivity of terrestrial vegetation (*24, 25*). The interactions between global solar irradiance, diurnal temperature range, and pan evaporation, which have been highlighted here, are all related to variations in the transmission of solar irradiance through the atmosphere and appear to be very general features of the climate and the climate-vegetation systems.

References and Notes

1. C. K. Folland *et al.*, in *Climate Change 2001: The Scientific Basis*, J. T. Houghton *et al.*, Eds. (Cambridge Univ. Press, Cambridge, 2001), pp. 99–181.
2. T. C. Peterson, V. S. Golubev, P. Y. Groisman, *Nature* **377**, 687 (1995).
3. N. Chattopadhyay, M. Hulme, *Agric. For. Meteorol.* **87**, 55 (1997).
4. A. Thomas, *Int. J. Clim.* **20**, 381 (2000).
5. S. Cohen, A. Ianetz, G. Stanhill, *Agric. For. Meteorol.* **111**, 83 (2002).
6. W. Brutsaert, M. B. Parlange, *Nature* **396**, 30 (1998).
7. G. Stanhill, S. Cohen, *Agric. For. Meteorol.* **107**, 255 (2001).
8. V. Ramanathan, P. J. Crutzen, J. T. Kiehl, D. Rosenfeld, *Science* **294**, 2119 (2001).
9. V. S. Golubev *et al.*, *Geophys. Res. Lett.* **28**, 2665 (2001).
10. J. Szilagyi, G. G. Katul, M. B. Parlange, *J. Water Resour. Plann. Manage.* **127**, 354 (2001).
11. D. J. Gaffen, R. J. Ross, *J. Clim.* **12**, 811 (1999).
12. P. J. Robinson, *Int. J. Clim.* **20**, 985 (2000).
13. T. R. Karl *et al.*, *Bull. Am. Meteorol. Soc.* **74**, 1007 (1993).
14. D. R. Easterling *et al.*, *Science* **277**, 364 (1997).
15. H. L. Penman, *Proc. R. Soc. London Ser. A* **193**, 120 (1948).
16. E. T. Linacre, *Agric. For. Meteorol.* **64**, 237 (1993).
17. ———, *Water Int.* **19**, 5 (1993).
18. C. H. B. Priestley, R. J. Taylor, *Mon. Weather Rev.* **100**, 81 (1972).
19. G. M. Abakumova, E. M. Feigelson, V. Russak, V. V. Stadnik, *J. Clim.* **9**, 1319 (1996).
20. H. Gilgen, M. Wild, A. Ohmura, *J. Clim.* **11**, 2042 (1998).
21. A. Dai, K. E. Trenberth, T. R. Karl, *J. Clim.* **12**, 2451 (1999).
22. D. J. Travis, A. M. Carleton, R. G. Lauritsen, *Nature* **418**, 601 (2002).
23. K. L. Bristow, G. S. Campbell, *Agric. For. Meteorol.* **31**, 159 (1984).
24. M. L. Roderick, G. D. Farquhar, S. L. Berry, I. R. Noble, *Oecologia* **129**, 21 (2001).
25. L. Gu *et al.*, *J. Geophys. Res.* **107**, ACL 2-1 (2002).

26. We thank M. Canny, I. Cowan, F. Dunin, E. Linacre, and S. Roxburgh for helpful discussions.

Supporting Online Material
www.sciencemag.org/cgi/content/full/298/5597/1410/DC1
SOM Text
References and Notes

24 June 2002; accepted 1 October 2002

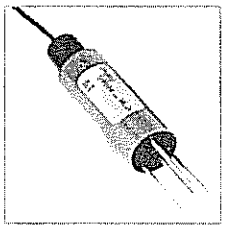
OMEGASCOPE®
Handheld Infrared Thermometer
Loaded with Features–New Distance Measurement Option Available!

OMEGASCOPE®
OS533E
$550
Other models available starting at $295

New! Built-In Distance Measurement Options Available! *See Page J-16.*

Products

ThetaProbe Soil Moisture Sensor - ML2x



- ±1% accuracy
- Easy data logger connection (DC in DC out)
- Excellent temperature and salinity stability
- Dual purpose: either hand-held for spot readings or left in-situ for data logging

With the ThetaProbe it's easy to make reliable, accurate soil moisture measurements. Simply insert the probe into the soil, connect to your data logger or meter, provide 5-15V DC at 20mA, and within seconds you can be logging soil moisture.

ThetaProbes are robust, buriable and maintenance free. They can be easily installed at depth in the soil by inserting them into augered holes using the optional extension tubes.

ThetaKit

This portable kit contains all the items needed to make rapid spot readings of soil moisture content with a ThetaProbe. The Thetakit includes an Moisture Meter type HH2, spare ThetaProbe rods, insertion kit and carrying case.

Applications

Typical application areas include irrigation, hydrology, civil engineering, soil water profiling, pollution monitoring and forestry. Because the ML2x has a predictable saline response (which actually declines as salinity increases) it can be used even in very saline soils - up to 2000 mS.m-1. The ThetaProbe is not limited to the measurement of soil moisture content - it is also used in non-soil media; please enquire for further details.

ThetaProbes are the result of collaborative development with the Macaulay Land Use Research Institute (MLURI). Please click on the MLURI link, below, to visit the ThetaProbe pages of the MLURI web site.

Downloads and Documentation

' Soil Moisture Measurement Catalogue '

'Grower Product Summary'

TK3 ThetaKit Data Sheet

ThetaProbe Soil Moisture Sensor type ML2x User Manual, v1.21, May 1999. Document Code: ML2x-UM-1.21
Link to ThetaProbe ML2x Principles of Operation and Applications. MLURI Technical Note (2nd ed). J D Miller and G J Gaskin, Macaulay Land Use Research Institute

FAQs

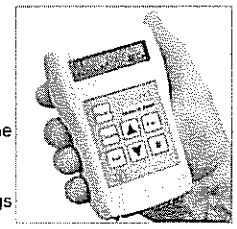
Related Products

Data Logger - DL2e

Data Logger and Irrigation Monitor - GP1

Moisture Meter - HH2

Moisture Meter - HH2



- Holds multiple user-defined soil types
- Stores up to 2000 time-stamped readings
- Includes PC data collection software

The Moisture Meter type HH2 is a versatile readout unit for use with Delta-T soil moisture sensors: the Profile Probe, ThetaProbe, SM200 and WET Sensor.

The HH2 offers impressive functionality in a compact, hand-held unit, designed for field use. Readings are displayed on the LCD and can be stored to memory for later download to a PC.

The unit can be operated with one hand, for convenience in the field. Each time-stamped reading includes a unique sample number, a plot identification number (A to Z), and a sensor location number (1 to 255).

Data is transferred to a PC using the RS-232 cable provided with each unit. The HH2Read Windows PC software provides a data import wizard for direct download into Excel or other PC spreadsheet packages, or into irrigation scheduling programs. Alternatively, data can be downloaded in comma-separated ASCII data file (.CSV) format.

Downloads and Documentation

' Soil Moisture Measurement Catalogue '

Dataset Import Wizard Notes for HH2 Users, v3 22/11/2004. Document Code: none

HH2 HelpSheet v4, Nov 2005

User Manual for the Moisture Meter HH2, v4.0 Oct 2005. Doc Code: (HH2-UM-4.0)

HH2Read 2.4

FAQs

Related Products

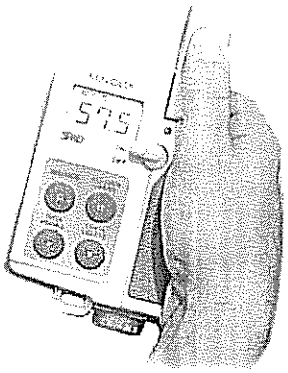
ThetaProbe Soil Moisture Sensor - ML2x

Soil Moisture Sensor - SM200

Profile Probe - PR2

WET Sensor - WET-2

Minolta SPAD 502 Meter



Measure and record Chlorophyll N measurements in just seconds with the SPAD 502 Meter - now exclusively available with or without a built-in data logger!

The SPAD 502 Chlorophyll Meter instantly measures the amount of chlorophyll content, a key indicator of plant health. Simply clamp the meter over leafy tissue, and receive an indexed chlorophyll content reading (0-99.9) in less than 2 seconds.

Assess nitrogen needs by comparing in-field SPAD readings university guidelines or adequately fertilized check or reference strips. Research shows a strong correlation between SPAD measurements and leaf N content. You benefit by increasing reducing costly under/overfertilizing, increasing N-efficiency and producing healthier, higher-yield crops.

The SPAD 502 is now available with an integrated datalogger! The SPAD 502 DL includes all the features of a regular SPAD meter along with a GPS-compatible data logger. Store up to 4,096 measurements (1488 with GPS coordinates) for easy analysis. You can also add a data logger to your existing SPAD 502 - call for details.

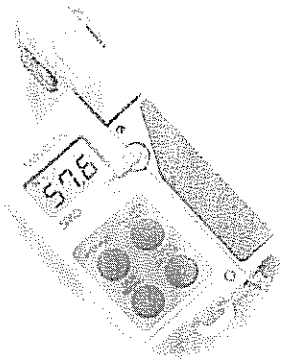
Click to view a study on Chlorophyll measurement for Nitrogen in Wheat.
Click to view a study on Chloropyll Measurement for Nitrogen in Corn.
Click to view a study on Use of SPAD 502 for Nitrogen Assessment.
SPAD 502 Manual coming soon!

Item #	Description	Price	Qty	
2900	Minolta SPAD 502 Chlorophyll Meter	$1495.00	1	Order
2900DLUP	Minolta SPAD 502 Upgrade (includes data logger, RS-232 port, & software)	$395.00	1	Order
2950CV5	GPS/DGPS Cable	$39.00	1	Order

Refer This Page To A Friend

12360 South Industrial Dr., East - Plainfield, Illinois 60585
(800) 248-8873 / (815) 436-4440 Fax: (815) 436-4460
info@specmeters.com

Minolta SPAD 502 DL Meter



Measure and record Chlorophyll N measurements in just seconds with the SPAD 502 Meter - now exclusively available with or without a built-in data logger!

The SPAD 502 Chlorophyll Meter instantly measures the amount of chlorophyll content, a key indicator of plant health. Simply clamp the meter over leafy tissue, and receive an indexed chlorophyll content reading (0-99.9) in less than 2 seconds.

Assess nitrogen needs by comparing in-field SPAD readings university guidelines or adequately fertilized check or reference strips. Research shows a strong correlation between SPAD measurements and leaf N content. You benefit by increasing reducing costly under/overfertilizing, increasing N-efficiency and producing healthier, higher-yield crops.

The SPAD 502 is now available with an integrated datalogger! The SPAD 502 DL includes all the features of a regular SPAD meter along with a GPS-compatible data logger. Store up to 4,096 measurements (1488 with GPS coordinates) for easy analysis. You can also add a data logger to your existing SPAD 502 - call for details.

Click to view a study on Chlorophyll measurement for Nitrogen in Wheat.
Click to view a study on Chloropyll Measurement for Nitrogen in Corn.
Click to view a study on Use of SPAD 502 for Nitrogen Assessment.
SPAD 502 Manual coming soon!

Item #	Description	Price	Qty	
2900DL	Minolta SPAD 502DL with Datalogger 5+ Units, $1825.00	$1895.00	1	Order
2900DLUP	Minolta SPAD 502 Upgrade (includes data logger, RS-232 port, & software)	$395.00	1	Order
2950CV5	GPS/DGPS Cable 5+ Units, $39.00	$39.00	1	Order

Refer This Page To A Friend

12360 South Industrial Dr., East - Plainfield, Illinois 60585
(800) 248-8873 / (815) 436-4440 Fax: (815) 436-4460
info@specmeters.com

Corning® Checkmate II Modular Meter System

Order what you need now-expand later

The Checkmate II has a broad selection of specific, dedicated sensors that measure many parameters, including pH, mV, redox/ORP, ion concentration, conductivity, total dissolved solids, temperature and dissolved oxygen. Module expands as your needs expand.

Features:

- Upgradeable software, plus display has flexible area to enable new units of measure to be added.
- Extension cable converts a Checkmate II sensor to a leaded sensor.
- Duo-function probe lets you measure temperature, pH/mV and conductivity/TDS simultaneously. Trio-function probe also allows you to measure dissolved oxygen. Probes sized to fit standard beakers.
- Automatic switch off. If unit is not operated for 10 min after end point, it turns off. For continuous measurement, this feature can be deactivated.
- Self-diagnostic. Continuously monitors battery power, verifies that sensors are calibrated, and critiques slope values in pH. If it detects a disparity, meter displays problem-specific code.
- Environmentally sealed against dust and moisture.

The Checkmate II meter can save results of up to 199 measurements per parameter with a total storage capacity of 350 data records. Each measurement includes result, measured temperature, and time and date of measurement. Results can be downloaded to computer via RS232 interface cable, sold separately.

Other accessories include a ring stand holder to be used during lab measurements or data downloading and a field case that holds meter, sensors, spare AA batteries, test plug, sample

container, and sachets of calibrating standards.

Adapters add flexibility. ISFET pH adapter enables the Checkmate II meter module to use Corning's Ion Sensitive Field Effect Transistor (ISFET) sensors. The BNC adapter connects any pH electrode with a BNC connector to the meter module. Also enables the meter's onboard Ion Concentration mode of operation. Using the Temperature Sensor adapter, the full range (-50°C to 950°C) of the meter's temperature measuring capability is accessible using any of Corning's K-type temperature probes.

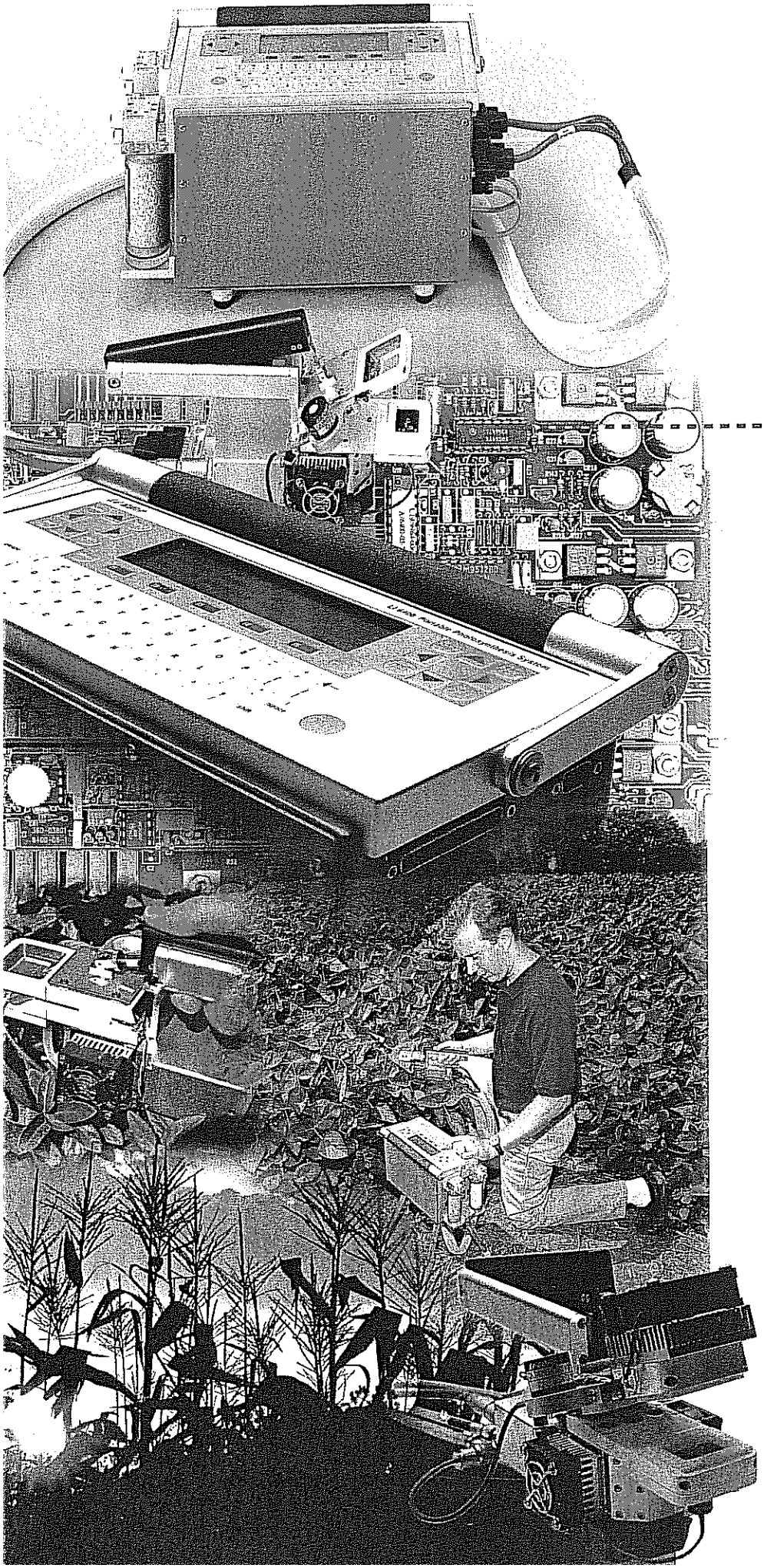
Specifications for the Checkmate II Modular Meter System

Mode	Range	Resolution	Accuracy
pH	0-14	0.1/0.01/0.001 (selectable)	±0.01
ATC	0-100°C		
mV	±1999.9	0.1	±0.2
Conductivity	0.00-1999µS	0.01/0.1/1µS	±0.5% MSV
	2.00-199.9mS	0.01/0.1mS (auto ranging)	
TDS	0.00-999mg/L	0.01/0.1/1mg/L	±0.5% MSV
	1.00-99.9g/L	0.01/0.1g/L (auto ranging)	
ATC	0-50°C		
$\%O_2$	0-200%	0.1	±1% O_2
mg/L O_2	0-20	0.01	±0.10mg/L
ATC	0-40°C		
Concentration	0-19,999	±1LSD	±0.5% of value
mV	±1999.9	0.1	±0.2 mV
°C	-50 to 950	0.1/1 (auto ranging)	±1°C; ±0.5% of value
°F	-58 to 1742	0.1/1 (auto ranging)	±2°F; ±0.5% of value

Meters

Click on price to add to basket.

Cat.No.	Description	Price
37-475632	Deluxe field system (Includes in hard-sided case: meter; pH, conductivity, dissolved oxygen probes; selection of calibration sachets; rinse solution and 2 AA batteries)	CALL FOR PRICING CS of 1
37-475631	Deluxe field system with extension cable (Includes in hard-sided case same items as no. 1-475632)	CALL FOR PRICING CS of 1
37-475633	pH system complete	CALL FOR PRICING CS of 1
37-475634	Conductivity/TDS system	CALL FOR PRICING CS of 1
37-475635	Dissolved oxygen system	CALL FOR PRICING CS of 1



LI-6400 Portable Photosynthesis System

LI-COR®
ENVIRONMENTAL DIVISION

LI-6400XT Portable Photosynthesis System

- Precise measurements and rapid response times
- Integrated gas exchange/fluorescence
- Internal and removable Flash memory
- Software simulator and autoprograms

Take the Tour!

Why the LI-6400XT?

Multiple Applications
Performance
Integration
Software
Support

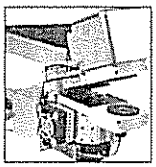
Whatever the demands, the LI-6400XT can provide a solution for your research needs.

Photosynthesis

The LI-6400 was the first photosynthesis measurement system to put the CO_2 and H_2O gas analyzers in the sensor head. These dual path, non-dispersive infrared analyzers feature an open path design with the optical bench of the sample analyzer open directly to the leaf chamber mixing volume. Leaf dynamics are measured in real time, preventing confounding correlations between gas exchange and changes in environmental driving variables

Fluorescence

The field-installable Leaf Chamber Fluorometer easily attaches to the LI-6400XT sensor head. This integrated system gives the user complete control of the leaf environment for simultaneous collection of gas exchange and chlorophyll fluorescence data from a single, portable unit

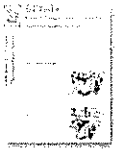


Soil Respiration

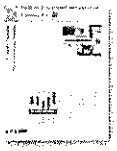
Attach the Soil CO_2 Flux Chamber to the LI-6400XT System for an additional carbon cycle application. A pre-defined software protocol and automated measurement cycling ensure ease of use and accurate data collection.

What's New

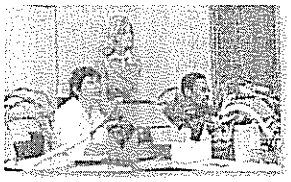
6400-89 Insect Respiration Kit
Use this new kit to measure the respiration rate of insects, small mammals, small fruits, nuts, etc.
View document



6400-88 Expanded Temperature Control Kit
Use this new kit to increase the range of temperature control of the LI-6400/6400XT sensor head block.
View document



LI-6400/6400XT Training



- 6400-810 Training Course - Gas Exchange
- 6400-820 Training Course - Gas Exchange plus Fluorescence

More Video preview

Biotechnology
4647 Superior St
Lincoln, NE 68504
Toll-Free: 800-645-4267
Email: biohelp@licor.com

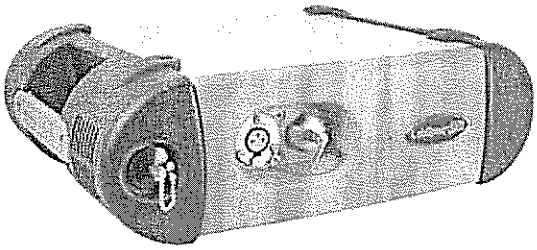
Environmental
4421 Superior Street
Lincoln, NE 68504
Toll-Free: 800-447-1576
Email: envsales@licor.com

ASD Inc. NIR Solutions for the Real World.

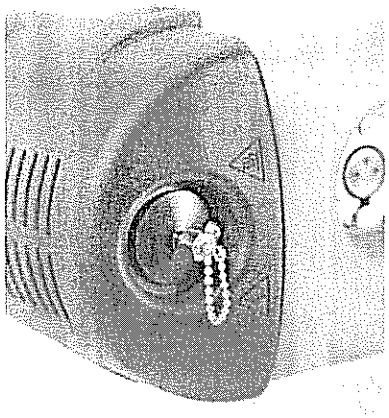
2555 55th St., Suite 100 • Boulder, CO 80301 • Phone: (303) 444-6522 • Fax: (303) 444-6825 • Email: info@asdi.com

VIS/NIR SPECTROMETERS — LABSPEC® 5000 / 5100 SERIES

Product Specifications

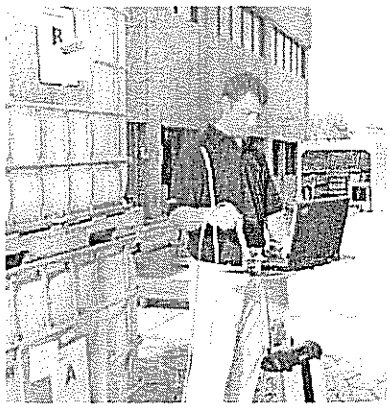


LabSpec® 5000 / 5100 series—the latest in truly portable post-dispersive ultra-rugged spectrometers. The LabSpec® 5000 / 5100 series incorporates the benchmark power of the award winning LabSpec® Pro's broad spectral range (350-2500 nm) and combines it with Ethernet and optional wireless functionality, as well as expanded temperature operating parameters for reliability even in extreme environments. Also standard is a more ruggedized exterior design with non-slip, urethane end-caps and easily accessible, integrated, high performance Wide Band Halogen light source featuring higher output and stability. In addition to the ASD Indico software, the LabSpec® 5000 / 5100 series includes a streamlined compatibility with LabVIEW® software for autonomous control of the spectrometer. The new series also offers enhanced remote instrument diagnostics, embedded Remote Trigger port, and the new NIR Cooled InGaAs TurboScanner™ technology from ASD. LabSpec® 5100 is the higher resolution version of the series.



Shown left: Close-up of the new easily accessible, integrated, high-performance Wide Band Halogen light source.

The LabSpec® 5000 / 5100 Series is a rapid, hybrid post-dispersive system with high sensitivity and extremely low stray-light for more robust qualitative and quantitative applications. The integrated light source, standard SMA 905 fiber optic connectors and ASD's wide array of sampling accessories offer maximum flexibility, making LabSpec® 5000 and 5100 incredibly powerful tools for a wide range of applications. ASD's spectrometers are ideally suited to a growing list of applications for solids, powders, slurries and liquids in many forms for a variety of markets addressing incoming raw and in-process materials, all the way through finished product.



Shown right: LabSpec® 5000 and Helma Dip Probe with ASD's new light weight goLab™ Mobile Workstation for incoming inspection of bulk liquids on a receiving dock.

Labspec® 5000 (10 nm NIR resolution) and Labspec® 5100 (6 nm NIR resolution) are the latest in truly portable, post dispersive, NIR analyzers from Analytical Spectral Devices (ASD). They offer research-grade instrument performance in a rugged package suitable for transport to the sample location.

New features with the LabSpec® 5000/5100 series:

- Easily accessible integrated high performance Wide Band Halogen light source featuring higher output and stability
- Smaller and lighter (12 lbs or 5.44 kg)
- Improved ruggedness, now with protective non-slip urethane end caps
- Ethernet connectivity with optional wireless operation
- ASD Software Developer's Kit to allow for autonomous control of spectrometer (compatible with LabVIEW® systems, and C)
- New NIR Cooled InGaAs TurboScanner™ technology
- Expanded temperature operating parameters (0-40°C)
- Multiple battery options along with DC and AC power
- Enhanced remote diagnostics (via internet)
- Embedded trigger
- Comes standard with ruggedized Pelican case for easy transport and storage
- New goLab™ Mobile Workstation or Ergonomic ProPack for convenient field use (available separately)

The 5000/5100 series also provides the benchmark characteristics of the award winning LabSpec® Pro:

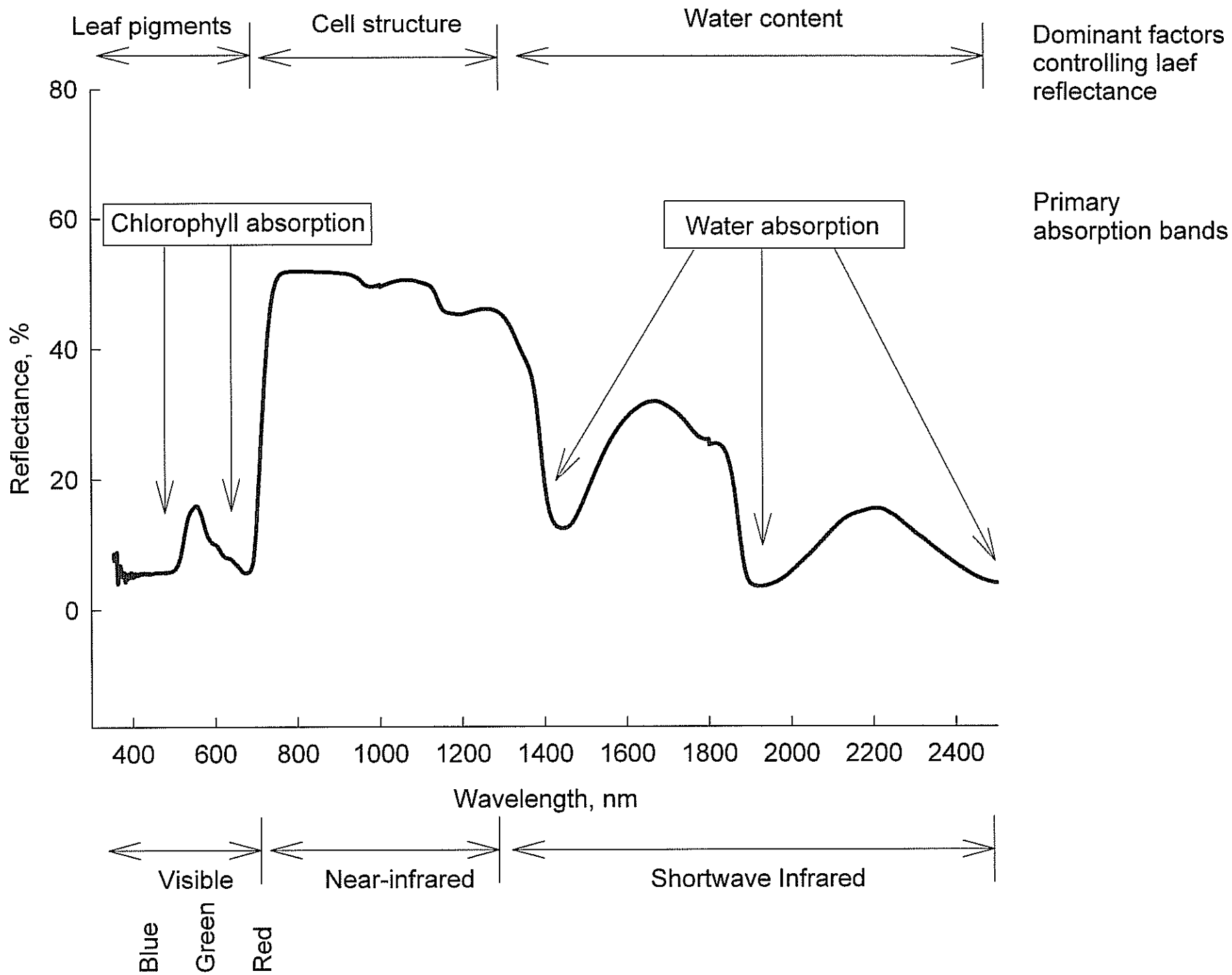
- 350-2500 nm spectral coverage, available in six modular configurations, offers the added benefit of the Visible and Third Overtone Regions
- Post-dispersive hybrid system with extremely low stray light
- Qualitative and quantitative capabilities
- Rapid scan time (100 ms)
- Industry standard SMA 905 fiber optic connectors
- Multiple sampling accessories for compatibility with a wide array of specialized sampling requirements
- User friendly Indico™ Pro software with the proprietary ASD Rapid Classifier
- Real time interface with Grams™ and Unscrambler® chemometrics packages

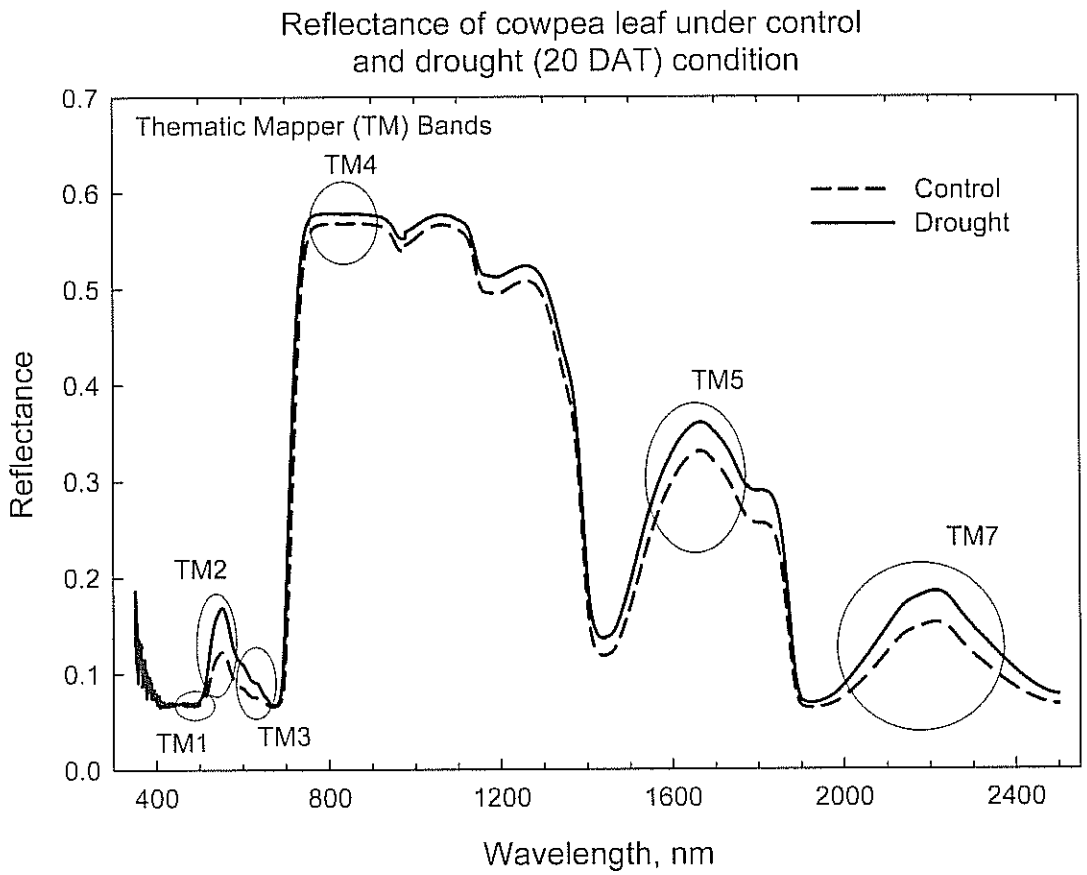
The LabSpec® analyzers are ideally suited to a growing list of applications for solids, powders, slurries and liquids in many forms for a variety of markets:

- Raw materials to finished products
- Pharmaceuticals/nutraceuticals
- Foods, dairy, and grains
- Petrochemicals
- Wood and wood products (resins and wax)
- Pulp and paper
- Carpet
- Biomass/Biodiesel

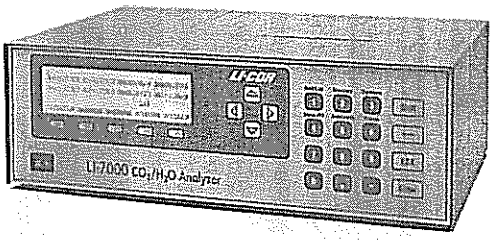
Value-Added Benefits of ASD Vis/NIR Technology for Industry

Typical Spectral Characteristics for Green Vegetation




Reflectance of cowpea leaf under control
and drought (20 DAT) condition
Thematic Mapper (TM) Bands
TM4
TM5
TM7
TM2
TM1
TM3
Control
Drought
Reflectance
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
400
800
1200
1600
2000
2400
Wavelength, nm

LI-7000 CO_2/H_2O Gas Analyzer: Features and Benefits for Eddy Covariance Studies



High flow rates with minimal pressure drop, ***lightning fast*** data output rates (USB, RS-232) and support for a new ***digital input trigger*** are some of the key features of the LI-7000 for use in eddy covariance studies.

A new 400 MHz microprocessor allows for even more flexibility when integrating the LI-7000 into ***carbon cycle measurement systems***, with important new features that include:

- Increased ***auxiliary input bandwidth*** allows fast response analog data (such as from a sonic anemometer) to be input to the LI-7000 and then output along with analyzer data as a single data string to the USB or RS-232 interface.

- An ***external trigger signal input*** is now available via the RS-232 port. This is a tool that allows an external host computer or datalogger to poll the LI-7000 for the nearest 1/600 second measurement (e.g. CO_2, H_2O, Temperature, Pressure, Diagnostics) in order to synchronize with data from another device such as a sonic anemometer. The serial data request is then transmitted to both the RS-232 and USB interfaces.

- A choice of ***multiple baud rates*** (9600-115,200 bps) allows flexibility for custom data acquisition programs. High data transfer speeds are important when synchronizing data from multiple high speed devices on the host computer.

  For example, at 115,200 baud, as many as 20 variables logged at 40 Hz can be output with no missed data points.*

- A ***data checksum*** feature ensures the integrity of data (RS-232 and USB) transmitted between the LI-7000 and a computer. This is important in electrically noisy environments where high flow rate pumps can induce noise into data cables.

- Four 14-bit user-scalable ***Digital-to-Analog Converters (DAC) with update rates*** that have been increased from 300 to 600 Hz. Analog representation of LI-7000 measurements such as concentration, temperature and pressure can be fed into high speed dataloggers or sonic anemometers supporting an analog-to-digital conversion.

* Assumes minimum computer configuration as follows: 850 MHz Pentium III processor, 256 MB RAM, Windows® 2000/XP, no charting.

LI-COR Biosciences

4647 Superior Street • P.O. Box 4425 • Lincoln, Nebraska 68504 USA
North America: 800-447-3576 • International: 402-467-3576 • FAX: 402-467-2819
envsales@licor.com • envsupport@licor.com • www.licor.com

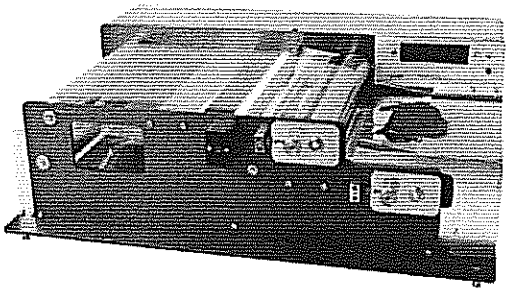
In Germany and Norway - LI-COR GmbH: +49 (0) 6172 17 17 771
envsales-gmbh@licor.com • envsupport-gmbh@licor.com
In United Kingdom and Ireland - LI-COR UK Ltd: +44 (0) 1223 422102
envsales-UK@licor.com • envsupport-UK@licor.com

LI-COR Biosciences

Measuring Change in a Changing World

LI-3100C Area Meter

Precise, Rapid Measurements of Large or Small Leaves



The LI-3100C Area Meter is designed for efficient, exacting measurements of both large and small objects. User-selectable area resolution of either 1 mm^2 or 0.1 mm^2 is available without having to change optics. This versatility provides the flexibility necessary for diverse project requirements.

- Area, Length, Maximum Width, Average Width
- A single lens provides adjustable resolution of 0.1 or 1 mm^2
- High accuracy and repeatability, and fast, continuous operation for large quantities of samples with individual or cumulative area recorded
- Large (25 cm wide, 2.5 cm thick with 1 mm^2 resolution) or small (<1 cm^2 area when using 0.1 mm^2 resolution) leaves or other objects, including needles
- Quiet belt system with adjustable press roller to flatten curled leaves
- Data are shown on the instrument LED display or on the computer screen using Windows® software to collect and store data via RS-232 or USB

Why the LI-3100C Area Meter?

- Simple, Fast and Accurate
- Proven Technology
- Choice of resolutions
- Windows® Interface Software
- Data stored directly to a computer

LI-COR Biosciences

Biotechnology
4647 Superior St
Lincoln, NE 68504
Toll-Free: 800-645-4267
Email: biohelp@licor.com

Environmental
4421 Superior Street
Lincoln, NE 68504
Toll-Free: 800-447-3576
Email: envsales@licor.com

LI-COR Biosciences

Measuring Change in Changing World

Env Home | Applications | Products | Support | Contact | Search

LAI-2000 Plant Canopy Analyzer

New! LAI-2000 Windows™ Software

For Direct, Rapid, Non-Destructive LAI Measurements

Why Measure Leaf Area Index (LAI)?

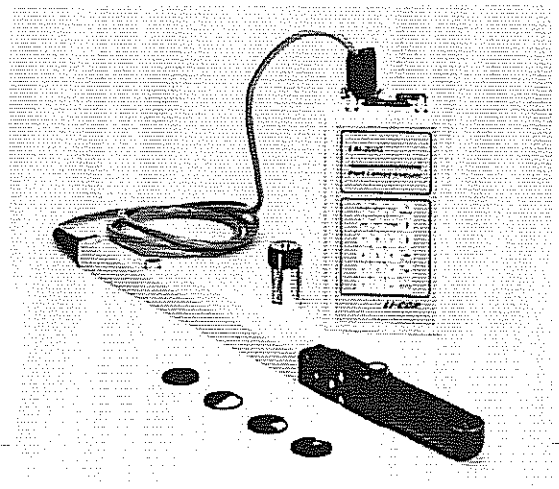
Leaf Area Index (LAI) is the ratio of the foliage area to the ground area. The measurement of LAI is of fundamental importance in agricultural and ecological research because LAI is a measure of plant growth; it directly affects the interception and absorption of light by the canopy and it influences the heat balance and evaporation from the landscape.

Why should you consider the LAI-2000 to measure Leaf Area Index?

The LAI-2000 is the premier LAI instrument in the world.
- Saves time and labor
- Provides on-site evaluation of LAI data
- Can be used for short or tall canopies (i.e. grass to forest)
- Used for broad canopies (i.e. forest), small isolated canopies (i.e. individual trees) or row crop canopies
- Calculates foliage inclination angle and other relevant parameters
- Can be used under a variety of sky conditions, including sunny conditions
- Either of three modes of operation can be chosen, depending on the canopy

The LAI-2000 calculates Leaf Area Index (LAI) and other canopy structure attributes from radiation measurements made with a "fish-eye" optical sensor (148° field-of-view). Measurements made above and below the canopy are used to determine canopy light interception at 5 angles, from which LAI is computed using a model of radiative transfer in vegetative canopies.

NEW! FV2000 Windows Software for downloading and post-processing of LAI-2000 data. For more information click here.



LI-COR Home | Biotechnology | Environmental | Careers | Contact LI-COR | Search

LI-COR Biosciences

Biotechnology
4647 Superior St
Lincoln, NE 68504
Toll-Free: 800-645-4267
Email: biohelp@licor.com

Environmental
4421 Superior Street
Lincoln, NE 68504
Toll-Free: 800-447-3576
Email: envsales@licor.com

Questions & Answers

LAI-2000 Plant Canopy Analyzer

Q. *How can it correctly measure leaf area if the sensor can't see all the leaves, or if the leaves overlap?*

A. Leaf area is not calculated by viewing all the leaves. Rather, it is calculated from how much radiation is extinguished as it passes through the canopy. Random leaf positioning is assumed, implying a certain amount of leaf overlap. In fact, if a particular canopy had leaves positioned so that no leaf overlap were present, it would cause an error in the LAI-2000's computed result, because radiation is extinguished faster than the ideal in this case.

Q. *How big a plot is necessary?*

A. A rough rule of thumb is that plot radius (distance from the sensor location) should be 3 times the plot height. However, in dense canopies less distance may be required, because the sensor may not be able to see that far through the canopy.

Q. *What if a plot isn't that big?*

A. View caps can be used to prevent the sensor from seeing in a particular direction, allowing readings to be made near the edge of a plot, and reducing the total plot size necessary. Another remedy for small plots is to do the analysis neglecting the outer ring. The LAI-2000 software does not support this, but it can be done using the C2000 program.

Q. *How short can a canopy be and still get good measurements?*

A. There are several considerations when determining if a canopy is too small. First, does the presence of the sensor disturb the canopy? (Are new gaps created when the sensor is pushed in?) Second, the LAI-2000 assumes the foliage elements are small compared to the area of view of each ring. In general, the distance from the optical sensor to the nearest foliage at an angle of 30° should be at least 4 times the leaf width.

Q. *Will the LAI-2000 work in coniferous forests?*

A. Recent work by Gower and Norman (1990) indicates that the LAI-2000 can be successfully used in forest settings. In conifer stands, they found that the LAI-2000 underestimated LAI by 35-40%, apparently due to the fact that the instrument is sensing projected area of shoots, rather than needles. They further found that a correction factor, which is based solely on shoot morphology and can be independently measured, appears to adequately compensate for this. Their suggested technique is to determine the ratio of projected shoot area to total needle area for the particular species being measured, and then multiply the LAI-2000's results by this ratio.

Q. *Can the LAI-2000 differentiate between species - weeds and corn, for example?*

A. No. It only responds to objects (foliage, etc.) that block the transmission of radiation.

Q. *Will the LAI-2000 detect insect defoliation?*

A. Yes, but measurements should be made in the exact same places each time to remove spatial variability from the results.

Q. *Can I measure a single plant?*

A. Yes, assuming that the plant is isolated enough and that the leaves are small enough.

Q. *At the location where my research is conducted, it is almost never cloudy. Can I still take accurate measurements with the LAI-2000?*

A. Sunlit foliage will cause the LAI-2000 to underestimate LAI. To make measurements under these conditions, two techniques should be used. First, a view cap should be used to mask the portion of the sky that contains the sun. Second, the canopy should be shaded as much as possible within the sensor's field of view. Measurements could be taken at dawn or dusk when the sun is near the horizon which minimizes the sunlit leaf area seen by the sensor. When the sun is low in the sky, it is much easier to shade the canopy.

Q. *I have a line quantum sensor that I was going to use to measure LAI. What advantages does the LAI-2000 offer?*

A. Measurements with the LAI-2000 will be much quicker than with a line quantum sensor. A typical measurement with the LAI-2000 takes less that one minute for a short canopy. The line sensor technique relies on direct solar radiation and necessitates waiting for the sun angle to change in order to determine canopy interceptance at several angles. Or, if you assume an extinction coefficient (leaf angle distribution), a line quantum sensor can be used at one angle. The LAI-2000 looks at 5 angles simultaneously for each measurement.

The sample size when using the line sensor technique is limited, since the sensor only samples the portion of the canopy that lies between the sun and the sensor. With its fisheye field-of-view, the LAI-2000 can see 360° (with no view cap).

Lastly, the LAI-2000 calculates LAI immediately after the measurement, allowing on-site inspection and verification of the data.

Q. *Can I measure canopy PAR absorption with the LAI-2000?*

A. Not directly. The LAI-2000 is designed to measure foliage structure, which is only one of several factors determining absorption. Also, the spectral range of the sensor does not correspond to the PAR region, so it should not be used as a PAR sensor. The diffuse non-interceptance value (DIFN) calculated by the LAI-2000 is a direct estimate of how much diffuse sky radiation gets through the canopy, and (1 - DIFN) would be the absorbed sky radiation; but all this assumes that the foliage does not scatter radiation. Also, this neglects what happens to direct beam radiation, which is a function of solar position. The direct beam absorption could be inferred, perhaps, from the mean gap fraction measurements at the five zenith angles based on diffuse radiation, but this would still neglect the contribution of scattered radiation.

Another approach is to model canopy absorption based on the canopy structure (as measured with the LAI-2000), the foliage reflectance and transmittance, the reflectance of the ground, and measurements of incident total PAR and the fraction thereof that is direct beam.

Q. *What is Mean Tip Angle (MTA) good for?*

A. Gap fraction data at different angles potentially hold two types of information: amount of leaf area and leaf orientation distribution. See Perry et al (1988) for a discussion of how much information can be reliably extracted from gap fraction data. The LAI-2000 calculates MTA as a measure of how the leaves are oriented.

Q. *I've never heard of this "indirect" way to measure LAI. Has the model and the LAI-2000 be thoroughly tested?*

A. Actually, the only thing that is new in the LAI-2000 is the technique used to obtain the gap fraction. Methods of inverting gap fraction data to get canopy structure have been used for many years.

During the development of the LAI-2000, there were a number of verification studies, as described in recent work by Welles and Norman (1990) and in an application note available from LI-COR. Verification work started in summer 1988 and has continued on since then. A wide variety of canopies were used in the verification research, ranging in size from forests to prairie grass. The LAI-2000 data was compared to data from other indirect measurement techniques (fisheye photograph analysis, etc.), and to data from canopies which were harvested (100%) and measured with an electronic area meter.

Q. *Is the C2000 program necessary? What does it do?*

A. The program is not necessary to calculate LAI or MTA. C2000 is useful, because it duplicates and extends many of the calculations and output functions of the control unit. The C2000 program requires input data in the form of LAI-2000 files (one or more) that have been stored as DOS text files. The 1000-90 Communication Software (included with the LAI-2000) can transfer the data from the LAI-2000 to DOS text files.

Q. *How does the LAI-2000 method compare with other indirect methods?*

A. Other gap fraction methods of determining canopy structure include point quadrats (Warren Wilson and Reeve 1959), high-contrast fisheye photography (Anderson 1970, Bonhomme and Chartier 1972), traversing a light sensor beneath a canopy (Norman et al 1979, Lang et al 1985, Perry et al 1988), and using a linear light sensor (Walker et al 1988). The LAI-2000 method is closest to fisheye photography. The LAI-2000 has the advantage over photography of immediate on-site analysis, but the disadvantage of not having a picture (permanent record) on which to do a number of other types of analyses. The point quadrat technique is only suited to small canopies. The remaining techniques involve using the sun as a canopy probe. The obvious disadvantages are two: the sun must be out, and one must wait for the sun to move to get data at various angles. The LAI-2000 gets all the angle data at once, and does not require the sun to be out. (In fact, it is best if the sun is *not* out). On the other hand, the LAI-2000 requires an above canopy reference reading, whereas techniques that use the sun do not.

LAI can be deduced from measurements of light attenuation at only one solar angle, using an integrating radiometer (Pierce and Running 1988). However, canopy extinction (that is, leaf angle distribution) must be assumed beforehand, and is not deduced from the measurement. An above canopy reference reading is also required.

Q. *Can I use a LAI-2050 Optical Sensor with a general purpose data logger?*

A. No. The complexity of the LAI-2050, and the unique data reduction software make it very difficult, if not impossible.

References

Bonhomme, R. and Chartier, P. (1972). The interpretation and automatic measurement of hemispherical photographs to obtain sunlit foliage area and gap frequency. Isr. J. Agric. Res. 22:53-61.

Gower, S.T., and Norman, J.M. (1990). Rapid estimation of leaf area index in forests using the LI-COR LAI-2000. Ecology, 72(5) 1896-1900.

Lang, A.R.G., Xiang, Y., and Norman, J.M. (1985). Crop structure and the penetration of direct sunlight. Agric. & For. Meteor. (35) 83-101.

Perry, S.G., Fraser, A.B., Thomson, D.W., and Norman, J.M. (1988). Indirect sensing of plant canopy structure with simple radiation measurements. Agric. and For. Meteor. (42) 255-278.

Pierce, L.L. and Running, S.W. 1988. Rapid estimation of coniferous forest leaf area index using a portable integrating radiometer. Ecology 69(6) 1762-1767.

Walker, G.K., Blackshaw, R.E., and Dekker, J. (1988). Leaf area and competition for light between plant species using direct sunlight transmission. Weed Technology (2) 159-165.

Warren Wilson, J., and Reeve, J.E. 1959. Analysis of the spatial distribution of foliage by two-dimensional point quadrats. New Phytol. (58) 92-101.

Welles, J.M. (1990). Some indirect methods of estimating canopy structure. In: Instrumentation for Studying Vegetation Canopy for Remote Sensing in Optical and Thermal Regions. (eds. N.S. Goel and J.M. Norman). Remote Sensing Reviews. 5(1) pp. 31-43.

Welles, J.M. and Norman, J.M. (1990). An instrument for indirect measurement of canopy architecture. Agronomy J., 83:818-825.

LI-COR, Inc. • P.O. Box 4425 • 4421 Superior Street • Lincoln, Nebraska 68504. USA.
Telephone: (402) 467-3576 • FAX: 402-467-2819
Toll-free 1-800-447-3576 (U.S. & Canada)

BOX 3.2

Measuring Water Potential

CELL GROWTH, photosynthesis, and crop productivity are all strongly influenced by water potential and its components. Like the body temperature of humans, water potential is a good overall indicator of plant health. Plant scientists have thus expended considerable effort in devising accurate and reliable methods for evaluating the water status of a plant. Four instruments that have been used extensively to measure Ψ_w, Ψ_s, and Ψ_p are described here: psychrometer, pressure chamber, cryoscopic osmometer, and pressure probe.

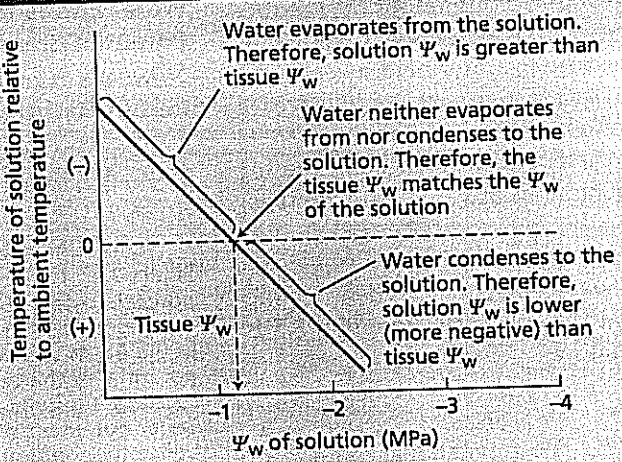


Figure 2 The temperature of the sensor in the psychrometer shown in Figure 1 depends on the water potential of the solution relative to the water potential of the tissue sample.

Psychrometer (Ψ_w measurement)

Psychrometry (the prefix "psychro-" comes from the Greek word *psychein*, "to cool") is based on the fact that the vapor pressure of water is lowered as its water potential is reduced. This is one of the *colligative properties* of solutions. Psychrometers measure the water vapor pressure of a solution or plant sample, on the basis of the principle that evaporation of water from a surface cools the surface.

One psychrometric technique, known as *isopiestic psychrometry*, has been used extensively by John Boyer and coworkers (Boyer and Knipling 1965) and is illustrated in Figure 1. Investigators make a measurement by placing a piece of tissue sealed inside a small chamber that contains a temperature sensor (in this case, a thermocouple) in contact with a small droplet of water. Initially, water evaporates from both the tissue and the water droplet, raising the humidity of the air inside the sealed chamber.

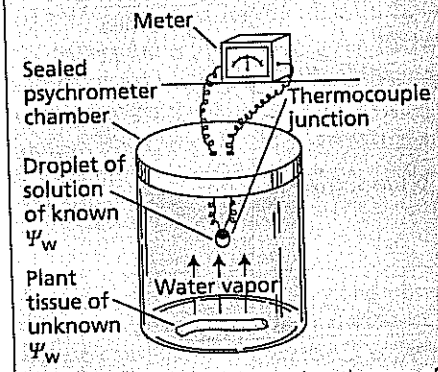


Figure 1 Diagram illustrating the use of isopiestic psychrometry to measure the water potential of a plant tissue.

Evaporation continues until the air becomes saturated or nearly saturated with water vapor. At this point, if the plant tissue and the water droplet have the same water potential, the net movement of water from the droplet stops, and the temperature of the droplet, measured with the temperature sensor, is the same as the ambient temperature. But if the tissue has a lower water potential than that of the droplet, water evaporates from the droplet, diffuses through the air, and is absorbed by the tissue. This slight evaporation of water cools the drop. The larger the difference in water potential between the tissue and the droplet, the higher the rate of water transfer and hence the cooler the droplet.

Rather than placing pure water on the temperature sensor, one may place a standard solution of known solute concentration (known Ψ_s and thus known Ψ_w). If the standard solution has a lower water potential than that of the sample to be measured, water will diffuse from the tissue to the droplet, causing warming of the droplet. Measuring the change in temperature of the droplet for several solutions of known Ψ_w makes it possible to match exactly the water potential of the solution with that of the sample (Figure 2). When the match is perfect, the change in temperature of the droplet is zero.

Psychrometers have been used to measure the water potentials of excised and intact plant tissue. Moreover, the method is applicable to solutions in which Ψ_w equals Ψ_s. Thus psychrometry can measure both the water potential of living tissue and the osmotic potential of a solution. Frequently, the Ψ_w of a tissue is measured with a psychrometer, and then the tissue is crushed and the Ψ_s value of the expressed cell sap is measured with the same instrument. By combining the two measurements, researchers can estimate the turgor pressure that existed in the cells before the tissue was crushed ($\Psi_p = \Psi_w - \Psi_s$).

This method is very useful, but it is very sensitive to temperature fluctuations. For example, a change in temperature of 0.01°C may correspond to a change in water potential of about 0.1 MPa (the value varies with the type of temperature sensor). Since it is often desirable to have a resolution of 0.01 MPa, the instrument must be kept under stringent conditions of constant temperature. For this reason, the method is used primarily in laboratory settings and has found only limited use for fieldwork, where temperature is not easily controlled. There are many variations in psychrometric technique; interested readers should consult Brown and Van Haveren 1972 and Slavik 1974.

Pressure chamber (Ψ_w measurement)

A relatively quick method for estimating the water potential of large pieces of tissues, such as whole leaves and shoots, is by use of the **pressure chamber**. This method was pioneered by Henry Dixon at Trinity College, Dublin, at the beginning of the twentieth century, but it did not come into widespread use until P. Scholander

BOX 3.2 (continued)

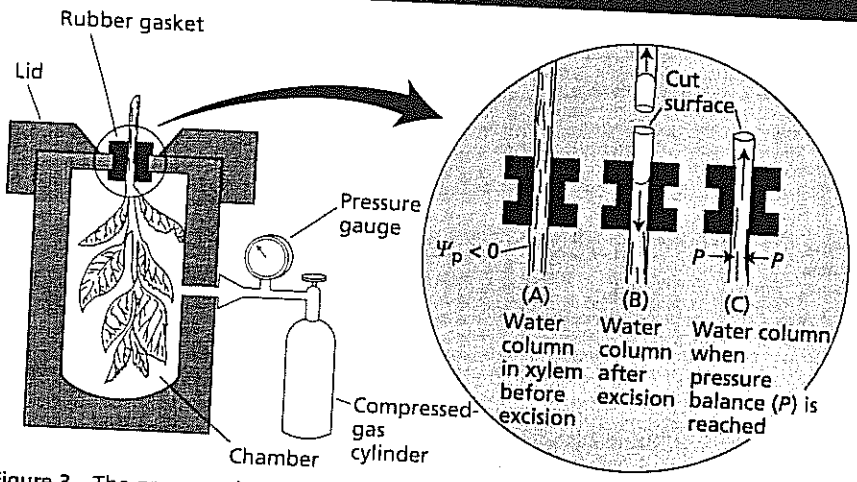


Figure 3 The pressure chamber method for measuring plant water potential. The diagram at left shows a shoot sealed into a chamber, which may be pressurized with compressed gas. The diagrams at right show the state of the water columns within the xylem at three points in time: (A) The xylem is uncut and under a negative pressure, or tension. (B) The shoot is cut, causing the water to pull back into the tissue, away from the cut surface, in response to the tension in the xylem. (C) The chamber is pressurized, bringing the xylem sap back to the cut surface.

and coworkers at the Scripps Institution of Oceanography improved the instrument design and showed its practical use (Scholander et al. 1965).

The pressure chamber measures the negative hydrostatic pressure (tension) that exists in the xylem of most plants. The water potential of the xylem is assumed to be fairly close to the average water potential of the whole organ—an assumption that is probably valid, because (1) in many cases the osmotic potential of the xylem solution is negligible, so the major component of the water potential in the xylem is the (negative) hydrostatic pressure in the xylem column, and (2) the xylem is in intimate contact with most cells in the plant.

In this technique, the organ to be measured is excised from the plant and is partly sealed in a pressure chamber (Figure 3). Before excision, the water column in the xylem is under some tension. When the water column is broken by excision of the organ, the water is pulled into the xylem capillary by the now unopposed tension. The cut surface consequently appears dull and dry. To make a measurement, the investigator pressurizes the chamber with compressed gas until the water in the xylem is brought back to the cut surface. The pressure needed to bring the water back to the surface is called the *balance pressure* and is readily detected by the change in the appearance of the cut surface, which becomes wet and shiny when this pressure is attained.

The balance pressure is equal in magnitude (but opposite in sign) to the negative pressure that existed in the xylem column before the plant material was excised. For example, if a balance pressure of 0.5 MPa is found, then Ψ_p in the xylem before excision was –0.5 MPa. If we know Ψ_s for the xylem sap from other measurements, we may calculate the water potential of the xylem, which, as already stated, is assumed to be close to the water potential of the whole organ.

In many outdoor plants, Ψ_p in the xylem may be –1 to –2 MPa, whereas Ψ_s may be only –0.05 to –0.2 MPa. Therefore, in many situations pressure chamber measurements by themselves provide an adequate estimate of the water potential of the plant. Because the pressure chamber method is rapid and does not require delicate instrumentation or elaborate temperature control, it has been used extensively under field conditions to estimate water potential (Tyree and Hammel 1972).

Cryoscopic osmometer (Ψ_s measurement)

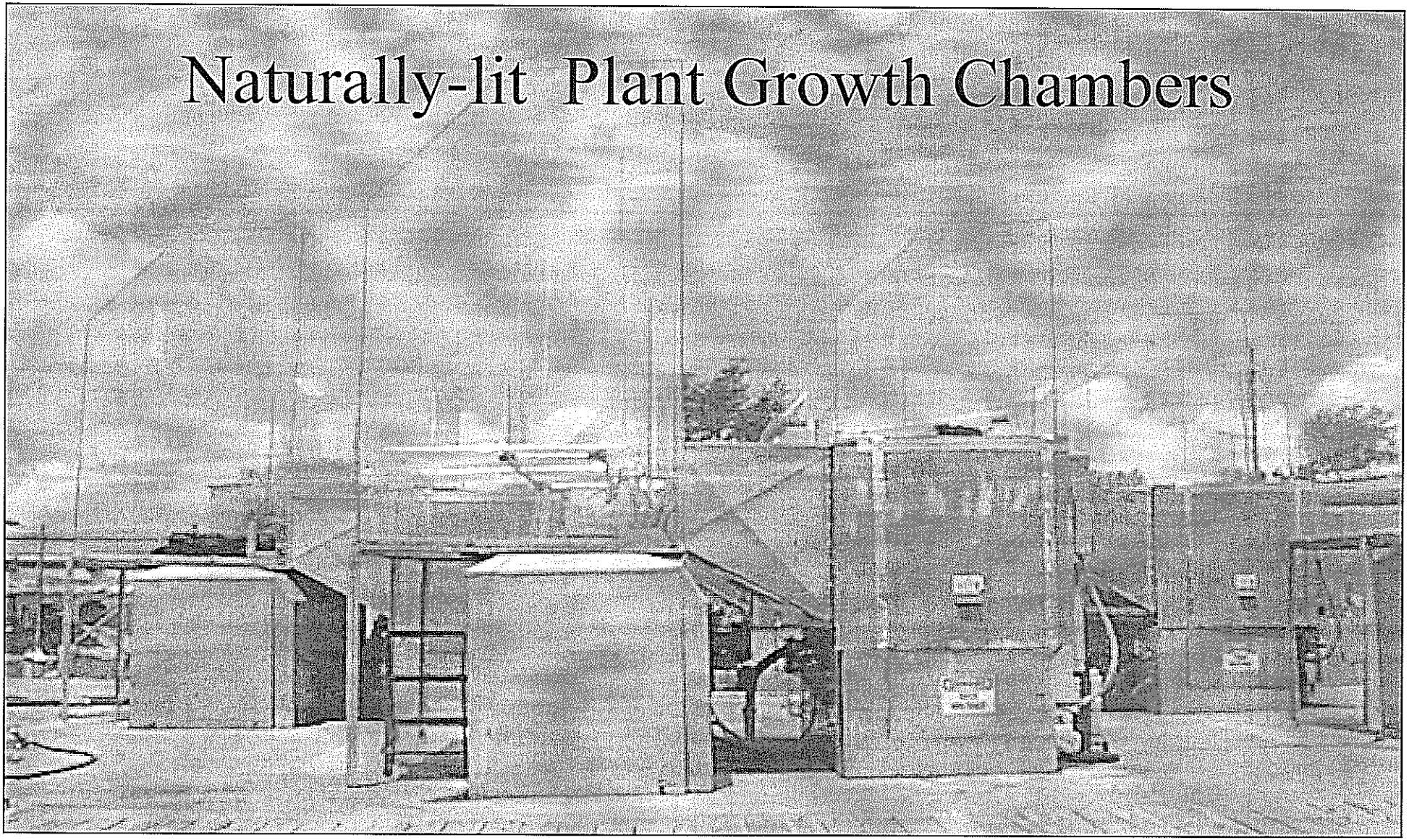
The **cryoscopic osmometer** measures the osmotic potential of a solution by measuring its freezing point. One of the *colligative properties* of solutions is the decrease in the freezing point as the solute concentration increases. For example, a solution containing 1 mol of solutes per kilogram of water has a freezing point of –1.86°C, compared with 0°C for pure water.

Various instruments can be used to measure the freezing-point depression of solutions (for two examples, see Prager and Bowman 1963 and Bearce and Kohl 1970). With a cryoscopic osmometer, solution samples as small as 1 nanoliter (10^{-9} L) are placed in an oil medium located on a temperature-controlled stage (Figure 4). The very small sample size allows sap from single cells to be measured and permits rapid thermal equilibration with the stage. To prevent evaporation, the investigator suspends the samples in oil-filled wells in a silver plate (silver has high thermal conductivity). The temperature of the stage is rapidly decreased to about –30°C, which causes the sample to freeze. The temperature is then raised very slowly, and the melting process in the sample is observed through a microscope. When the last ice crystal in the sample melts, the temperature of the stage is recorded (note that the melting and freezing points are the same). It is a straightforward job to calculate the solute concentration from the freezing-point depression; and from the solute concentration (c_s), Ψ_s is calculated as $-RTc_s$. This technique has been used to measure droplets extracted from single cells (Malone and Tomos 1992).

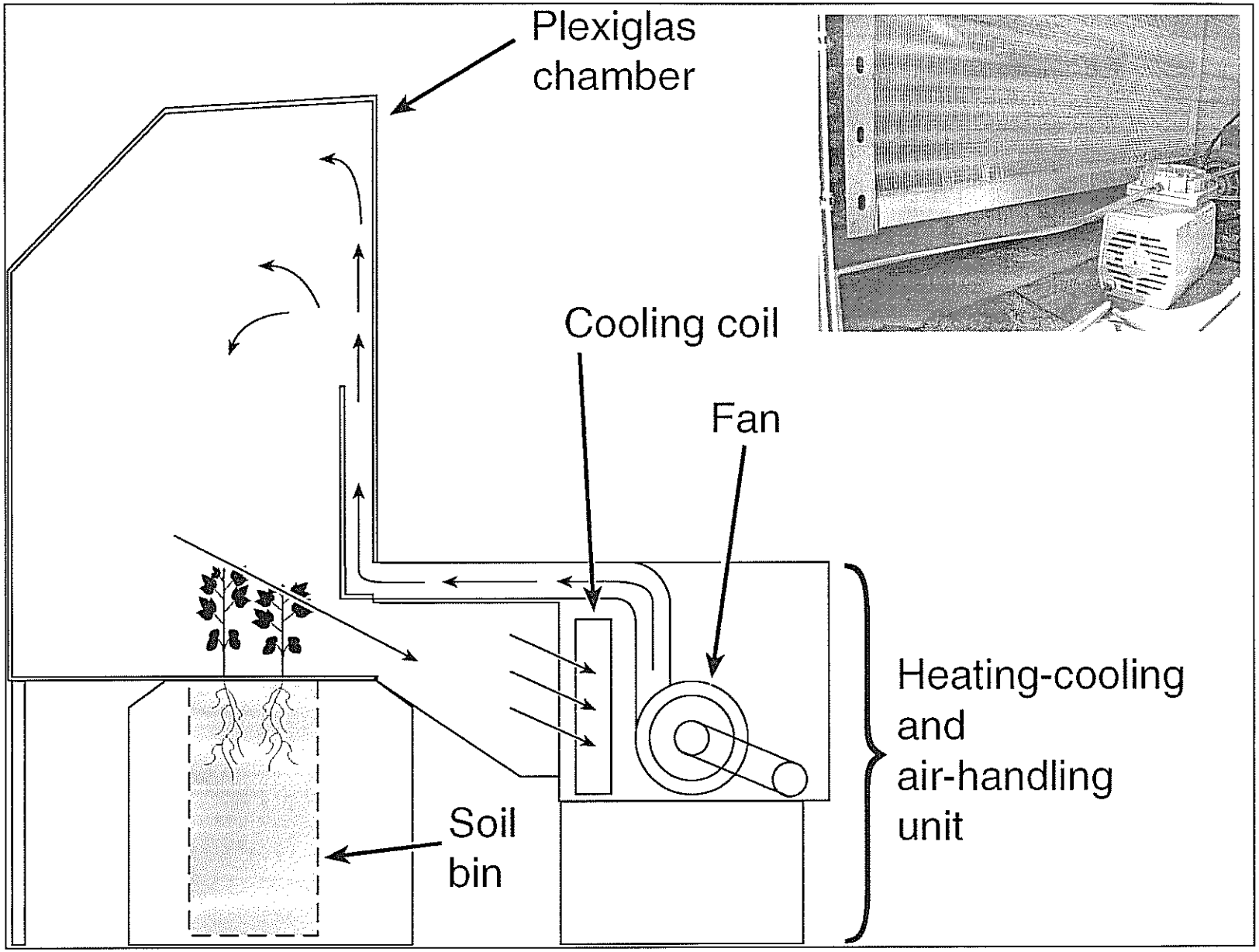
Pressure probe (Ψ_p measurement)

If a cell were as large as a watermelon or even a grape, measuring its hydrostatic pressure would be a relatively easy task. Because of the small size of plant cells, however, the development of methods for direct measurement of turgor pressure has been slow. Paul Green at the University of Pennsylvania developed one of the first direct methods, using a micromanometer, for measuring turgor pressure in plant cells (Green and Stanton 1967). In this technique, an air-filled glass tube sealed at one end is inserted into a cell (Figure 5). The high pressure in the cell compresses the trapped gas, and from the change in volume one can readily calculate the pressure of the cell from the ideal gas law (pressure × volume = constant). This method works only for cells of relatively large volume, such as the giant cell of the filamentous

Crop Responses to Environment - Tools



SPAR- Schematic Diagram the Operational Capabilities



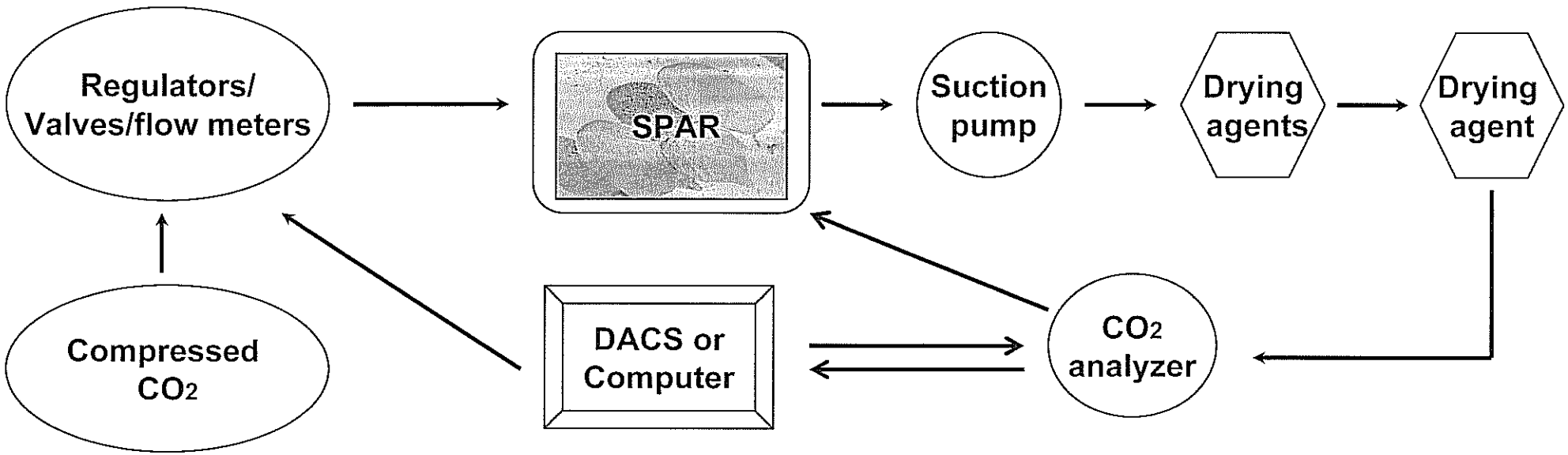
Measuring Carbon Fluxes

Carbon Fluxes: Mass balance approach

During sunlit hours, by maintaining steady or constant CO_2 concentration inside the SPAR chamber, we can calculate,

Net photosynthesis = Amount of CO_2 injected – leak rate

Gross Photosynthesis = Net photosynthesis + Respiration

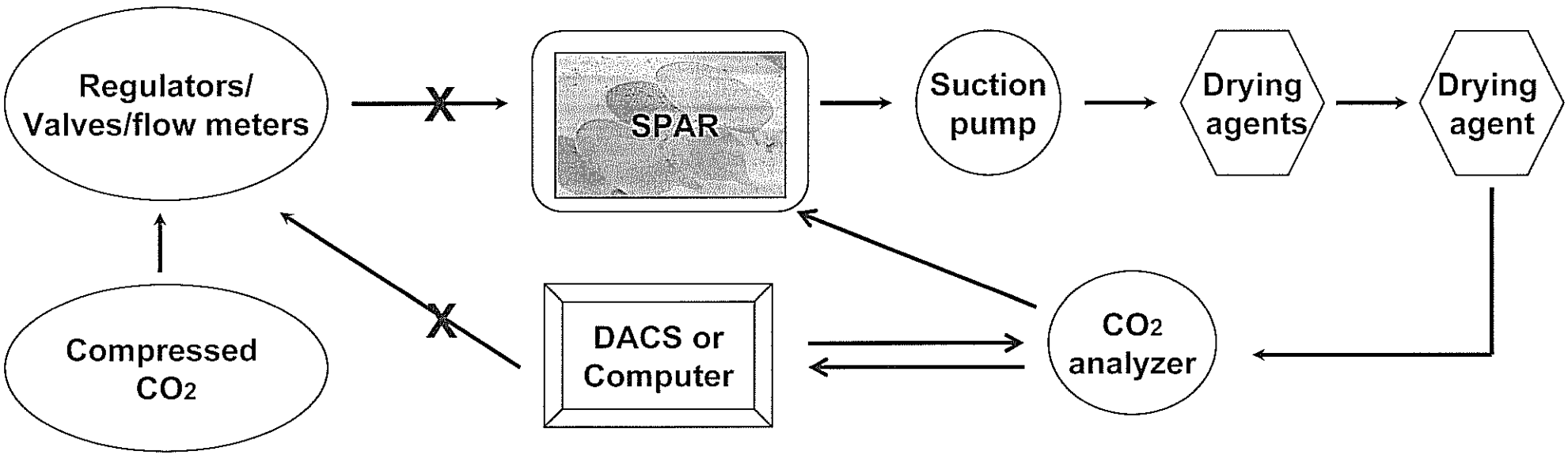


Measuring Carbon Fluxes

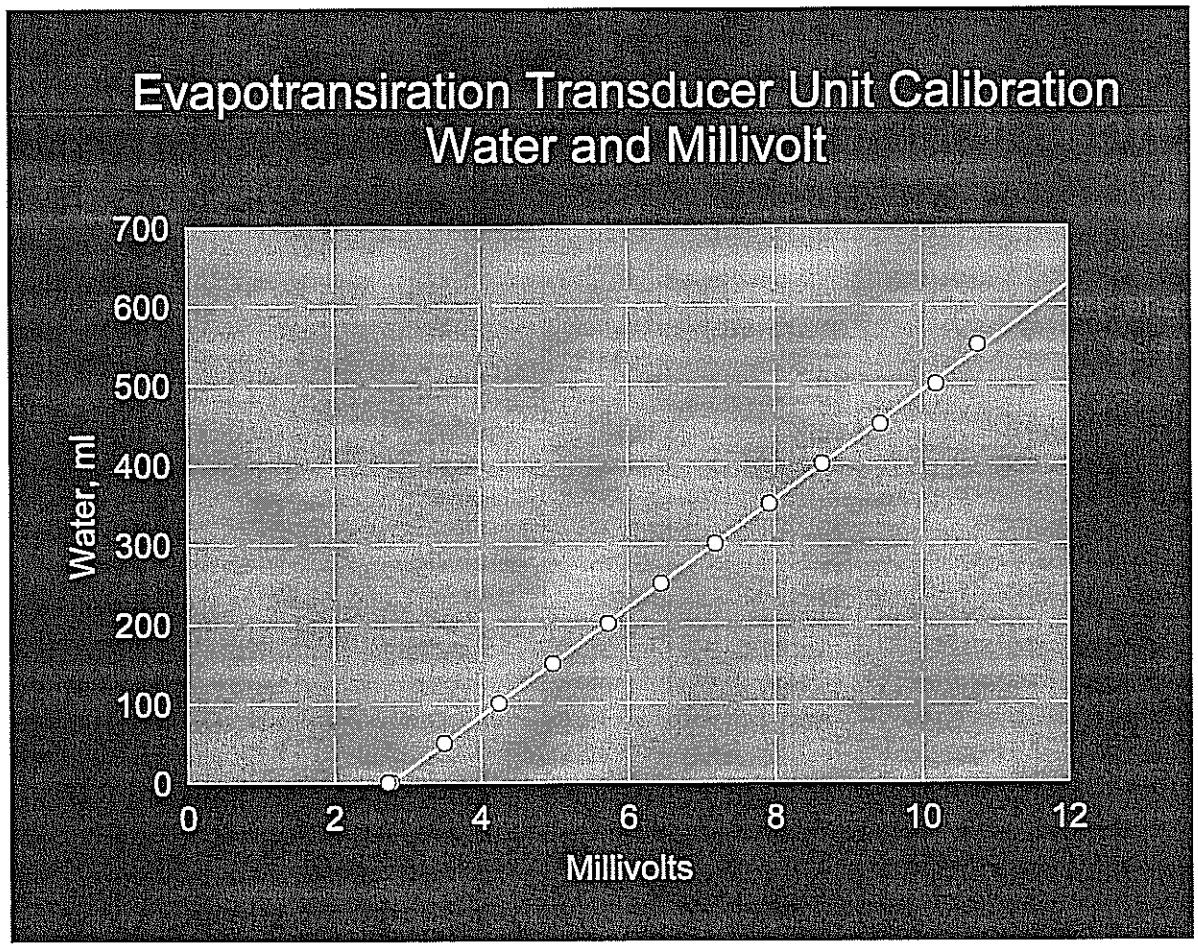
Measuring Respiration:

During nighttime, by measuring the rise or build up CO_2 concentration inside the SPAR chamber, we can calculate,

Respiration rate = [(CO_2 Conc., at T2 - CO_2 Conc., at T1) – leak rate]



Measuring Evapotranspiration/transpiration



The Evapotranspiration Device