PROTOCOL: Integrated paper sensors for quantification of photosynthetically active radiation

Author affiliations

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Overview

Integrated paper sensors are custom-made, low-cost sensors that record cumulative photosynthetically active radiation (PAR). These are made of small booklets of paper sheets coated on one side with light-sensitive compounds. Upon exposure to solar radiation, light penetrates through the various sheets of the booklet. As the light is more intense or exposure time is longer, deeper sheets of the booklet are whitened; cumulative PAR values can be estimated using a calibration equation.

Background

Integrated paper sensors use a special paper coated with diazo compounds, a type of organic compound that has two linked nitrogen atoms (azo) as a terminal functional group, which is bleached upon exposure to light and developed with dry ammonia vapors.

The first published article using such papers as a method to measuring integrated light values is attributed to Friend (1961). Up to date, at least 142 articles indexed in the ISI Web of Knowledge (Thomson Reuters) have been inspired by this work (Ackerly 1992; Baraloto and Goldberg 2004; Pugnaire et al. 2004).

Integrated paper sensors consist of small booklets of diazo-coated sheets (9-12), which are placed in black envelopes with a circular aperture in the front 1.5-3 cm in diameter that allows light to shine directly on the photosensitive paper face. After exposure, light penetrates through the various sheets of the booklet. Exposed sheets are then exposed to dry ammonia vapors, showing a white circle where the light has reached through. As the light is more intense or exposure time longer, deeper sheets of the booklet are whitened, so that after a calibration equation, integrated PAR values can be estimated from the number of bleached sheets.

Light penetration through the paper sheets closely follows the Beer-Lambert law of light absorption, through which an exponential relationship between the transmission of light through a substance and the substance concentration is found. Therefore, the number of layers exposed in a time period is proportional to the logarithm of the amount of light received in that period.

Materials/Equipment

- Diazo-coated paper sheets
- Scissors, cutter or guillotine
- Black (opaque) paper/light cardboard envelops
- Hole puncher or perforator (>1 cm diameter)
- Sealable zipper plastic bags (transparent)
- PAR sensor and datalogger
- Ammonia-based cleaner

Units, terms, definitions

IPS = Integrated paper sensors.

PAR = Photosynthetically Active Radiation (µmol photons $m^{-2}s^{-1}$). It designates the wave band of solar radiation from 400 to 700 nm that photosynthetic organisms are able to use in photosynthesis.

Integrated PAR = Amount of PAR absorbed over a time period (mol m^{-2}).

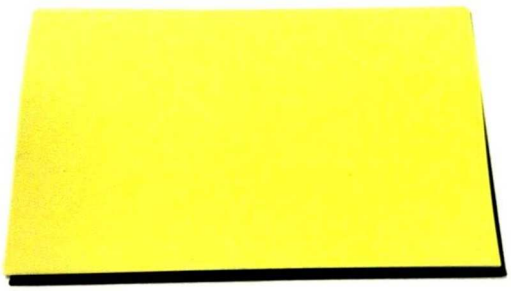
PPF = Photosynthetic photon flux (µmol $m^{-2}s^{-1}$).

Photosynthetic photon flux de nsity PPFD (µmol $m^{-2}s^{-1}$).

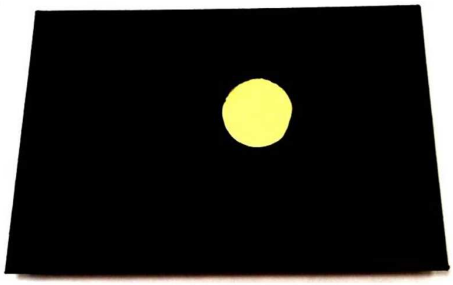
PAR = PPF = PPFD

Procedure

- Cut the diazo-coated paper sheets into ca. 9 x 6 cm cards (your envelop size determine the dimension of the cards and zip lock bags).



- Pile 8-12 sheets with the coated side facing down, thus creating a small booklet.
- Punch a hole (1 to 2 cm diameter) in the face of the envelops.
- Put one booklet of diazo-sheets in the envelope with the coated side facing the aperture and close the envelop.



- Seal the envelop in a zipper plastic bag and there you go, an IPS!

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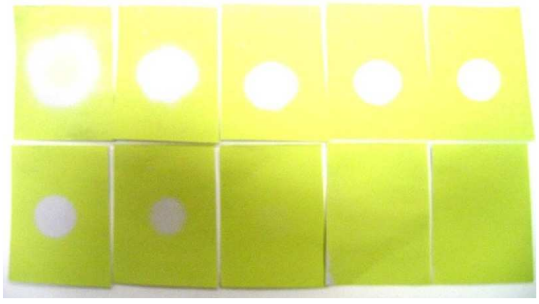
Procedure for calibrating IPS

- Place several IPS on a flat surface with the aperture facing down, and then place a commercial PAR sensor, connected to a datalogger recording PAR values every minute, close to them.
- Turn over the IPS and launch the datalogger. Be sure that both IPS and PAR sensor are exposed to light and launched at the same time.
- Expose the IPS and PAR sensor to a wide range of light conditions, including shade and full sun, and soon collect one IPS to inspect the number of layers that have been bleached in that period. Record time of exposure in seconds.
- Calculate integrated PAR (µmol photons m^{-2}) received over the period the IPS was exposed to light using values recorded in the datalogger (µmol photons $m^{-2}s^{-1}$).
- To determine the number of layers bleached in the exposure period, take the IPS to the lab and develop each sheet of the booklet by exposing it to dry ammonia vapors for ten minutes in a closed, black box. A white circle will evidence PAR was able to bleach that point.



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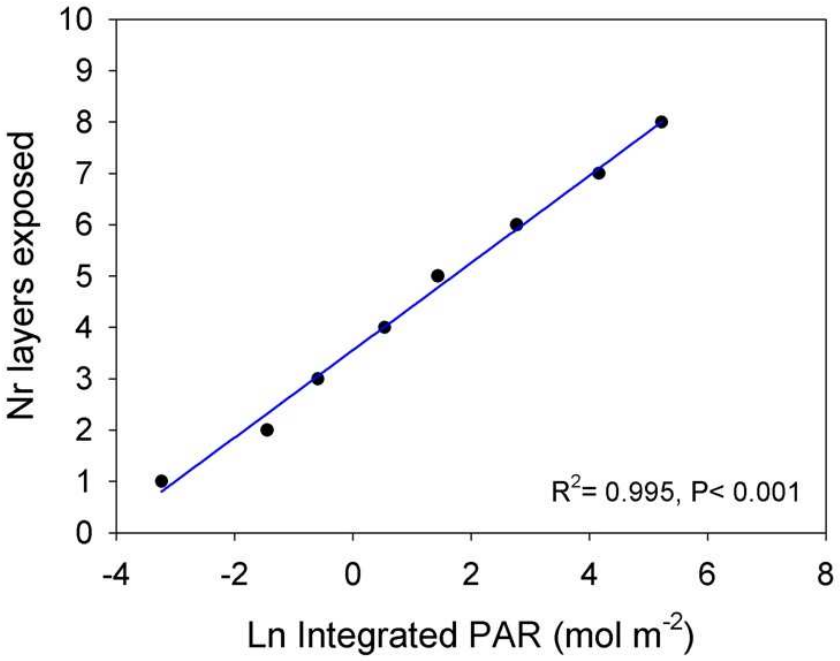
- Write down the integrated PAR corresponding to the number of sheets bleached. Create a two-way table with *x* = Ln integrated PAR and *y* = numbers of layers bleached.
- Collect a new IPS regularly and follow above steps to determine the amount of light corresponding to the number of sheets bleached.
- Fit a linear regression between the LN integrated PAR and the number of layers bleached.

Light integrated paper sensors calibration curve

Black card envelope in transparent zip bag



- From this calibration equation, integrated PAR over a certain period can be estimated from the number of layers bleached.

$$\text{Nr layers exposed} = 3{,}5579 + 0{,}8506 * \text{Ln Int PAR}$$

$$\text{Ln Int PAR} = (\text{Nr layers exposed} - 3.5579) / 0.8506$$

$$\text{Int PAR (mol m}^{-2}) = e^{(\text{Nr layers exposed} - 3.5579) / 0.8506)}$$

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Other resources

See also: PROTOCOL: Light sensitive films to measure light microenvironment

Notes and troubleshooting tips

- Diazo-coated paper sheets must be manipulated under dim light before and after exposure, otherwise they will keep absorbing light. Incandescent light is best because it contains little UV and blue wavelengths.
- Put IPS in zipper plastic bags to prevent moisture. Wrap them up in transparent film if available.
- Keep unexposed IPS booklets in the dark.
- We found that IPS of 8 layers of diazo-coated sheets were able to estimate integrated PAR of up to 185 mol m $^{-2}$, equivalent to 2.5 days under PAR conditions of 1800 µmol $m^{-2}s^{-1}$for 12 hours continuously. Modifications of booklet layers can result in different ranges. However, light-sensitivity of diazo-coated paper sheets may differ depending on the manufacturer. It is thus required to calibrate your IPS every time you change diazo-coated paper maker.

Links to resources and suppliers

Diazo-coated paper: Diazo Blue Line Jet Media (Dietzgen, Nashua Corporation, Park Rdige, IL, US); Polymex D070ARB (Polyester Converters Ltd., PSG Group, London, UK); Heliographic paper (Diatecnologia, S.A., Diatec Group, Madrid, Spain).

Literature references

Ackerly, D. D. (1992) Light, leaf age, and leaf nitrogen concentration in a tropical vine. *Oecologia,* **89,** 596-600.

Baraloto, C., Goldberg, D. E. (2004) Microhabitat associations and seedling bank dynamics in a neotropical fores. *Oecologia, **141,*** 701-712.

Friend, D. T. (1961) A Simple method of measuring integrated light values in the field. *Ecology,* **42,** 577-580.

Pugnaire, F. I., Armas, C, Valladares, F. (2004) Soil as a mediator in plant-plant interactions in a semi-arid communit. *Journal of Vegetation Science,* **15,** 85-92.

Health, safety & hazardous waste disposal considerations

- Because of the toxicity of ammonia vapors, work in a well-ventilated area and wear globes and other personal security equipment at all times.
- Dilute the used ammonia solution with tap water before disposal.