TECHNICAL REPORT
A field-portable instrument for mapping the micro-environment within grass canopies

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Abstract. A battery-operated field-portable instrument designed to measure the ratio of red/infra-red (R/IR) light beneath grassland canopies on a micro-scale is described. Because the ratio is correlated with leaf area index, a grid of ratio measurements may be used to map the location and size of canopy gaps. These are potential entry points into the vegetation for new individuals and for new species of plants. Measurements are made with a 1.5 mm diameter fibre optic probe which scans beneath the canopy under the control of a portable microcomputer. Data are stored on magnetic tape and processed by mainframe computer to produce contour maps of R/IR ratio.

Key-words: Canopy gaps, fibre-optic, light, grassland, micro-environment, microcomputer

Introduction
In most kinds of vegetation where the Leaf Area Index is greater than unity, new individuals are only able to grow where there are gaps in the canopy and these form entry-points for new plant genotypes and new species. This is particularly obvious in forests where gaps can be viewed from beneath by the human observer but it is also true of grasslands where direct observation from beneath is not possible (e.g. Fenner, 1978; Silvertown, 1981; Silvertown & Wilkin, 1983; Wells & Haggard, 1984). Although forest gaps are easy to observe, their physical scale and the long turnover-time of tree populations makes experimental manipulation with adequate replication difficult. Populations of grassland species have rapid turnover times and grassland gaps are small in size and therefore easy to manipulate. The only drawback is that their small size makes grassland gaps difficult to observe and measure quantitatively. The instrument described here is designed to overcome this problem and make grassland vegetation a tractable experimental system for the investigation of the role of disturbance in plant population dynamics and community structure.

Description of the instrument
The instrument is designed to map the fluence rate under vegetation in the field, with as little disturbance to plants as possible, at two broad, non-overlapping wavebands in the red (R) and near infra-red (IR). There is a close relationship between R/IR and Leaf Area Index (Jordan, 1969; Frankland & Poo, 1980) so that a quantitative picture of the distribution of gaps, or conversely of the distribution of vegetation cover, is obtained from an R/IR map. We emphasize that we are using measurements of R/IR only as a means to the end of mapping gaps, not only because of its acknowledged importance as an environmental variable in itself.

Readings are taken at points in a grid of sampling locations in a plane of dimensions up to 25 cm × 30 cm, beneath the canopy. Measurements are made automatically by the instrument which is controlled by a microcomputer. The instrument is battery-powered and field-portable and consists of five parts:

1 A fibre-optic probe attached to –
2 A dual-wavelength detector which produces an analogue output.
3 A mechanical scanning arm driven by stepper motors which allow the probe to be moved to any location within a horizontal plane.
4 A measurement and control unit (MCU) which converts the analogue output of the detector to a digital signal and which controls the movement of the scanning arm. The MCU also incorporates a rechargeable battery which powers the arm and the MCU itself.
5 A battery-powered microcomputer (Epson HX 20) interfaced with the MCU and running a programme called SENSOR which is used to input coordinates for the movement of the scanning arm, to trigger readings at programmed positions, to store digital data on tape and to perform other functions described in more detail below.

Parts 2 and 3 are contained in an acrylic box with a horizontal slit running along the length of each side to accommodate the movement of the probe; parts 4 & 5 are housed in a moulded polypropylene case with a clear acrylic lid. Fig. 1 shows the arrangement of the parts of the instrument and their interconnections.

**Probe**

The probe is a 1.5 mm diameter, polymer, fibre-optic waveguide (Crofon™) cut at one end to form a smooth surface, 45° to the axis of the fibre. A gold mirror is formed on this surface by evaporation and is coated on the back with black enamel paint. The waveguide is inserted in a 26 cm long stainless steel tube 2.05 mm in external diameter, with its mirrored end located beneath an aperture 1.5 mm from the distal end of the tube which is sealed with epoxy resin. The other end of the tube is attached to the end of the scanning arm by an adjustable clamp and the tail of the fibre emerging from the tube is clad in opaque black plastic. The tail of the probe forms a 74 cm long flexible link to the detector.

**Detector**

At the detector, the waveguide mates through a removeable coupling with the stem of a ‘Y’ junction which splits the signal into two. One arm of the ‘Y’ junction terminates in a silicon photodiode (type BPX 65, stock no. 309-307 from R.S. Components, Corby, U.K.) covered with a red filter (Calflex) and the other in a photodiode covered with an infra-red filter (Kodak Wratten 88A). Pre-amplifiers in the detector circuit amplify the output of the photodiodes which passes through a low-pass R-C filter to reduce noise and is transmitted to the MCU by a screened lead. The detector circuit includes passive photodiodes blacked-out and wired to provide compensation for drift caused by changes in ambient temperature in the field. Photodiode dark currents are measured and compensated for in a subroutine of SENSOR (Fig. 2).

Auto-ranging of the instrument is carried out in a board in the MCU (see Fig. 1). Switching between ranges on this board is controlled by the microcomputer software (Fig. 2). Six gain ranges are used to cover a 1000-fold range in fluence rate.

**Scanning arm**

The carriage and arm are driven by two 4-phase stepper motors. The arm has a reach of 25 cm × 30 cm which enables the probe to be moved to any location within this area and to be positioned with an accuracy of 1 mm. Measurements may be taken automatically at points on any rectangular grid by
specifying (in mm) the minimum \((X_{\text{min}}, Y_{\text{min}})\) and the maximum \((X_{\text{max}}, Y_{\text{max}})\) coordinates of the grid and the interval between readings \((x_{\text{step}}, y_{\text{step}})\) in the \(X\) and \(Y\) directions. These parameters are keyed in to the microcomputer before readings begin or default values selected on a previous occasion may be used (Fig. 2). The arm begins by moving the tip of the probe to the top right hand corner of the grid, located at \(X_{\text{min}} Y_{\text{max}}\). The arm then withdraws the probe from the vegetation, stopping every \(y_{\text{step}}\) to take a reading. By taking measurements as the probe withdraws, disturbance to the vegetation is minimized. When the probe reaches \(Y_{\text{min}}\) it is moved a distance \(x_{\text{step}}\) along the \(X\) axis of the grid before it moves to \(Y_{\text{max}}\) again. The cycle is repeated until the probe takes its last reading at \(X_{\text{max}}, Y_{\text{min}}\). Limit switches prevent the arm moving outside the predetermined limits of 25 cm \(\times\) 30 cm and allow the position of the arm to be returned to the origin when desired. The speed of the stepper motors and their gearing limit the speed of operation of the instrument in the field. At present 676 readings take 21 min to execute in the field, though we are hoping to improve considerably on this in the near future.

Measurement and Control Unit

This contains a measurement board (A/D converters, variable gain amplifiers) and an interface and control board for the stepper motors and interfaces for the microcomputer and scanning arm. The unit is powered by a rechargeable 12-v, 9.5-Ah sealed gel lead-acid battery which is mounted in the case with a trickle charger for convenient recharging in the laboratory.

Microcomputer and software

An Epson HX20 microcomputer is used with an internal micro-cassette tape drive and microprinter. It is powered by its own rechargeable battery. The memory expansion port is used as an interface with the MCU and this limits all activities in the computer to the standard 16 K capacity of the machine. About 8 K is taken up by software, control and communications. The rest of the available RAM is used for temporary data storage. Seven hundred and twenty pairs of readings with associated positional information and a 50-character comment can be stored before it is necessary to offload data to tape. A micro-cassette tape holds six files of this size. A flow chart for the programme SENSOR which controls the operations of the instrument is shown in Fig. 2. It is written in BASIC with some machine code routines. A version of the instrument incorporating a Husky Hawk microcomputer is currently being developed.

Calibration and sensor characteristics

The instrument autoranges to cope with fluence rates between 2 \(\mu\text{mol m}^{-2}\text{s}^{-1}\) and 1000 \(\mu\text{mol m}^{-2}\text{s}^{-1}\). The response of the instrument is linear within this range, the limits of which can be
adjusted by changing the value of feedback resistors in the
amplifier circuits of the detector. Linearity of response was
tested by calibration against a LI-Cor quantum radiometer (LI
185B) with a LI 190SB quantum sensor using neutral-
density filters to attenuate the fluorescence rate of
natural daylight.

The normalized spectral response of the sensor
and filters is shown in Fig. 3. This spectrum is a
composite calculated from the individual spectral
characteristics of the optic fibre, the optical filters
and the photodiodes. The two channels record
across relatively broad, but non-overlapping,
Wavelength (nm)

![Graph](image)

Fig. 3. Spectral response of the instrument in the red and infra-red channels.

Festuca rubra L. cut into a gradient in turf height.
Readings in natural daylight were taken at a total of
442 points located at one cm intervals. Data were
transferred from the Epson HX20 via an RS232
interface to a BBC Master microcomputer and from
there to a mainframe Digital Equipment Corp.
VAX. A contour map of R/IR ratios was drawn from
the R/IR ratio values by the UNIRAS package run-
ning on the VAX (Fig. 5)

A mainframe computer programme has been
written for quantifying the number and size of
areas ('gaps') within a map that have a R/IR ratio
above any specified value. Programmes for quanti-
fying changes between successive contour maps
taken from the same sites and for correlating
seedling distribution with R/Fr maps are also being
developed (details available from the authors).

![Polar plots](image)

Fig. 4. Polar plots of light sensitivity, shown on a relative
scale along the radii, versus angle of incidence for the
fibre-optic probe described in the text. (a) Probe aligned
left-to-right with its axis in the plane of the page; (b)
probe aligned with its axis perpendicular to the plane of
the page.

Discussion

The evidence that seed germination, seedling fate
and plant development are correlated with plant
cover on a local scale in temperate grasslands is
overwhelming (e.g. Gross & Werner, 1982; Silvertown & Wilkin, 1983; Watt, 1987; McConnaughay & Bazzaz, 1987; Derebibus et al., 1985). Some of
these effects of plant cover are a direct effect of
radiation quality (Frankland, 1980) but the micro-
environment beneath a canopy and in a gap also
differ in other ways, such as the amplitude of
temperature fluctuations which is known to influ-
ence seed germination (Thompson, Grime & Mason, 1977). Although our instrument uses a
measure of radiation quality to detect gaps it is
necessary to emphasize that it is not intended to
measure either absolute fluence rates or some

Sample results

For demonstration purposes we used the instru-
ment to map a 16 cm × 26 cm box of two-month old
specific ratio of wavelengths (Homes & Smith, 1977) but simply to provide us with a variable which correlates with spatial variation in vegetation cover (Fig. 5). Once this correlation has been achieved it becomes possible to map gaps and therefore to follow their appearance, colonization and disappearance and, so-to-speak, to study their demography. The sensor of this instrument has been miniaturized to a scale relevant to seeds and seedlings which are the most vulnerable stages of the plant life-cycle. Future work using the instrument described will report upon the correlation between gap demography and plant demography. Modifications to the instrument could allow the investigator to compare PAR above and below the grassland canopy and we are intending to develop the instrument so that dual measurements of R/IR may also be made.

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References


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