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Short Communication

A hand-held red–infrared radiometer for measuring radiation interception by crop canopies*

R.C. Nageswara Rao[a], J.H. Williams[b], V.M. Rao[a], and K.D.R. Wadia[a]
[a]*International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru 502 324 A P India*
[b]*ICRISAT Sahelian Center Niamey Niger*

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ABSTRACT

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A simple and portable two-band radiometer to measure simultaneously, reflectance of red (r) and near infrared (ir) radiation from canopies of peanut (*Arachis hypogaea* L) is described A strong linear relationship ($r^2=0\ 94$) was observed between the normalised reflectance ratio (NR) calculated from r and ir reflected, and the fraction of incident photosynthetically active radiation (PAR) intercepted by peanut canopies up to a leaf area index of 3 0 The importance of and scope for measurements on radiation interception in crop improvement programs is discussed

INTRODUCTION

The measurement of radiation interception by canopies is becoming an increasingly important observation in crop physiological experiments and crop modelling. These data are often used to evaluate and compare crop growth in experiments using the equation; $Y_b=R\times f\times q$, where Y_b is the biomass yield, R is the quantity of photosynthetically active radiation (PAR) incident on the crop, f is the fraction of R intercepted by the canopy and q is the light-use ratio (a ratio of dry matter produced:PAR intercepted) of the crop (Monteith, 1977). In general, the f of a crop at a given time is estimated as the difference between the radiation incident on the crop and that measured below the canopy using linear radiation probes. This method of determining f is tedious and often inaccurate, particularly where spatial sampling difficulties

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exist because crop plants are close to the ground (at the seedling stage or in short-saturated cultivars/crops) or canopies are composed of a small number of spatially separated plants (e.g., a segregating population).

It is well established that spectral reflectance characteristics of crop canopies are closely related to intercepted radiation (Daughtry et al., 1983) and leaf area index (L) (Asrar et al., 1984). Reflectance properties have been used for remote-sensing of intercepted PAR (Kumar and Monteith, 1981) and standing biomass in natural communities (Jensen, 1980; Mayhew et al., 1984), at ground level, from aircraft (Curran, 1981) or from space (MacDonald and Hall, 1980).

Several models of ground-based equipment to measure canopy reflectance have been designed and developed (Tucker et al., 1981; Mayhew et al., 1984). These have been largely successful but also have limitations for routine use in crop improvement programs because of cumbersomeness, high cost, complexity in usage and absence of data logging facilities.

This paper describes a low-cost, portable, red–infrared radiometer designed at ICRISAT Center for remote-sensing of radiation interception in small canopies of peanut, a short-statured crop. It also discusses possible applications of the technique in crop improvement.

MATERIALS AND METHODS

Instrumentation

The red (r) and infrared (ir) reflectance are sensed by red and infrared light emitting diodes (LEDs) having a peak response at 650 nm (red) and 920 mm (infrared) wavelengths (Fig. 1). The signal from these LEDs are amplified separately using low power, high impedance CMOS current amplifiers IC2 and IC3. The amplifier IC1 provides symmetric supply bias for the other stages in the circuit. The gain of the signals at this stage is made adjustable, using feedback potentiometers (R5 and R10) to avoid saturation of the amplifiers at high radiation intensities. The outputs of the current amplifiers are fed to red and infrared potentiometers through IC4 and IC5 inverting amplifiers. The potentiometers are used for calibrating individual sensor outputs. The circuit, mounted on a printed circuit board along with the sensors, is housed in a collimator (with inner diameter 40 mm) painted black. The entire circuit is operated on a 9 V PP-3 size battery.

The radiometer is interfaced with a polycorder (Ominidata International[1]) in which a resident program scans the analogue output from the r and ir sensors at 5-ms intervals and stores the data in an active data file.

[1]Mention of commercial products of companies does not imply endorsement or recommendation by ICRISAT over others of similar nature.

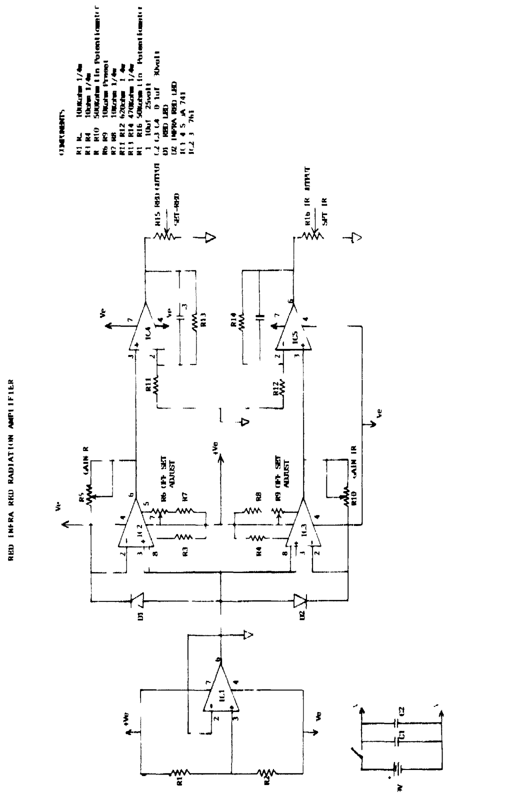

Fig. 1 Circuit diagram of a portable hand-held red–infrared radiometer to measure radiation interception by crop canopies

Calibration

The radiometer is calibrated in full sun-light by suspending the collimator at 75 cm above a clean white cardboard sheet and the outputs from both r and ir sensors are adjusted to 1 V using the potentiometers (Fig. 1). The instrument is then ready for use.

Experiment

Measurements were made on a peanut crop (cultivar ICGS 11) grown at eight population densities (1,2,4,8,16,33,59,133 plants m^{-2}) with three replications, during the rainy season (July–Nov) 1989, on an Alfisol at ICRISAT Center, Patancheru, near Hyderabad, India (17°32′N, 78°16′E). The crop was sown on 2 July, 1989, adequately irrigated, and protected from foliar pests and diseases using appropriate chemicals. By 100 days after sowing (DAS), a wide range of L (0.1–5.0) was achieved across plant populations.

Starting after 100 DAS, the r and ir reflectance measurements were recorded on the crop under clear sky conditions between 12:00 and 13:00 h, when the solar zenith angle was about 50° above the horizon. After calibration, the measurements on the canopies were made by holding the collimator by hand at 75 cm the canopy. Reflectance measurements were done at three locations in each plot with a minimum of six readings at each location. Spot measurements of PAR above and below the crop canopy were also made simultaneously, at the same three locations, using a line quantum sensor (Licor Inc.) to estimate fractional PAR interception (f) by the crops. This procedure was repeated several times during the season.

Quantification of reflectance ratio and f

Reflectance ratio (*NR*) was calculated as (ir−r)/(ir+r). The f was calculated as $(P_a\text{-}P_b)/P_a$, where P_a and P_b are PAR measured using the line quantum sensor, above and below the crop canopy respectively. The *NR* and f measurements were averaged for each location within a plot.

Leaf area and biomass analysis

Plants from a given ground area were sampled from each plot at 107 DAS, after a routine run of *NR* and f measurements. The leaves were separated from plants and their area recorded using a leaf area meter (Li-3100, Licor Inc.). The leaves, stems and pods were oven-dried at 80°C and their weights recorded.

RESULTS AND DISCUSSION

The *NR* was very strongly related to *f* in peanut canopies ($r^2=0.94$) (Fig. 2). The *L* was linearly related to *NR* up to $L=3$ while at higher *L*, there was little relationship with *NR* (Fig. 3). Similarly, the standing crop biomass was linearly related to *NR* until *NR* reached about 0.5, beyond which it was not related (Fig. 4), because of complete interception of radiation by the canopy

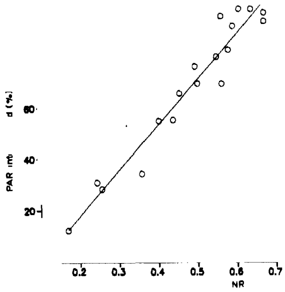

Fig. 2. Relationship between PAR absorbed and *NR* of peanut crop ($Y=-17.7+179.2X$, $r^2=0.94$).

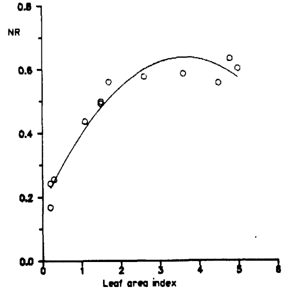

Fig. 3. Relationship between *NR* and *L* in peanut ($Y=0.18+0.25X-0.035X^2$, $r^2=0.70$).

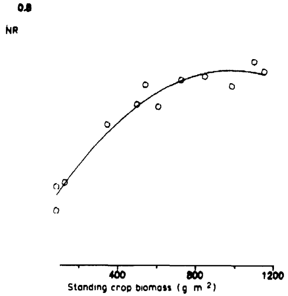

Fig 4 Relationship between *NR* and the standing biomass of peanut ($Y=0\ 14+0\ 0009X-4\ 8E-07X^2\ \ r^2=0\ 82$)

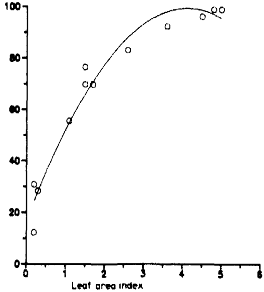

Fig 5 Relationship between PAR intercepted and leaf area index in peanut ($Y=16\ 6+40\ 4\lambda-4\ 92\lambda^2\ \ r^2=0\ 82$)

at $L \geq 3.0$ (Fig. 5). These observations agree well with earlier findings (Steven et al., 1983; Asrar et al., 1984).

The importance of radiation and its relationship with crop biomass productivity is well understood in many crops (Monteith, 1977; Kumar and Monteith, 1981) and this knowledge has been used to interpret results from field experiments. Ground-based measurements of spectral reflectance from crops can provide additional analytical tools to infer radiation interception, evapotranspiration, crop growth and yield (Wiegand and Richardson, 1990).

Plant stress induced by environmental factors like temperature, drought and nutritional disorders may influence the efficiency of radiation conversion by affecting photosynthetic mechanisms. Mathews et al. (1988) have shown variation in peanut cultivars for q under drought conditions. Measurement of f and estimation of q may provide a feasible method of selecting for better light-use efficiency in a given environment.

However, techniques for measuring f have yet to be exploited in crop improvement programs, mainly because of the relatively small numbers of observations that can be made using existing methods. The remote sensing instrument described in this study overcomes these problems particularly for short-statured crops, like peanut.

A range of commercial instruments is available for reflectance measurements on crops, but an important feature of this study is that the instrumentation is simple, inexpensive (costing about Indian Rs. 800=US$50) and portable for non-destructive measurements of f. Interfacing the radiometer with a data logger can provide an easy, rapid and convenient method of measuring f over a large number of plots. When data loggers are not available, it should be possible to fix a 3.5 digit LCD to R15 and R16 in the circuit through a selector switch to display r and ir outputs.

The relationship between NR and f holds well for healthy vegetation on a given soil type. The reflectance properties could vary appreciably depending on the soil background colour and presence of senescent vegetation (Curran, 1981). The technique therefore requires standardisation for a given crop-location.

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