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FIELD SPECTROMETER TO MEASURE PERCENT GROUND COVERAGE AND LEAF AREA INDEX OF AGRICULTURE CROPS

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Summary

Measurement of percent ground cover (PGC) and leaf area index (LAI) are required for crop modelling, yield estimation and for ground truth data in remote sensing studies.

An instrument which traverses on a track above a crop and continuously measures the ratio of incident and reflected radiation at various wavelengths was developed and tested.

Spectral irradiance and reflectance measurements were made at four wavelengths (647.8, 675.5, 739.9, 790.4 nm) at eight stages of growth of wheat and barley for three crop densities. Data provided information on the relations between spectral properties at selected wavelength and leaf area expansion at different growth stages. The spectral data were highly correlated with leaf area index measurements.

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1. INTRODUCTION

Percent ground coverage and leaf area index measurements have been used for estimating light interception and biomass production in crop yield modelling (1, 2, 3). To measure PGC and LAI with conventional methods is time consuming especially when the measurements are required throughout the growth cycle of the crop.

In this paper we define LAI as the total area of green leaf in the plant canopy per unit area of soil as viewed perpendicularly to the soil surface. The PGC is defined as the total vegetative material per unit soil area viewed perpendicularly.

Field spectroscopy lends itself well to measure LAI as well as PGC of plant canopies and can be used to monitor hourly, daily and weekly changes in their parameters.

The measurement and interpretation of the LAI and PGC of a plant canopy during the season is based on the study of changes in the canopy reflectance at selected spectral bands caused by changes in the spectral properties of plants through their growth cycle. The green (500-600 nm), red (600-700 nm) and near infrared (700-1300 nm) spectral bands of the incoming radiant energy are most useful to qualify variations in the canopy structure. (4). The relationship between plant physiology and crop spectral properties has been extensively covered in the literature (5, 6). The same is true for the possible cause-effect relationship influencing vegetation canopy reflectance. The spectral properties of plant canopies are influenced by the sun elevation angle, incidence look angle, and the azimuth angle between sun, crop and detector (8).

The spectral quality of the reflected energy from the crop canopy is dependent on the spectral quality of the incident energy falling upon it. The energy from the sun reaching the plant traverses through the atmosphere, where a portion is absorbed by atmospheric gases and scattered by air molecules, aerosols, etc. The visible and near infrared spectra is attenuated by cloud cover. These influences on the crop spectra have been taken into consideration in the design and application of the field spectrometer discussed.

2. INSTRUMENT DESIGN

The schematic of the field spectrometer is shown in Figure 1. When the folding mirror (M_2) is in the upper position the incoming radiant energy N is collected by a cosine corrected collector (C.C.) directed by a

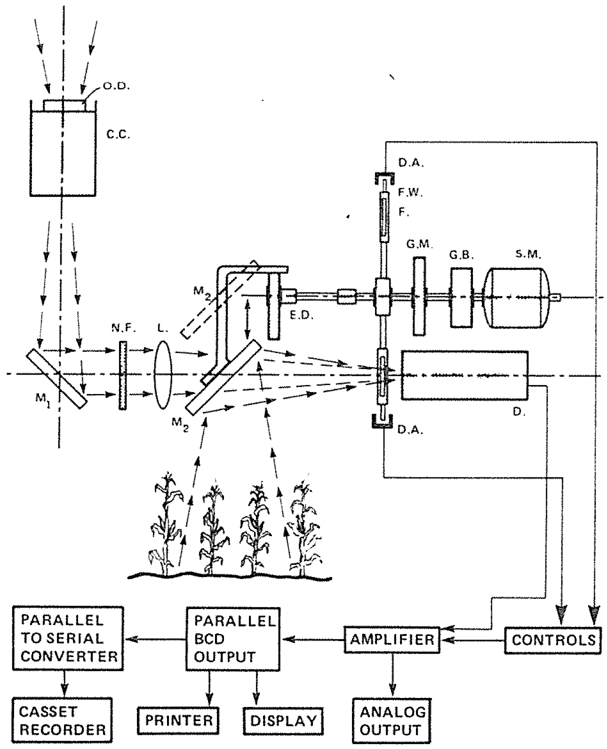

FIGURE 1. Schematic diagram of field spectrometer. (OD, optical difuser; CC, cosine corrected collector; M_1, 45^o plane mirror; NF, neutral density filter; L lens; D, detector; M_2 folding mirror; F, interference filter; FW, filter wheel; SM, synchronus motor; G.B. gearbox; GM, geneva indexing mechanism; ED, eccentric drive; DA optical detector assembly.

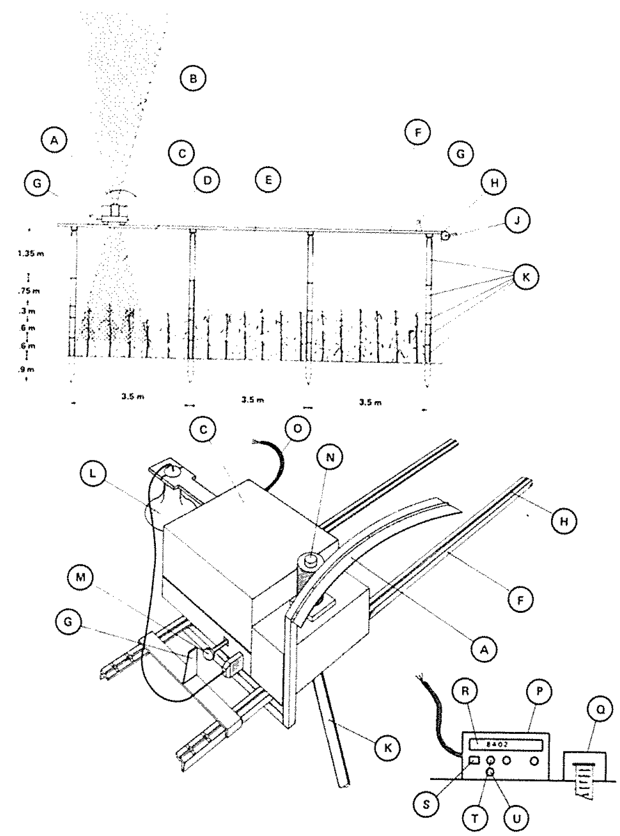

FIGURE 2. Experimental setup of leaf area index and percent ground coverage measurement. (A, shadow bar; C, spectrometer; D field of view; E, crop; F, track; G, stopper, H, cable; J, Winch; K, telescopic poles; L, lamp for night experiments; M microswitch; O, power cable; P, data acquisition system; Q, printer; R, digital readouts; S, power switch)

45^o plane mirror (M_1) through a neutral density filter (N.F.) and lens (L) to the detector (D). When the folding mirror (M_2) is in the lower position the incoming radiant energy is blocked from the detector and the reflected energy R is folded by M_2 on to the detector. N and R energies are intercepted by interference filters (F) with various centre wavelength values λ_c. The filters are placed in a filterwheel (F.W.) holding 25 mm diameter filters, and is driven by a motor (S.M.) via a gearbox (G.B.) at the desired speed. A geneva indexing mechanism (G.M.) is attached to the gearbox, indexing the filterwheel to place each filter alternately in front of the detector for a predetermined time. The time is divided evenly between N and R energies by an eccentric drive (E.D.). The geneva mechanism is rotated at 3.75 RPM, which provide a 4 second exposure for each filter. Two seconds are used to measure the incident radiant energy and 2 seconds for the reflected energy. Coding holes in the filterwheel identify the beginning of a measuring cycle (0_{DA1}) and which λ_c filter is before the detector (0_{DA2}). As the coding holes pass through the optical detection assembly (0_{DA1}, 0_{DA2}) they provide a signal to a control circuit that identifies which filter produced each set of spectral data.

The detector is a silicon detector which has a broad spectral range from 350 - 1100 nm and a sensitivity of 10^{-12} watts cm^{-2}. The amplifier is provided with two outputs a) analog 0-5VDC; b) parallel BCD $3\frac{1}{2}$ digits and sign. A recorder can be attached to the analog output, and a digital display is connected to a cassette recorder from the BCD output for digital data collection which is used most frequently.

3. MEASUREMENT SETUP

The field spectroscopy measurement system was set up in the field where wheat and barley were grown. A portable traversing unit (Figure 2) was developed to accommodate the spectrometer. Four telescopic poles (K) are spaced 3.5 meters apart. The total height of the poles can be adjusted to a maximum of 3.6 m. The spectrometer (C) traverses on a track (H) and is driven by an electric motor at 1 cm/sec. At both ends of the track there are stops (G) which operate microswitches (M) each time the spectrometer reaches the end of the track. As the microswitch is pushed, the direction of travel changes. A shadow bar (A) is provided above the incoming radiant energy collector (N) to measure diffused radiation as an incoming radiant energy. The signal from the detector is connected via a cable (O) to the data acquisition system (P) and cassette recorder (Q). The field of view of the field spectrometer is 8^{o}, therefore at ground level it measures or integrates the spectral values of 0.5 m wide strip of crop. If the plant canopy reaches the height of 1.8 m then the area to be measured will be a 0.25 m wide strip.

To reduce the effect of the sun altitude angle, and azimuth angle between sun, crop and detector, measurements were only taken between 10:00-14:00 h. separated into four 1 hour periods. To eliminate the cloud atmospheric effect and instrumentation errors, incoming incident radiant energy and reflected energy from the crop canopy were taken at the same wavelength in a close proximity and their spectral values ratioed.

$$\text{Ratio} = \frac{R}{N}$$

Three different species, wheat, barley and corn were planted in three different densities (D) (D_1, 239 plant/m^2; D_2, 208 plant/m^2; D_3, 182; plant/m^2). The field spectrometer was calibrated against a known standard. Since in this experiment all spectral data were ratioed, the instrument inaccuracies cancel.

4. RESULTS

To measure and evaluate LAI from the spectral reflectance values, and determine which wavelength ratios provided the closest fit to a LAI obtained by more conventional methods, four wavelength ratios were established:

$$R_1 = \frac{\lambda_{790.4}^{\downarrow\uparrow}}{\lambda_{647.8}^{\downarrow\uparrow}} ; \quad R_2 = \frac{\lambda_{790.4}^{\downarrow\uparrow}}{\lambda_{675.5}^{\downarrow\uparrow}} ; \quad R_3 = \frac{\lambda_{739.9}^{\downarrow\uparrow}}{\lambda_{647.8}^{\downarrow\uparrow}} ; \quad R_4 = \frac{\lambda_{739.9}^{\downarrow\uparrow}}{\lambda_{675.5}^{\downarrow\uparrow}}$$

Each $\lambda^{\downarrow\uparrow}$ measurement indicates that at each wavelength the incident and reflected energies were ratioed and ratios R_1 to R_4 compose these ratios at two different wavelengths. Table I indicates how the ratio values follow LAI. It also indicates that change of about 15^{o} in the sun angle changes the ratio by up to 25%. Figure 3 shows the relationship between spectral output and LAI for all four ratios which indicates that R_2 has the best fit to LAI. When examining the values of the incoming radiant energy ratios (Table I) one finds that within each day the readings differ by less than 5%, and through the growing season by less than 10%. Figure 4 indicates the effect of plant canopy density on the spectral reflectance from wheat (Figure 4a) and barley (Figure 4b). Figure 4c shows the relationship between LAI and spectral output for barley grown at two different densities. Figure 5 shows the effect that the sun angle has on

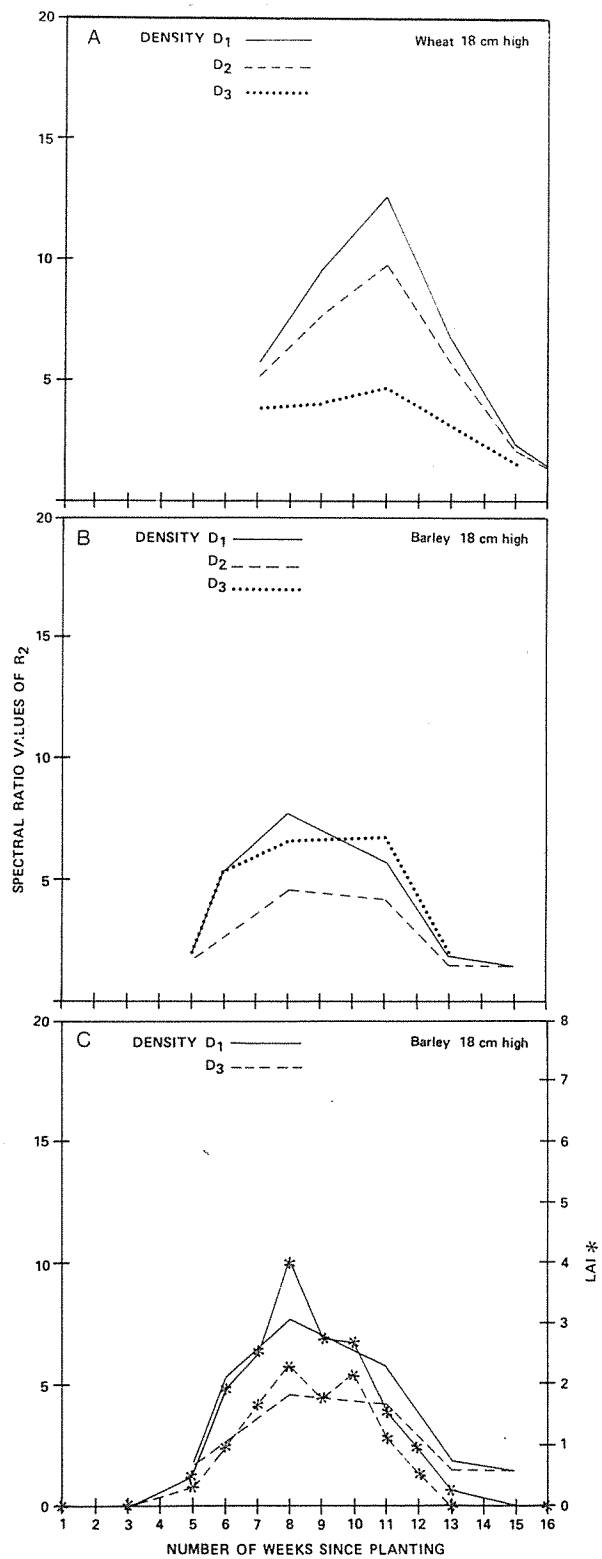

FIGURE 4. Effect of plant canopy density on ratio values A) three density values of wheat B) three density values of barley C) LAI relationship to two density values of barley.

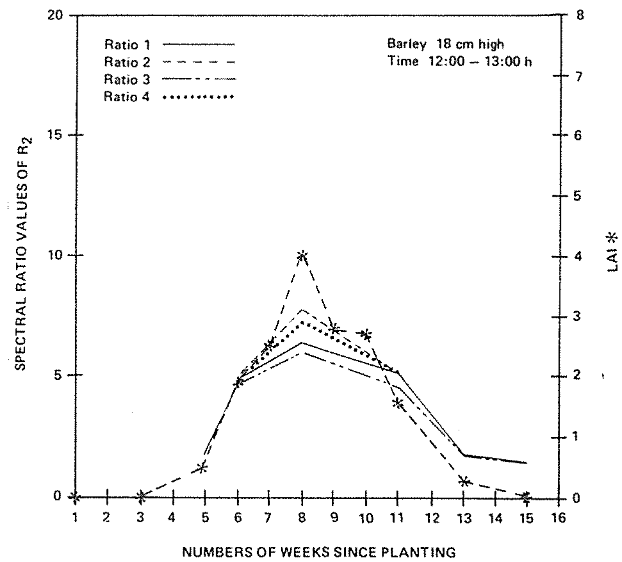

FIGURE 3. Relationship between LAI and the ratio values R_1 to R_4

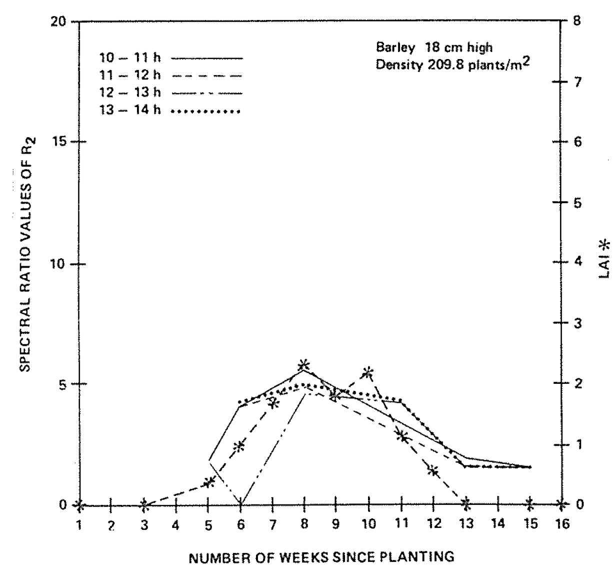

FIGURE 5. Effect of sun angle on ratio value R_2.

the measurement taken, and indicates that the best time to take spectral readings are from 10:00-11:00 h. Each data point in Figures 3 to 5 represent 60 replications. The data analysis of PGC are not yet available. It will be reported at a later date.

5. CONCLUSION

A field spectrometer to measure LAI has been described. Spectral measurements on wheat and barley planted at three different densities taken at four different time periods have been compared to LAI. The results indicate that LAI can be measured by field spectroscopy but sun angle and crop density must be known to obtain accurate LAI readings.

6. ACKNOWLEDGEMENTS

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TABLE I. Relationship of ratio values R_1 to R_4 and incoming radiant energy I_{r1} to I_{r4} to leaf area index and sun angle.

Date	Time (hr)	Crop	Leaf Area Index	Sun Angle	R_1	I_{r1}	R_2	I_{r2}	R_3	I_{r3}	R_4	I_{r4}
05-06-80	10-11	barley	1.93	58	5.696	2.75	6.357	3.27	6.198	3.61	6.917	4.28
sunny,	11-12	18 cm	"	60	5.097	2.71	5.789	3.20	4.841	3.58	5.499	4.24
slight	12-13		"	67	4.860	2.75	5.602	3.25	4.555	3.61	5.251	4.27
haze	13-14		"	68	4.898	2.71	5.334	3.21	4.685	3.59	5.102	4.25
17-06-80	10-11	barley	4.06	59	7.920	2.73	9.821	3.26	7.175	3.59	8.897	4.27
high,	11-12	18 cm	"	61	6.987	2.70	8.527	3.23	6.513	3.59	7.948	4.29
cirrus	12-13		"	68	6.767	2.68	8.381	3.20	6.189	3.55	7.665	4.24
clouds	13-14		"	70	6.428	2.66	7.758	3.16	6.012	3.55	7.255	4.21
25-06-80	10-11	wheat	3.86	59	9.752	2.92	11.458	3.52	7.870	3.82	9.247	4.60
hot,	11-12	18 cm	"	63	9.482	2.80	10.722	3.39	7.771	3.71	8.786	4.48
humid	12-13		"	68	9.109	2.81	10.069	3.40	7.489	3.70	8.277	4.47
	13-14		"	70	8.668	2.80	9.562	3.40	7.212	3.71	7.956	4.50
11-07-80	10-11	wheat	2.34	56	14.801	2.87	17.963	3.49	11.067	3.77	13.431	4.58
humid	11-12	18 cm	"	61	11.190	2.97	12.671	3.54	8.846	3.97	10.017	4.73
	12-13		"	65	11.978	2.86	13.976	3.46	9.269	3.76	10.816	4.55
	13-14		"	68	10.903	2.88	12.608	3.59	8.493	3.85	9.820	4.79
24-07-80	10-11	barley	0.27	56	2.239	2.97	2.295	3.54	2.062	3.84	2.114	4.59
clear,	11-12	18 cm	"	59	1.799	2.88	1.846	3.46	1.746	3.75	1.793	4.52
sunny	12-13		"	62	1.884	2.88	1.955	3.48	1.827	3.76	1.895	4.53
	13-14		"	66	1.786	2.87	1.841	3.46	1.700	3.74	1.753	4.52
25-07-80	10-11	wheat	1.09	55	7.825	2.99	9.003	3.59	6.350	3.88	7.306	4.66
sunny in	11-12	18 cm	"	60	5.653	2.88	6.341	3.31	4.758	3.96	5.338	4.55
morning,	12-13		"	62	6.241	3.00	6.909	3.59	5.095	3.85	5.641	4.61
cloudy in	13-14		"	66	5.734	2.82	6.736	3.53	4.886	3.78	5.740	4.73
afternoon												
24-08-80	10-11	wheat	.08	53	2.730	2.96	3.011	3.57	2.539	3.86	2.801	4.66
sunny	11-12	18 cm	"	58	2.388	2.86	2.487	3.46	2.162	3.77	2.252	4.56
	12-13		"	60	2.420	2.91	2.519	3.51	2.248	3.81	2.340	4.61
	13-14		"	64	2.226	2.89	2.335	3.49	2.121	3.78	2.225	4.57

$$R_1 = \frac{\frac{7904\uparrow}{7904\downarrow}}{\frac{6478\uparrow}{6478\downarrow}} \qquad R_1 = \frac{\frac{7904\uparrow}{7904\downarrow}}{\frac{6755\uparrow}{6755\downarrow}} \qquad R_3 = \frac{\frac{7399\uparrow}{7399\downarrow}}{\frac{6478\uparrow}{6478\downarrow}} \qquad R_4 = \frac{\frac{7399\uparrow}{7399\downarrow}}{\frac{6755\uparrow}{6755\downarrow}}$$

$$I_{r1} = \frac{6478\downarrow}{7904\downarrow} \qquad I_{r2} = \frac{6755\downarrow}{7904\downarrow} \qquad I_{r3} = \frac{6478\downarrow}{7399\downarrow} \qquad I_{r4} = \frac{6755\downarrow}{7399\downarrow}$$