V. R. Rao
Indian Space Research Organization Headquarters
Bangalore 560009, India
E. J. Brach
A. R. Mack
Research Branch, Agriculture Canada
Ottawa, Ontario K1A OC6, Canada

Crop Discriminability in the Visible and Near Infrared Regions*

Certain specific narrow bands of the spectral range, 350 to 1850 nm, were able to distinguish between selected cereal crops and their cultivars.

Abstract: *Field spectroradiometer data at 10-nm intervals in the region of 350 to 1840 nm, from 1976 experimental field plots of wheat, oats, barley, fababean, soybean, and rapeseed, were analyzed statistically to assess discriminability among the crops. At early stages of plant growth, interference from soil reflectance was dominant. Analysis of the data obtained between early heading and early seed development showed similar spectral patterns among the crops and their cultivars. Unique differences were obtained among them at certain narrow bands in relation to the over-all mean radiance based on coefficients of variation. An index of discriminability, determined to assess separability of crops throughout the spectrum, was used to distinguish between two wheat cultivars at 950 and 1400 nm which corresponds to the water absorption region for leaves.*

Introduction

Collection and analyses of crop spectra have been reported by Gausman *et al.* (1973). The selection of various spectral channels for improving crop classification using remotely sensed data has been discussed by Vincent (1973). Optimization of sensor wavelengths and bandwidths has been significance from coefficient of determination (r^2). The noise in the spectra, the atmospheric effects, and changes in the crop varieties need careful consideration to assess the spectral regions that show differences between different crops and their varieties. Field observations by truck and helicopter mounted spectrometers were performed to improve the determination of "spectral signatures" for utilization of the satellite and airborne remote sensing data (Verhoef and Bunik, 1974). The contribution of the underlying soil to the measured composite soil plant canopy spectral reflectance is one of the basic complexities in assessing spectral signatures (Tucker and Miller, 1977). Thus, due to soil influence, regional differences in the bio-physical properties of the crops, and the basic requirement to achieve operational goals. Tucker and Maxwell (1976) have investigated field spectra in the region 0.35 μm to 1.0 μm for grass and assessed the

* Contribution No. 699 from the Engineering and Statistical Research Institute and Contribution No. 658 from the Land Resources Institute, Research Branch, Agriculture Canada.

weather conditions, extrapolation of the spectral signatures and ground truth data to different geographical regions is difficult.

In 1976 a mobile field spectrometer was used for the reflectance measurements of several of field crops during their growth cycles. The atmospheric model given by Turner and Spencer (1972) is used in evaluating the incident solar energy on the crop. In this paper, the determination of the optimum wavelength region for maximum discriminability among crops based on 10-nm spectral bands is presented. Also, the usefulness of a discriminability index for measuring crop spectral differences was examined.

Experimental Conditions and Statistical Methods

Two replicates of various crops and their cultivars were seeded on two dates in 1976 (D_1, May 27; D_2, June 23, 1976. Table 1) in an arc-shaped field plot arrangement. This arrangement provided a similar viewing distance between plots within each replicate and the spectrometer (Brach *et al.*, 1977). Two spectroradiometers were located in a mobile laboratory for measuring visible and infrared spectra over the 350 to 1840 nm waveband. The resolution of the monochromators was better than 0.1 nm. In the analysis described, the average reflectances at 10 nm intervals were evaluated. The incident solar intensity was measured in close succession to the crop observations. The spectroradiometers were standardized using a calibrated tungsten lamp. A total of 487 spectra were collected in the growing season under cloud-free solar incident conditions. Special precautions were observed to ensure absence of cirrus-stratus cloud interference. Spectral data were collected from the crops ranging from heading (growth stage 5) to maturity (stage 9) (Table 2).

The spectra were plotted and the curves subsequently converted to digital format on magnetic tape using a high resolution (<1 nm), manually operated, digitizing system. The analog data were normalized to reduce angular radiation effects. Standard atmospheric transmission and scattering effects were taken from McClatchey *et al.* (1972) and incorporated into the calculations to correct for the major atmospheric absorption (Turner and Spencer, 1972). Day-to-day variation in the atmospheric visibility could not be incorporated, as simultaneous temporal measurements were not made. The transmission of the atmospheric water vapour in the IR was included using relative humidity measurements made at a nearby (100 metres)

Table 1. Crop Species Studied

Number of experimental plots:	Two replicates of 46 each
Period of observations:	July 9—September 28, 1976
Growth stages	Heading (5) to Mature (10)
Seeding dates:	D_1—May 27 D_2—June 23
Plot size:	First replicate 2.44 × 0.73 m Second replicate 3.05 × 0.91 m
Crops:	Cultivars:
Wheat	Glenlea, Hercules, Marquis, SR6, Neepawa, Sinton, Napayo, Macoun
Oats	Garry, Hudson, Terra, Harmon
Barley	Herta, Conquest, Fergues, Bonanza
Soybeans	Altona
Fababean	Herzpreya, Diana
Rapeseed	Torch, Tower
Grass—lawn sod	Kentucky Blue
Soil	clean of vegetation
Total number of spectra:	487
Calibration:	Tungsten lamp precalibrated Kodak gray, black paper, Aluminium plate for IR

TABLE 2. CHARACTERISTICS OF SELECTED CROPS

Crop	Cultivar		Plot	Aug. 17/76 G.S.	Aug. 17/76 Height cm	Sept. 8/76 G.S.	Sept. 8/76 Height cm	Sept. 21/76 G.S.	Sept. 21/76 Height cm
1. Wheat	Hercules	D2	22	5 (Chlorotic)	67	7	81	8 (Half cut)	8
2. Oats	Garry	D2	36	6 (Rusted)	—	8	—	10	—
3. Barley	Herta	D2	37	5 (Chlorotic)	69	7	—	9	—
4. Rapeseed	Torch	D2	29	7	—	8-9	—	10	—
5. Soybean		D2	31	7	40	7	66	7-8	72
6. Fababean	Diana	D2	14	6-7	95	6-7-8	104	8	108

G.S.-Growth Stage: 1-seeded; 2-emerged; 3-tillering; 4-booting; 5-heading; 6-headed; 7-turning; 8-½-green; 9-ripe; 10-fully matured

agrometeorology station. The bi-directional changes were of considerable magnitude, which complicated the analyses. However, by selecting spectral measurements which were taken at nearly the same local times, and by normalizing for sun angle and viewing geometry, the bi-directional effect was minimized.

For each cultivar, the spectral values at each 1-nm interval were averaged for the different measuring dates from August 4 to September 28. The standard deviations of the periodic measurements were calculated and coefficient of variation (*CV*) was obtained. The *CV* spectra was thus obtained and plotted.

The Discriminability Index (*DI*) among any two crops was also evaluated. *DI* is defined as*

$$DI = \Delta\mu/(\sigma_{\text{Tot}}\sqrt{n})$$

where

$\Delta\mu$ = difference between mean reflectances

$$\sigma_{\text{Tot}} = \sqrt{\sigma^2_A + \sigma^2_B + 2\,\rho\,\sigma_A \cdot \sigma_B}$$

ρ = correlation coefficient between crop A and B,
σ_A = standard deviation of crop A,
σ_B = standard deviation of crop B,
σ_{Tot} = pooled standard deviation, and
n = total number of observations of crops A and B.

The observations of the crops on the same clear days were used, thus avoiding the complex variabilities of the atmosphere and limiting the bi-directional properties to their minimum.

* Dr. P. Castruccio, ECO Systems Intern., Ganbrills, Va., U.S.A. personal correspondence

RESULTS AND DISCUSSION

The average of the spectral characteristics for the periodic measurements obtained from August 4 to September 28, 1976 are presented for six crops (Figures 1A and 1B). Usually six to eight spectral measurements were made on each crop during this period, covering growth stages from early heading (5) to maturity (10). Selected stages of plant growth and heights are shown in Table 2. The data showed that the average of the

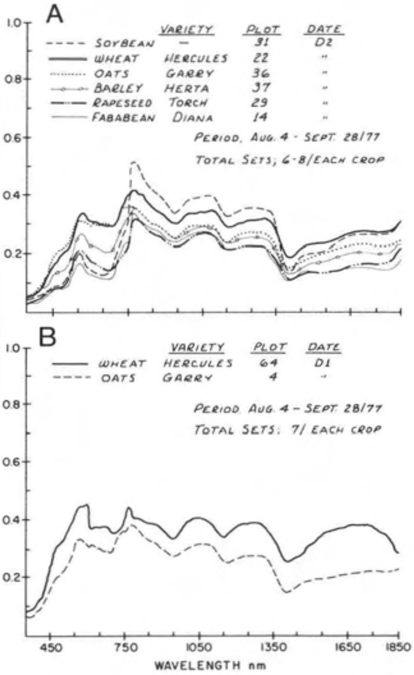

FIG. 1. The average of reflectance values from August 4 to September 28 for six crops seeded on June 23, 1976 (A) and for two cultivars seeded on May 27, 1977 (B).

spectral values for each crop were similar but that the magnitude of their reflectances were different at certain wave bands. For example, in the visible band, the average reflectances for the wheat and oat crops were higher than for rapeseed or fababean; but in the IR band, the reflectance for soybeans was higher than for the cereals (750 nm and 1300 nm). The absorption bands for chlorophyl (near 650 nm) and for water (950, 1150, 1450 nm) are prominently shown in all spectra to a varying degree.

The fluctuations around the mean spectral values were considerable for many of the crops throughout the spectrum (Figure 2). The coefficient of variation ($CV = \sigma/\mu$) is plotted for each wavelength (1 nm) and crop. σ is the standard deviation and μ is the average spectral value for each 1.0 nm bandwidth. Due to the differences in the calibration system between the visible and the near-IR regions, a 750-nm discontinuity occurred which may be due to a difference in the absolute calibration and the assumed reflection coefficients used in the measurement of the incident solar intensity. A Kodak neutral gray has been used for determining intensity in the region from 0.35 μm to 0.75 μm and a well calibrated aluminum plate is used for the region 0.75 μm to 1.84 μm. This, in turn, was periodically calibrated against a tungsten lamp. However, the general variations are clearly shown and relative comparisons are accurate to about 5 percent accura-

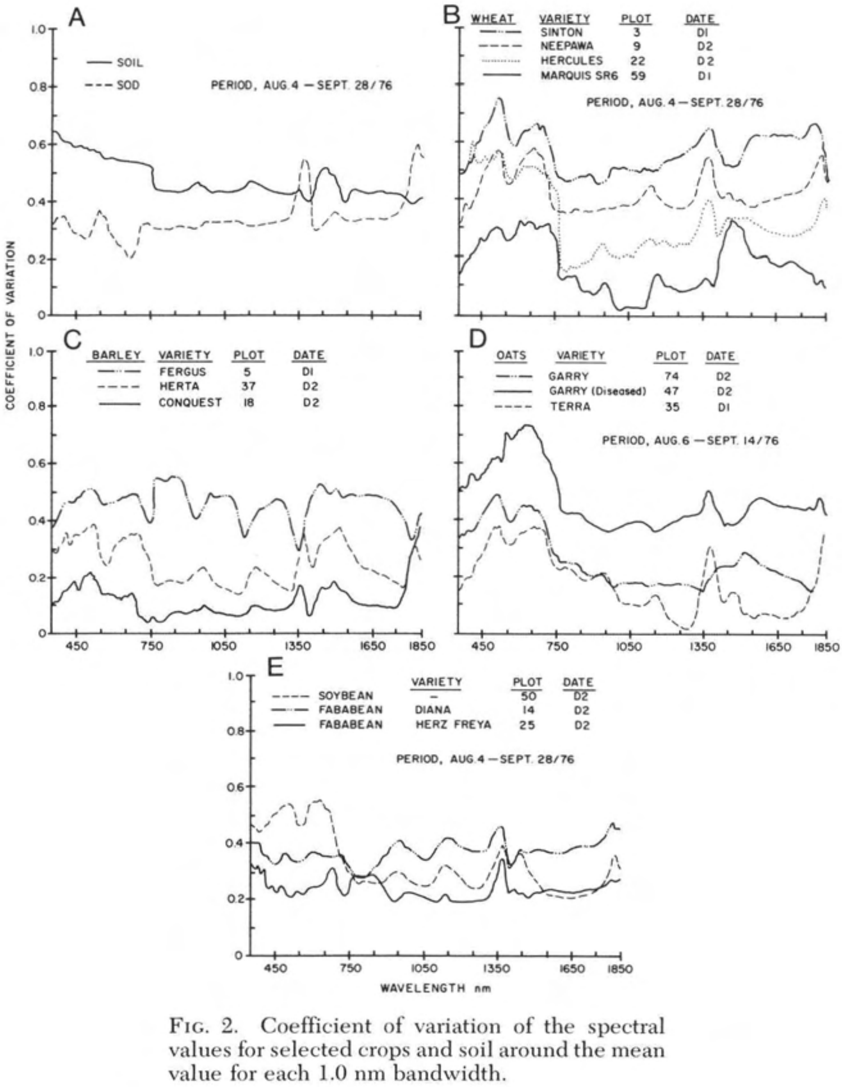

FIG. 2. Coefficient of variation of the spectral values for selected crops and soil around the mean value for each 1.0 nm bandwidth.

cy. The soil showed a relatively smoother spectrum than the sod except in the water absorption regions (Figure 2A). The sod showed a difference in the coefficient of variation between 450 to 700 nm and the soil near 1350 nm.

The *CV* varied among the wheat cultivars throughout the entire spectrum (Figure 2B). Among the wheat varieties (Sinton, Neepawa, Hercules, and Marquis SR6), Sinton (D2) had the largest *CV* (60 percent) while Marquis SR6 (D1) had the smallest (15 percent to 20 percent). The general pattern of the *CV* throughout the spectral range 350 to 1850 nm was somewhat similar. Large *CV* occurred near 500 to 550 nm, 650 to 700 nm, and 1250 to 1350 nm, which correspond physiologically to the wavelength regions of minimal radiation absorption by plants, of absorption by chlorophyll and plant water, respectively. Among the barley cultivars (Figure 2C), Fergus (D1) showed the maximum *CV* of 45 percent and Conquest (D2) the lowest of 10 percent. The pattern for Fergus was distinctly different from the others, having a number of broad plateaus with low indentations near 750, 925, 1125, and 1350 nm. Among the oat varieties (Figure 2D), Garry showed a high *CV*, >40 percent, particularly in the range of 550 to 650 nm, whereas Terra (D1) was low, <40 percent. The variation among the fababeans, from 350 to 1850 nm, was less and generally between 20 to 40 percent (Figure 2E).

The Discriminability Index (*DI*) for soil and crop such as Garry oats showed particularly high values in the region of 750 to 1250 nm (Figure 3A). The *DI* for soybean and fababeans (Figure 3D) is particularly low between 450 and 700 nm, and has a maximum at 1250 nm and at 1550 to 1750 nms. The *DI* between Marquis SR6 and Marquis (Diseased) and between Marquis SR6 and Neepawa was low throughout the range except for narrow bands near 1000, 1400, and 1700 nm. Between the varieties of wheat, discriminability is possible at the locations of the leaf water band. For use in satellite observation careful consideration is needed

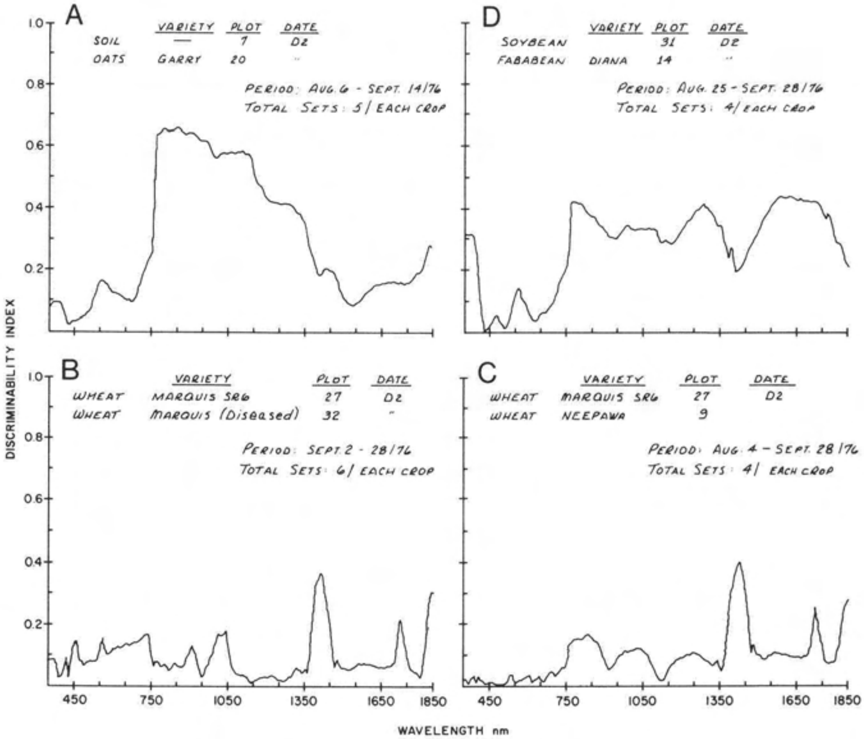

FIG. 3. The Index of Discriminability between selected crops seeded June 23 (D2) based on the difference of their reflectances throughout the spectrum.

to account for the atmospheric water vapor absorption as has been done here.

Conclusions

Certain specific narrow bands of the spectral range, 350 to 1850 nm, were able to distinguish between selected cereal crops and their cultivars. Even though the average reflectance values for the spectrum were similar, the fluctuation around the mean values at specific wavelengths could be used as a quantitative measure for possible separation of the crops and cultivars. The Discriminability Index showed that the differences in reflectances between two crops may be a useful critieria for selecting these narrow-band areas. Two wheat cultivars, for example, were separated near 950 nm and 1400 nm. Thus, radiation may need to be measured at particular bands other than those used in Landsats 1 and 2 for use in distinguishing certain crops and crop conditions.

Acknowledgments

Dr. V. R. Rao wishes to thank the National Research Council Canada for the offer of a visiting fellowship to work at Canada Centre for Remote Sensing, Ottawa, and to Mr. B. A. Hodson and Dr. E. Shaw for their encouragement in this work.

References

Brach, E. J., R. W. Tinker, and G. T. St. Amour, 1977, Improvements in Spectral Reflectance Measurement of Field Crops, *Can. Agr. Eng.* 19: 78-83.

Gausman, H. W., W. A. Allen, R. Cardinas, and A. J. Richardson, 1973, Reflectance Discrimination of Cotton and Corn at Four Growth Stages. *Agron. J. 65: 194-198.*

Kondratyev, K., O. Vassilyev, A. Grigorijev, and G. Ivanian, 1973, An Analysis of the Earth's Resources Satellite (ERTS-1) data, *Remote Sensing Env.* 2: 273-283.

McClatchey, R. A., R. W. Fenn, J. E. A. Selby, F. E. Volz, and J. S. Garing, 1972, *Optical Properties of the Atmosphere.* AFCRL, Report 72-0497, Environmental Research Paper No. 411 (Airforce Cambridge Research Laboratories Report), Bedford, Mass.

Tucker, C. J., and E. L. Maxwell, 1976, Sensor Design for Monitoring Vegetation Canopies, *Photogram. Eng. & Remote Sensing* 42 (11): 1399-1410.

Tucker, C. J., and L. D. Miller, 1977, Soil Spectra Contribution to Grass Canopy Reflectance, *Photogram. Eng. & Remote Sensing* 43 (6): 721.

Turner, R. E., and M. M. Spencer, 1972, Atmospheric Model for Correcting the Space Craft Date. *Proc.* Eighth Int. Symp. on Remote Sensing of Env. pp. 895-934.

Verhoef, W., and N. J. J. Bunnik, 1974, *Spectral Reflectance Measurements on Agricultural Field Crops During the Growing Season,* NIWARS publication No. 31, Delft, Netherlands. pp. 1-72.

Vincent, R. K., 1973, *The NASA Earth Resources Spectral Information System: A Data Compilation.* Second Supplement. NASA CR-ERIM 31650-156-T.

(Received September 30, 1977; revised and accepted May 24, 1978)

Forthcoming Articles

Dr. Uzi Ethrog, Photogrammetric Positioning of Supersonic Wind Tunnel Models.
S. Hsu, Texture-Tone Analysis for Automated Land-Use Mapping.
Alan D. Jones, Computers and the Teaching of Airphoto Interpretation.
Chi-Hai Ling, Lowell A. Rasmussen, and *W. J. Campbell,* Flight Path Curvature Distortion in Side-Looking Airborne Radar Imagery.
Kenneth R. Piech, John R. Schott, and *Kenton M. Stewart,* The Blue-to-Green Reflectance Ratio and Lake Water Quality.
Dr. Frank L. Scarpace, Densitometry on Multi-Emulsion Imagery.
Dr. F. L. Scarpace and *G. A. Friederichs,* A Method of Determining Spectral Analytical Dye Densities.
R. L. Talerico, J. E. Walker, and *T. A. Skratt,* Quantifying Gypsy Moth Defoliation.
Arnaldo M. Tonelli, Surface Texture Analysis with Thermal and Near Infrared Scanners.
Compton J. Tucker, A Comparison of Satellite Sensor Bands for Vegetation Monitoring.