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Soil Spectra Contributions to Grass Canopy Spectral Reflectance

The contribution of a soil-litter background to the composite grass canopy spectra can, in some grassland cases, be extracted and quantified.

ABSTRACT: *The soil or background spectra contribution to grass canopy spectral reflectance for the 0.35 to 0.80 μm region was investigated using in situ collected spectral reflectance data. Regression analysis was used to estimate accurately the unexposed soil spectral reflectance and to quantify maxima and minima for soil-green vegetation reflection contrasts.*

INTRODUCTION

THE CONTRIBUTION of the underlying soil spectra to the composite canopy spectral reflectance of vegetated surfaces has recently been addressed (Colwell, 1974; Driscoll and Spencer, 1972; Richardson *et al.*, 1975; Wiegand *et al.*, 1974). Remotely sensed data of vegetated surfaces could be analyzed more accurately if the contribution of the underlying soil spectra were known and thus possibly could be removed from the canopy spectral radiance to yield more information about the vegetation. It would generally be impractical to take detailed soil spectra measurements of the area in question because the vegetation canopy obscures the soil surface and the time involved for these *in situ* measurements is usually prohibitive.

The work reported in this article was part of a larger effort sponsored by the U.S. International Biological Program's Grassland Biome. The data were collected with the objective of evaluating non-destructive spectro-optical techniques for measuring aboveground standing crop biomass of grasslands. Early in the study it became apparent that the soil or background spectra dominated low biomass grass canopy spectral radiance or reflectance. It was therefore necessary to examine the contribution of the soil spectra to the composite grass canopy spectral reflectance as a function of biomass and wavelength.

BACKGROUND

Let us assume that the soil background (realizing that the "soil" background is actually a soil-litter background) has a characteristic spectra for a given particular area (Figure 1). The soil spectra for the field study site was a monotonically increasing function with wavelength over the spectral range of 0.35 to 1.00 μm. The dry soil surface was more highly reflective than the wet soil surface. Dry refers only to the uppermost layer as determined by visual inspection.

The plant canopy on the grassland soil surface will be viewed as some statistical ensemble of foliage elements superimposed over the soil-litter background. The density of the ensemble of foliage elements will be a

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function of biomass. The incoming spectral irradiance will interact with the grass canopy and, depending upon the vegetational density or biomass, can also interact with the soil background. The interaction(s) with the soil background become less and less as the vegetational density or biomass increases until the asymptotic spectral radiance or reflectance is reached (Tucker, 1977). Increases in the vegetational density or biomass effect no change in the canopy spectra when the asymptotic spectral radiance or reflectance has been reached. This can be explained because the canopy is of sufficient density and thickness to prevent the penetration of the incident spectral irradiance to lower biomass levels of the canopy. Hence, the incident spectral irradiance does not interact with additional (and lower level) biomass. As the vegetational density increases to the point where the spectral reflectance begins to asymptote at a given wavelength, the soil spectra contribution to the canopy spectra is minimal at that wavelength. When the canopy is of sufficient density or biomass to result in the asymptotic spectral reflectance, there is no soil spectral reflectance contribution to the composite canopy spectral reflectance. Thus the relative contribution of the soil spectra to the composite canopy spectra is inversely related to the biomass or vegetation density.

The asymptotic spectra for green grass canopies were quite different from those for the soil surface at the study site (Figure 1). As plant growth and development result in increasing amounts of green plant material above the dry soil surface, the canopy spectra changes. In regions of the spectrum where absorption occurs, the composite canopy spectra decreases and approaches the asymptotic green reflectance spectra. In

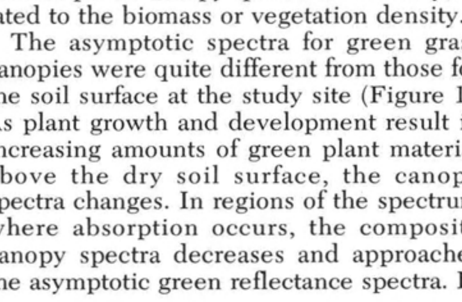

FIG. 1. Spectral reflectances for dry soil, wet soil, and the asymptotic green reflectance. The dry soil and wet soil are for five bare soil plots measured when dry and wet, respectively. The asymptotic green reflectance curve is from a plot of blue grama grass having a total dry biomass of 530 g/m².

the near infrared region of ~0.71 to 0.74 μm, the composite canopy spectra does not change appreciably. In spectral regions where minimal or no absorption occurs, such as the ~0.74 to 1.20 μm region, the composite canopy spectra increases and approaches the asymptotic green reflectance spectra. Discrimination of vegetation biomass, for example, is strongly dependent upon the soil surface-vegetation spectral reflectance or radiance contrast. For this reason, some wavelengths are far superior to others for discrimination of green vegetation biomass (Tucker and Maxwell, 1976).

The effectiveness of some wavelengths decreases while that of others increases when the soil surface is wet (Figure 1). The soil-vegetation reflectance contrast decreases in the red and blue regions while it increases in the photographic infrared region. This has also been reported by Colwell (1974).

Theoretical considerations indicate that the soil spectra can be extracted by regressing canopy spectral reflectance against some measured biophysical characteristic of the canopy such as total biomass, green biomass, brown biomass, chlorophyll, and leaf water concentration. The simple model used for this extraction was a general linear regression model of the form:

$$\text{Reflectance}_\lambda = \beta_{0\lambda} + \beta_{1\lambda}\,(\text{plot characteristic}) + \text{Error}_\lambda \qquad (1)$$

Note that the $\text{Reflectance}_\lambda$, $\beta_{0\lambda}$, $\beta_{1\lambda}$, and Error_λ are all functions of wavelength.

METHODS AND ANALYSIS

STUDY LOCATION

The experimental results reported herein were obtained on native shortgrass prairie at the IBP Grassland Biome Pawnee Site, the field research facility of the Natural Resource Ecology Laboratory, Colorado State University, located on the USDA Agricultural Research Service Central Plains Experimental Range about 35 miles northeast of Fort Collins, Colorado. Field measurements were made in the Ecosystem Stress Area (ESA) on control, irrigated, and/or nitrogen fertilized plots.

Prairie vegetation is dominated by various species of grasses. One species, blue grama (*Bouteloua gracilis* (H.B.K.) Lag.), comprises about 75 percent of the dry weight of the gramineous vegetation at the Pawnee Site (Uresk, 1971). For this reason, plots of blue grama grass were selected for experimentation purposes.

In situ measurements of spectral reflectance were obtained with the field spectrometer laboratory designed and constructed for the IBP Grassland Biome Program to test the feasibility of spectro-optically measuring the above ground plant biomass and plant cover (Miller *et al.*, 1976).

DATA USED

Forty ¼ m^2 plots of blue grama grass were sampled *in situ* by spectroradiometric measurement over the 0.350 to 0.800 μm region at every 0.005 μm interval with the mobile field spectrometer laboratory. All measurements were made normal to the ground surface and were sampled in early September, 1971.

Immediately after the reflectance measurements were completed, each plot was clipped of all standing vegetation. The clipped vegetation was placed in a plastic bag, quick-frozen on dry ice, and subsequently taken into the laboratory for weighing, chlorophyll extractions, and drying. Laboratory determinations were made for total wet biomass, total dry biomass, leaf water content, dry green biomass, dry brown biomass, and total chlorophyll content (Table 1).

Regression Analysis

A regression approach was undertaken to approximate the relationship(s) existing between the six sampled canopy variables and the spectral reflectance at each 0.005 μm interval. Standard regression notation after Draper and Smith (1966) will be used and denoted as a function of wavelength by the subscript λ.

Statistically, both variables were sampled with error. However, the reflectance variance for all 40 replications was approximately the same. The reflectance measurements were considered as 91 independent regressions over the 0.350 to 0.800 μm spectral region because the reflectance was measured at a fixed wavelength. Because of the statistical model used, reflectance could be treated as the dependent variable even though it was sampled with error for a fixed wavelength. The biomass and spectral reflectance measurements were considered as a bivariate normal distribution of the form

$$\begin{bmatrix} Y_\lambda \\ X \end{bmatrix} \sim \mathrm{BVN}\left[\begin{bmatrix} Y_\lambda \\ x \end{bmatrix}; \begin{bmatrix} \mu_{y\lambda} \\ \mu_x \end{bmatrix}, \begin{bmatrix} \sigma^2_{y\lambda} & \mathrm{cov}(y_\lambda, x) \\ \mathrm{cov}(y_\lambda, x) & \sigma^2_x \end{bmatrix}\right] \quad (2)$$

and, for fixed $X = x$,

$$(Y_\lambda \mid X = x) \sim \mathrm{N}(y_\lambda; \beta_{0\lambda} + \beta_{1\lambda} x, \sigma^2_{y_\lambda}) \quad (3)$$

where

Y_λ = measured spectral reflectance;

X = measured biomass, chlorophyll, leaf water, etc.; and

$\sigma^2_{Y_\lambda}$ = measurement error associated with spectral reflectance.

Although the regression model used was a simple linear regression model, the interaction of solar irradiance with a plant canopy is very definitely nonlinear. However, the functional relationship between spectral reflectance and the biophysical plot variables sampled for the experimental plots in question could be accurately approximated by a linear model. If the range of total wet biomass values for the experimental plots would have exceeded 500 g/m^2, then a nonlinear model would have been necessary.

Table 1. Statistical Summary of the Biophysical Characteristics of the Sample Plots. A Statistical Description of the Vegetative Canopy Characteristics of the 40 1/4 m^2 Sample Plots of Blue Grama Sampled in Early September, 1971.

Sample	Range	Mean	SD	Coef. of variation	SE
Wet total biomass (g/m^2)	70.83–491.22	261.31	134.40	51.44	21.25
Dry total biomass (g/m^2)	41.50–337.84	168.55	90.81	53.88	14.36
Dry green biomass (g/m^2)	17.12–185.04	89.38	50.15	56.11	7.93
Dry brown biomass (g/m^2)	20.40–186.42	82.41	48.54	58.90	7.68
Leaf water (g/m^2)	28.03–190.80	92.75	50.93	54.91	8.05
Chlorophyll (mg/m^2)	53.02–778.97	319.58	238.73	74.70	37.75

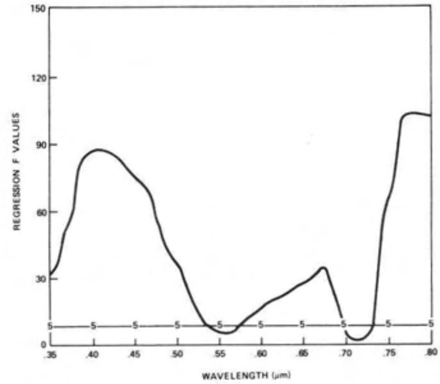

FIG. 2. F value curve resulting from the simple linear regression model analysis of variance for the regression between reflectance and dry green biomass for each of the 91 wavelength intervals between 0.35 and 0.80 μm. The horizontal (-5-) line represents the 0.5 percent level of significance for 1 and 38 df.

The regression model in Equation 1 was estimated at the 91 0.005 μm intervals between 0.350 to 0.800 μm using the 40 replicated measurements of spectral reflectance and the canopy variables. The simple correlation coefficient (r), the coefficients of determination (r^2), the resulting regression model analysis of variance F values (F) (Figure 2), and the final regression equations at each of the 91 0.005 μm wavelengths were calculated (Table 2). These statistics, expressed as functions of wavelength, defined the relative sensitivity on a spectral basis between the various biophysical variables of the sample plot and the plot's spectral reflectance.

The regression equation intercept ($\beta_{0\lambda}$ in Equation 1) was considered as the contribution of the soil surface to the composite canopy spectral reflectance. Restating Equation 1 we have

$$\text{CANOPY RFL}_\lambda = \text{SOIL RFL}_\lambda + \beta_{1\lambda} \, (\text{BIOMASS (g/m}^2)) \quad (4)$$

The terms "CANOPY RFL" and "SOIL RFL" were percentages, the biomass (in this example) was in g/m², and $\beta_{1\lambda}$ has units of percent/(g/m²) or the weighting coefficient of the respective biophysical plot variable.

The regression model simplifies when the biophysical plot variable was zero to the expression:

$$\text{CANOPY REFLECTANCE}_\lambda = \text{SOIL REFLECTANCE}_\lambda \quad (5)$$

The relative contribution of the underlying and somewhat obscured soil surface was related to the composite canopy spectral reflectance and plot variable by the general linear regression model with a minimum of assumptions.

These assumptions included the following:

(1) The biomass range of the sampled gramineous canopies varied from 0.0 g/m² to 500 g/m² (Table 2),
(2) A linear relationship existed between canopy spectral reflectance and the respective plot variable, and
(3) The canopy spectral reflectance was measured *in situ*.

RESULTS

The estimated regression equation intercepts plotted as a function of wavelength closely resemble a soil spectra curve (Figure 3). This curve was considered as the result-

TABLE 2. TABULAR RESULTS FOR THE SIMPLE LINEAR REGRESSION BETWEEN REFLECTANCE AT 0.775 μm AND THE DRY GREEN BIOMASS CLIPPED FROM 40 1/4 m² *IN SITU* SAMPLE PLOTS OF BLUE GRAMA.

Wavelength = 0.775 μm:

Correlation coefficient (r)	= 0.8493
Coefficient of determination (r^2)	= 0.7213
Standard error of the estimate	= 1.6657

Regression equation: Estimated reflectance (%) = 16.5695 + 0.0527 * (Green Biomass—g/m²)

Analysis of variance table

Source	df	Sum of squares	Mean squares	F ratio	$P(F > \text{comp } F)$
Regression	1	272.8683	272.8683	98.3517	0.0000
Residual	38	105.4277	2.7744		
Total	39	378.2959			

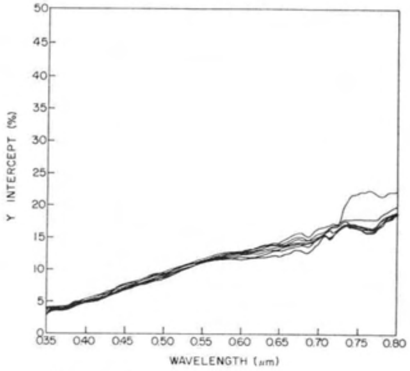

FIG. 3. Comparison between the spectral intercept curves for the six independently sampled canopy variables. Note the very close similarity between the six curves.

ing series of soil spectral reflectances from Equation 5.

The spectral intercepts (i.e., $\beta_{0\lambda}$) curves utilizing each of the six different available biophysical measures of the vegetation canopy variables were very similar, as in all cases the underlying soil surface was in fact the same and should have the same spectral reflectance (Figure 3).

Regardless of the biophysical measure of the canopy used, the regression intercepts closely resembled those of the other five intercept curves. All six of these curves in turn closely resembled the independently measured spectral reflectance of bare soil measured in the same area (Figure 4).

It was interesting to note that the soil spectra estimate was reasonably accurate in regions of the spectrum where there was a lack of regression significance between canopy spectral reflectance and the respective plot variable(s). The coefficient of determination (r^2) values and F ratios (Figure 2) resulting from the regression between canopy spectral reflectance and dry green biomass indicated a lack of statistical significance in the 0.530 to 0.600 μm and 0.700 to 0.740 μm regions of the spectrum. However, the estimate of the soil spectra in these same regions was as accurate as in other areas of the spectral interval studies where strong significance existed. The accuracy of the soil spectra estimate was apparently not dependent upon regression significance.

The plot of $\beta_{1\lambda}$ as a function of wavelength indicates the departure from the soil spectra for green vegetation (Figure 5). Maxima and minima correspond to those wavelengths with the greatest soil-green vegetation contrast for the soil present at the study site. It is interesting to note that the minimum values for $\beta_{1\lambda}$ lie in the 0.67 to 0.69 μm region of strong *in vivo* chlorophyll absorption while maximum values for $\beta_{1\lambda}$ lie in the 0.75 to 0.80

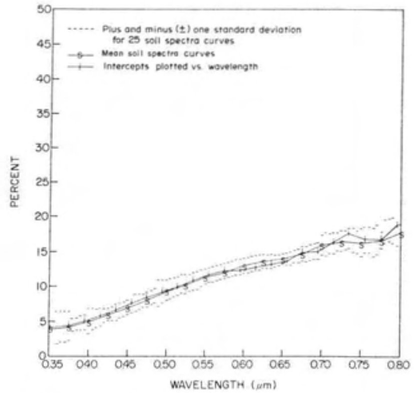

FIG. 4. Comparison among the mean of six computed soil spectral reflectances and the mean of soil spectral reflectance measured in the same area. -S- represents the mean spectral reflectance of 25 soil curves. – represent plus and minus one standard deviation of the mean. The + curve represents the mean of the six regression intercept curves. Note the close similarity between the two mean curves from 0.350 μm to 0.800 μm. The mean soil curve was formed by averaging 25 soil spectral reflectance curves for five bare soil plots with five repetitive curves per plot. The intercept mean curve was formed from the individual intercept curves (Figure 3) resulting from the simple linear regression between spectral reflectance and the plot variables for the 40 plots of blue grama grass.

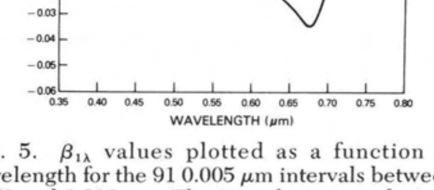

FIG. 5. $\beta_{1\lambda}$ values plotted as a function of wavelength for the 91 0.005 μm intervals between 0.350 and 0.800 μm. The $\beta_{1\lambda}$ values were derived from the series of regressions between spectral reflectance and the dry green biomass for the 40 plots sampled. Maxima and minima values for $\beta_{1\lambda}$ represent the greatest soil-dry green biomass reflectance contrast(s).

μm region of enhanced photographic infrared reflectance.

An interesting extrapolation of Figures 1 and 5 may explain some of the findings of Rouse *et al.* (1974) who reported greater grassland biomass mapping utility using Landsat MSS6 (0.70 to 0.80 μm) than MSS7 (0.80 to 1.10 μm). If we assume that the soil spectra data presented in Figure 1 applies to the American Great Plains test areas used by Rouse *et al.* (1974), it is apparent that greater soil-green vegetation contrast occurs in MSS6 (0.70 to 0.80 μm) than MSS7 (0.80 to 1.10 μm). This could explain the greater utility of MSS6 vs. MSS7 for Rouse *et al.*'s (1974) study areas.

Summary

(1) The contribution of a soil-litter background to the composite grass canopy spectra can, in some grassland cases, be extracted and quantified.
(2) Applied regression analysis was found to accurately estimate the soil spectral reflectance and to quantify the wavelengths of maximum soil-green vegetation reflectance contrast.
(3) The near infrared soil-green vegetation reflectance contrasts may explain why Landsat MSS6 has been found in some situations, superior to MSS7 for biomass monitoring.

Acknowledgments

I wish to thank Mike Garratt and Lee Miller for suggestions on the manuscript.

This paper reports on work supported in part by National Science Foundation Grants GB-7824, GB-31862X, GB-31862X2, GB-41233X, and BMS73-02027 A02 to the Grassland Biome, U.S. International Biological Program, for "Analysis of Structure, Function, and Utilization of Grassland Ecosystems." This is a drastically revised version of a paper presented at the 3rd Annual Remote Sensing of Earth Resources Conference (1974).

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