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Relationship of Sorghum Canopy Variables to Reflected Infrared Radiation for Two Wavelengths and Two Wavebands

Variables included the scene components (plant cover, shadow, and sunlit soil), plant population, biomass, and the conditions of the soil surface under the plant canopy.

INTRODUCTION

THE LIGHT REFLECTANCE from a cropped area is a composite of reflectances from sunlit and shadowed soil, and sunlit and shadowed leaf surfaces (Gerbermann *et al.*, 1969; Leamer *et al.*, 1978). The relative influence that each of these components has on the magnitude of reflectance must be known so that reflectance measurements can be properly interpreted.

Shadows cast by a crop canopy or occurring within the canopy tend to lower reflectance values and increase film densities (Gerbermann *et al.*, 1969; Richardson *et al.*, 1975). Sunlit soil tends to increase reflectance (Richardson *et al.*, 1975), with the level of reflectance being influenced by brightness, condition, and moisture content of the soil surface (Bowers and Hanks, 1964; Gates, 1964).

Leamer *et al.* (1978) found that soil reflectances were much higher than those for vegetation in the 1.65 and 2.20 μm wavelengths and that soil reflectance caused the reflectances for wheat plots to be high for conditions where plant canopy cover failed to completely obscure the soil surface. They also reported that percent plant canopy cover and reflectance for the 1.65 and 2.20 μm wavelengths were significantly negatively correlated.

We examined the relationships between percent reflectance (1.65 and 2.20 μm wavelengths, 1.55 to 1.75 and 2.10 to 2.30 μm wavebands) and (1) the scene components (plant cover, shadow, and sunlit soil), (2) plant population, (3) biomass, and (4) the conditions of the soil surface under the plant canopy.

MATERIALS AND METHODS

Grain sorghum (*Sorghum bicolor* (L.) Moench), Oro Special* a cultivar used for grain production, was sown broadcast (spread by hand as evenly as possible) on randomly selected square meter (m^2) plots on Hidalgo sandy clay loam (Typic Haplustolls) soil, on 14 September 1978 at rates of 50, 100, 175, 250, and 325 kernel/plot. Each sowing rate was replicated four times in a randomized complete block experimental design. A garden rake was used to cover the kernels with soil, and then a garden water hose with a sprinkler head attached was used to wet the soil to a depth of about 25 mm for each plot. The plots were arranged in two rows with one row being 2 by 5 plots and the other 2 by 7 plots. There was access from the outside to all plots from at least one side. The grain sorghum plants emerged on 25 September 1978.

Reflectance measurements were made (between 1000 and 1400 CST with sun angles being zenith ± 47.9°) on 18 October 1978, when the sorghum plants were about 30 cm tall with an Exotech Model 20 field spectroradiometer mounted on the boom of an aerial lift truck. The Model 20 spectroradiometer is a circular-variable-filter instrument (Leamer *et al.*, 1973) that measures the amount of energy entering the instrument at all wavelengths from 0.45 to

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* Contribution from Remote Sensing Research, Agricultural Research Service, U.S. Department of Agriculture, Weslaco, TX.

* Trade names are included for the readers' benefit and imply no endorsement or preferential treatment of the mentioned product by the U.S. Department of Agriculture.

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ABSTRACT: *Our objectives were to examine the relationships between percent reflectance (1.65 and 2.20 μm wavelengths, 1.55 to 1.75 and 2.10 to 2.30 μm wavebands) and (1) scene components (plant cover, shadow, and sunlit soil), (2) plant population, (3) biomass, and (4) the soil surface condition under the plant canopy. Reflectance measurements were made with an Exotech Model 20 field spectroradiometer on five grain sorghum plant populations ranging from 50,000 to 3.25 million plants/ha, all with the same soil surface condition, and on three plant populations ranging from 370,000 to 1.42 million plants/ha, each having three different soil surface conditions beneath the plant canopy.*

Relationships for percent reflectance (1.65 and 2.20 μm wavelengths and 1.55 to 1.75 μm and 2.10 to 2.30 μm wavebands) with percent sunlit soil were significantly positively correlated, while those for reflectance with percent plant cover, percent shadow, plant population, and biomass were significantly negatively correlated. For all plant populations, percent reflectances (1.65 μm wavelength and the 1.55 to 1.75 μm waveband) for canopies with dry-crusted soil surfaces were significantly higher statistically than those for canopies with dry-broken-crusted soil surfaces, while reflectances for canopies with dry-broken-crusted soil surfaces or wet-broken-crusted soil surfaces were alike statistically.

Results indicate that reflectance measured in these wavelengths and wavebands can be used to determine the quantity of living plant cover on the soil surface at a particular point in time and that the lightness or darkness of the soil surface under the plant canopy can have a significant effect on plant canopy reflectances, particularly at low plant populations.

2.50 μm (system spectral resolution 2.1 percent) as filters are rotated through the optical path in the instrument. The optics direct the filtered energy onto two sensors, a silica and a lead sulfide detector, which together are responsive over the wavelength range of the instrument (Leamer *et al.*, 1978). Percent reflectance was calculated, for each wavelength, by ratioing the amount of energy reflected from the target area to the amount of energy incident on the diffusing plate on top of the spectroradiometer. Percent reflectance was calculated for each waveband by calculating the area under the curve for each, energy reflected from the target and for energy incident on the diffusing plate on top of the spectrometer and ratioing areas as described for wavelengths above.

Measurements for this study were made with 15-degree field-of-view optics looking straight down on the grain sorghum plots from about 1.5-m above ground. All measurements were recorded with an *X-Y* recorder, with the instrument operating at a scanning speed of 30 sec/scan. One incident and one reflected spectra were recorded for all plots with the soil surface (under the plant canopy) in a dry crusted condition. The dry crusted soil surface on plots sown with 50, 100, and 175 kernels was broken up with a pitchfork to give a cultivated appearance. One incident and one reflected spectrum was again recorded. The plots with the broken soil surfaces were flood irrigated and, after all surface water disappeared, one incident and one reflected spectrum was recorded. Plant population was determined by counting all plants in each plot. Biomass/m^2 was determined by harvesting all vegetation material from a 1/4 m^2 area in each plot, drying in an oven at 60°C, weighing, and converting weights to a m^2 basis.

All plots were photographed by exposing 70-mm black-and-white (B&W) film from a vertical distance of 1.5-m above ground level with a Hasselblad 500 EL camera equipped with an 80-mm focal length lens with settings of 1/500 sec at *f*/11. Photographs were taken shortly after making the incident and reflected radiation measurements for each surface condition. The camera was positioned so that the plot area appeared in the centered portion of each photograph.

Percentages of vegetative cover (PVC), shadow (PSH), and sunlit soil (PSS) were determined for each plot by making 9 by 9-inch B&W enlargements (prints) from the 70-mm B&W negatives, overlaying these with a 1 by 1-inch grid and counting the number of points (81) that fell on vegetation, shadow, and sunlit soil, respectively. Ratios were calculated between total points and points for vegetation, shadow, and sunlit soil, respectively. These ratios were then multiplied by 100 to attain percentages for vegetative cover, shadow, and sunlit soil.

Correlation analysis was used to determine the degree of association and the F-ratio was used to judge the statistical significance of all relationships for reflectance with (1) scene components, (2) biomass, and (3) plant population. Analysis of variance was calculated to test for differences among reflec-

Table 1. Linear Correlation Coefficients (CC) for the Relationships of Percent Vegetative Cover (PVC), Shadow (PSH), and Sunlit Soil (PSS) with Percent Reflectance for 1.65 and 2.20 μm Wavelengths and the 1.55 to 1.75 μm and 2.10 to 2.30 μm Wavebands

Linear	1.65 μm	2.20 μm	1.55–1.75 μm	2.10–2.30 μm	Mean	Range
	CC	CC	CC	CC	—	—
PVC	−0.66**	−0.91**	−0.67**	−0.88**	35.67	68.4–6.4
PSH	−0.61*	−0.81**	−0.52*	−0.86**	33.00	50.0–13
PSS	0.66**	0.90**	0.63**	0.91**	31.33	76.6–9.3

* F significantly at $p = 0.05$.
** F significantly at $p = 0.01$.

tance means associated with the condition of the soil surface under the plant canopy. Duncan's multiple range test (DMRT) was used to make all possible mean comparisons (Steel and Torrie, 1960).

Results and Discussion

The linear correlation coefficients (CC) for the relations of percent reflectance for the 1.65 (WL-1) and 2.20 μm (WL-2) wavelengths and the 1.55 to 1.75 μm (WB-1) and 2.10 to 2.30 μm (WB-2) wavebands reflectance for the WL's and WB's tested was significantly negatively correlated with PVC, PSH, and significantly positively correlated with PSS. This agrees with Leamer *et al.* (1978) who found, for the WL's and WB's used in this paper, that bare soil had a higher reflectance than wheat plant canopies and that reflectances for various wheat canopies decreased as the area of exposed bare soil with these canopies decreased due to increases in wheat plant populations.

The CC's were larger for WL-2 and WB-2 than for WL-1 and WB-1. Leamer *et al.* (1978) observed this to be true for wheat plant canopies and stated that there was a higher contrast between bare soil and plant canopy reflectances at 2.20 um than at 1.65 um. From these observations, we think that the larger CC's for WL-2 and WB-2 occurred because of the larger contrast in reflectances between bare soils and plant canopies. Therefore, we agree with Leamer *et al.* (1978) that the best indicator of vegetative density or PVC would be reflectance measurements made at WL-2 or WB-2.

The CC's for the relation of reflectance for WL-1, WL-2, WB-1, and WB-2 with biomass are shown in Table 2. All relationships were significantly negative with the CC's for WL-2 and WB-2 being higher than those for WL-1 and WB-1. Myer *et al.* (1966) found a 2 percent increase in reflectance for WL-2 and WB-2 when the number of leaf layers (a surrogate for biomass (Holbein and Tucker, 1980; Aase, 1978)) placed over the spectrometer's port was increased from one to six which indicated a poor relationship between reflectance and biomass. When the CC for reflectance with biomass (Table 2) was compared with those for reflectance with PVC (Table 1), differences of 0.04 units-r or less existed. The high CC for reflectance with biomass was caused by PVC rather than by biomass, given that the CC for PVC with biomass was 0.85.

The CC's for the relation of reflectance with plant population were higher for WL-1 and WB-1 than for WL-2 and WB-2 (Table 2). Myers *et al.* (1966) found for WL-1 and WB-1 that reflectance was increased nearly 10 percent as the number of leaf layers placed over the spectrometer's port was increased from 1 to 6. Number of leaf layers is also a surrogate for leaf area index (LAI), which is directly related to plant population. We speculated that the relationship of reflectance with LAI explained the strong relationship of reflectance with plant population.

Reflectance means measured at WL-1, WL-2, and within WB-1 and WB-2 for three plant populations where two populations had three and one population had two different soil surface conditions established under each plant-population canopy are shown in Table 3. For WL-1 and WB-1, the canopy for each plant population had a significantly higher reflectance with a dry-crusted (DCR) soil surface than with a dry-broken crusted (DBC) or a wet-

Table 2. Linear Correlation Coefficients (CC) for Relationships of Biomass and Population with Percent Reflectance for the 1.65 and 2.20 μm Wavelengths (WL) and the 1.55 to 1.75 μm and 2.10 to 2.30 μm Wavebands (WB)

Parameter	WL (μm)		WB (μm)		Mean	Range
	1.65	2.20	1.55–1.75	2.10–2.30		
	CC	CC	CC	CC	—	—
Biomass (g/m^2)	−0.70**	−0.87**	−0.70**	−0.89**	71.2	118.0–7.1
Population (plants/m^2)	−0.83**	−0.78**	−0.86**	−0.77**	140.8	342–21

* Significantly at $p = 0.05$.
** Significant at $p = 0.01$.

TABLE 3. PERCENT REFLECTANCES FOR TWO WAVELENGTHS (WL) AND TWO WAVEBANDS (WB) FOR THREE GRAIN SORGHUM PLANT POPULATIONS WITH THREE SOIL SURFACE CONDITIONS (SSC), AVERAGE OF FOUR REPLICATIONS

Treatment		WL (μm) 1.65 %	WL (μm) 2.20 %	WB (μm) 1.55–1.75 %	WB (μm) 2.10–2.30 %
Plants per ha					
370,000	DCR[1]	36.1 a*	41.7 a*	34.5 a*	38.5 a*
370,000	DBC[2]	27.3 bc	29.5 b	27.0 b	29.8 b
670,000	DCR	29.9 b	24.7 c	29.3 b	22.7 c
670,000	DBC	24.3 cd	19.9 de	22.9 c	18.8 cd
670,000	WBC[3]	21.0 d	16.1 e	19.6 c	13.3 ef
1,240,000	DCR	27.6 bc	21.2 cd	27.2 b	19.7 cd
1,240,000	DBC	23.2 d	16.5 de	22.3 c	15.8 de
1,240,000	WBC	21.1 d	15.8 e	20.4 c	11.6 f

* Means followed by a common letter are not significantly different at $p = 0.05$, according to Duncan's multiple range test.

[1] DCR = Dry crusted soil surface (light color).

[2] DBC = Dry broken crusted soil surface (darker color than DCR).

[3] WBC = Broken crusted wet soil surface (dark soil color).

broken-crusted (WBC) soil surface. Reflectances for canopies with either a DBC or a WBC surface were statistically alike.

We attributed the high reflectance for the DCR surface to its light colored and smooth (having few voids) soil, while the lower reflectance for the DBC surface was attributed to its dark colored and rough (having many voids) soil. This agrees with the findings of Bowers and Hanks (1964) and Orlow (1966), who found for WL's between 0.4 to 2.5 um and 0.5 to 0.7 um, respectively, that light colored soils had higher reflectances than dark colored soils, and that smooth soil surfaces had higher reflectances than rough soil surfaces.

For WL-1 and WB-1, DMRT indicated that the average reflectance for a DCR soil surface with 370,000 plants/ha (POP-1) was higher and different from that for a DBC soil surface with 370,000 plants/ha and from that for a DCR soil surface with 670,000 plants/ha (Table 3). This indicated that a significant decrease in average reflectance was effected by either a DBC soil surface or an increase in plant population of at least 1.8 fold. For WL-2 and WB-2, the average reflectance for a DBC soil surface with POP-1 was significantly lower than that for a DCR surface with POP-1, but was significantly higher than that for a DCR surface with POP-2 or POP-3 (Table 3). This indicated that a significant decrease in average reflectance was affected by either a DBC soil surface or by increasing the plant population 1.8 fold, and that the decrease affected by an increase in plant population was significantly greater than that affected by a DBC soil surface.

SUMMARY AND CONCLUSIONS

For WL-1, WL-2, WB-1, and WB-2, linear correlation coefficients for percent reflectance with PVC, PSH, and PSS were significantly negative, negative, and positive, respectively. Linear correlation coefficients for percent reflectance with biomass and with plant population were significantly negative.

For WL-1 and WB-1, plant canopies had a significantly higher reflectance with a DCR surface than with a DBC surface. Wetting a DBC surface did not significantly affect canopy reflectance. This should be valid for all neutral gray toned soils similar to that used in our study.

Decreases in reflectance caused by different soil surface conditions (DCR to DBC) or by increases in plant populations up to 670,000 plants/ha were significantly different for WL-2 and WB-2.

Reflectance measured in these wavelengths and wavebands can be used to determine the quantity of living plant cover on the soil surface at a particular time, and the lightness or darkness of the soil surface under the plant canopy can have a significant effect on plant canopy reflectances, particularly at low plant populations.

These findings should have application in the analysis of data from the next generation satellite, the thematic mapper on Landsat-4, which has spectral bands of 1.55-μm to 1.75-μm and 2.08-μm to 2.35-μm.

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REFERENCES

Aase, J. K., 1978. Relationship between leaf area and dry matter in winter wheat. *Agron. J.* 70:563-565.

Bowers, S. A., and R. J. Hanks, 1964. Reflection of radiant energy from soils. *Soil Sci.* 100:130-138.

Gerbermann, A. H., H. W. Gausman, C. L. Wiegand, 1969. Shadow and other background effects on optical density of film transparencies. *Proc. Workshop on Aerial Color Photog. in the Plant Sci.*, University of Florida, Gainesville, 5-7 March. pp. 127-129.

Holben, B. N., and C. J. Tucker, 1980. Spectral assessment of soybean leaf area and leaf biomass. *Photogrammetric Engineering and Remote Sensing* 46:651-656.

Leamer, R. W., V. I. Myers, and L. F. Silva, 1973. A spectroradiometer for field use. *Rev. Sci. Instrum.* 44:611-614.

Leamer, R. W., J. R. Noriega, and C. L. Wiegand, 1978. Seasonal changes in reflectance of two wheat cultivars. *Agron. J.* 70:113-118.

Myers, V. I., C. L. Wiegand, M. D. Heilman, J. R. Thomas, 1966. Remote sensing in soil and water conservation research. *Proc. of the 4th Symp. on Remote Sens. of Environ.* pp. 801-813.

Orlov, D. S., 1966. Quantitative patterns of light reflection by soils. I. Influence of partial (aggregate) size on reflecting. *Daklody Soil Sci. Supplement Soviet Soil Sci.* 13:1496-1498.

Steel, R. G. D., and J. H. Torrie, 1960. *Principles and procedures of statistics*. McGraw Hill Book Co., New York.

Tucker, C. J., and L. D. Miller. 1974. Extraction of the underlying soil spectra from canopy spectroreflectance measurements of the short grass prairie. *Remote Sensing of Earth Resources*. 3:73-83.

——— 1977. Soil spectra contribution to grass canopy spectral reflectance. *Photogrammetric Engineering and Remote Sensing* 43:721-726.

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