INFLUENCE OF THE VIEWING GEOMETRY ON THE SPECTRAL PROPERTIES (HIGH RESOLUTION VISIBLE AND NIR) of SELECTED SOILS FROM ARIZONA

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ABSTRACT

The influence of view angle on the spectral signature of bare soils was investigated during a field campaign over five sites at the Walnut Gulch Experimental Watershed, in semiarid Arizona. Bidirectional reflectance factors (BRF) in the 400 to 900 nm wavelength range and C.I.E. color coefficients were computed from measurements made along the principal plane of the sun with a portable spectroradiometer. A strong backscatter effect was observed in the anti-solar direction. This non-lambertian behaviour is related to the surface roughness and can be interpreted with existing models. Viewing geometry also influenced the shape of the soil spectral reflectance curves and resulted in an increase in color hue in the antisolar direction and maximum color saturation at nadir. This was attributed to multiple reflections of direct light and diffuse illumination of the shadowed parts of rough surfaces. These viewing effects on soil surface spectral signatures are relatively small when compared to spectral variances normally encountered among soils. This is currently under further investigation.

Keywords: bidirectional reflectance factor, soils, roughness, color, spectroradiometer.

1. INTRODUCTION

Several sensors on different satellites provide multidirectional imagery, such as the coarse resolution AVHRR on-board the NOAA Nimbus, as well as the high resolution HRV on Spot 1 and 2. New pointable remote sensing instruments are also planned to be flown on the polar platforms to be launched at the end of this decade (Ref. 1).

The reflectance properties of the Earth's surface are known to be highly variable with viewing angle. As discussed recently by Jackson et al. (Ref. 2), this variability needs to be assessed for better use of multiple view angle data.

Recent studies have emphasized the importance of soil surface spectral properties in remote sensing of biomass over incomplete canopies using vegetation indices (Ref. 3). Under very dry climates, the assessment of the soil surface itself is a way to indirectly characterize various properties of arid biomes such as infiltrability and potential productivity (Ref. 4).

The objective of the experiment presented here is to investigate the effect of different viewing conditions on arid soil surface spectral signatures.

2. MATERIALS AND METHODS

2.1 Data collection

The study was conducted in the Walnut Gulch Experimental Watershed in southeastern Arizona. Five sites were selected, based on roughness and slope aspect, to represent the various bare soil surface types encountered in this area (Table 1).

Table 1. Characteristics of the soils of the 5 studied sites.

Soil#	U.S. Taxonomy	Munsell color	Surface roughness	Slope Aspect
1	Ustollic Haplargids	5YR 4/4	20% gravel 5% litter	2° slope North facing
2	Ustollic Haplargids	5YR 4/4	25% gravel,20% cobble 10% litter & dry veg.	1° slope North facing
3	Aridic Calciustolls	10 YR 5/2	30% gravel 10% dry veg.	1° slope North facing
4	Aridic Calciustolls	10 YR 5/2	20% gravel,35% cobble 15% dry veg.	11° slope South facing
5	Aridic Calciustolls	10 YR 5/2	50% gravel 10% dry veg.	10° slope North facing

Reflectance spectra were measured with a portable spectroradiometer during the morning hours of June 6 1990, under clear sky conditions. Using the bidirectional reflectance device designed by Jackson et al. (Ref. 2), a typical sequence of measurements included 9 different viewing angles along a plane, 100° azimuth to north (Fig. 1). This corresponded to the scanning and pointing directions of sun-synchronous remote sensing satellites such as Landsat and Spot.

2.2 Data processing

Reflectance factors were computed by ratioing the soil reading by the nadir-view measurement recorded over a calibrated reference panel before and after each target measurement sequence. Bidirectional reflectance factors (BRF) were obtained over 50, 10nm-bands from 400nm to 900 nm, with view angles from -40° (backscatter) to +40° (forwardscatter) in 10° increments.

The collected spectra were resampled to simulate the bandpasses of current remote sensing satellite sensors: Landsat Thematic Mapper (TM), Spot Haute Résolution Visible (HRV) and NOAA Advanced Very High Resolution Radiometer (AVHRR).

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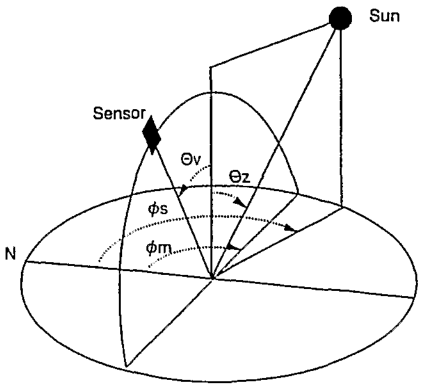

Figure 1. Parameters of the bidirectional reflectance factor (BRF) measurements: φs, solar azimuth, φm, measuring plane azimuth, θz, solar zenith angle, θv, view angle (the arrows show direction of positive angles).

Chromaticity coefficients were also computed from the reflectance curves using the C.I.E. standard method for a C-type illuminant. This computed color gives concise information on the curve shapes in the visible part of the spectrum (Refs. 5, 6).

3. RESULTS AND DISCUSSION

3.1 Shape of the soil spectra

Figure 2 shows the spectral reflectance curves of the 5 sites as measured with nadir viewing. Three main types of curves can be distinguished :
- darker soils with sigmoidal curves (red colored soils 1 and 2)
- light colored soils, with overall higher reflectance values and a less accentuated curve shape (soils 3 and 5)
- soil with rather featureless curve (soil 4).

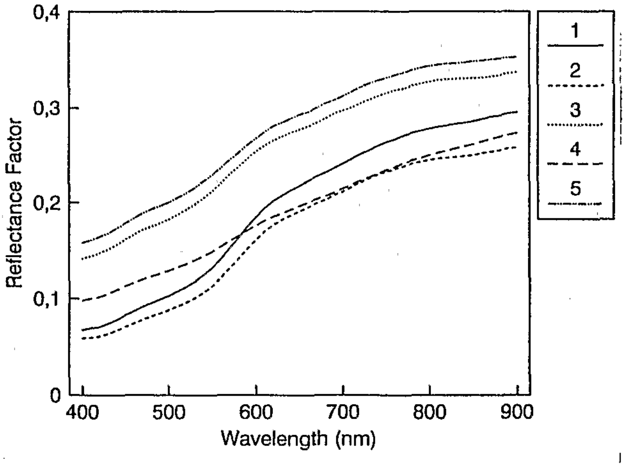

Figure 2. Spectral reflectance curves of the 5 soils described in Tab.1 (measured at nadir).

The spectral curve shape is related to the soil composition as recently discussed by Huete and Escadafal (Ref. 7). Here the spectra of soils 1 and 2 are clearly affected by the presence of iron oxides, while soils 3 and 5 have the same features but only slightly expressed. The flatness of curve 4 can be interpreted as material unaffected by iron oxides, which may have been influenced by the presence of dry vegetation and litter. Further investigation is needed to assess this point.

3.2 Reflectances simulated for different sensors

The computing of the correlation coefficients for the reflectance values resampled for different sensor bands showed an expected redundancy among similar bands. Hence, in the following discussion we will consider the data for the five visible and NIR bands: Landsat TM1, Spot XS1, XS2, XS3 and AVHRR1.

3.3 The influence of solar zenith angle

When comparing the variations of BRF relative to nadir for the five sites, the overall predominant effect is the influence of the sun zenith angle (labeled with triangular markers in Fig. 3). The larger this angle, i.e. the lower the sun elevation, the stronger the relative backscatter (soil 1). On the other hand, at site 5 the sun is closer to nadir and oblique viewing gives lower values in both directions (forward and backward, relative to the sun).

This non-lambertian behaviour is related to the amount of shadow present at the surface, depending on the surface roughness (created by gravels, cobbles, dry plants, litter) and the sun elevation. The maximum reflectance is observed when viewing in the antisolar direction, that is with minimum apparent shadow. Soils 1 and 2 demonstrate that the range of shadow-induced variation is more important at larger solar zenith angles, as expected. At positive view angles (in the forward scatter direction), the decrease in BRF relative to nadir appears more roughness-dependent and relatively less affected by the sun elevation.

This primary effect of viewing aspect is well described by geometric models such as Cierniewski's, which predicts the amount of shadow generated by regularly spaced spheres (Ref. 8).

3.4 Spectral variability of BRF

Here we focus on second order effects appearing in Fig. 3. The relative BRF for different bands is not affected in the same manner by the variations in viewing angle. In the case of soils 1 and 2, the bands of shorter wavelength show higher relative BRF values than the other bands, whereas the opposite trend is observed for soils 4 and 5.

In fact, this apparent contradiction is created by expressing the BRF relative to nadir. Fig. 4a shows the BRF values of soil 1 computed relative to the maximum observed at -40° (i.e., viewing in the sun direction). When deviating from this angle , the BRF is decreasing faster in the bands of shorter wavelength. This same phenomenon is observed for soil 5 in Fig. 3 where maximum of BRF is around nadir. This wavelength dependence of the BRF indicates that the reflectance is not decreasing linearly with increasing shadow amount (in which case all bands would behave similarly).

A comparable effect has already been described by Escadafal (Ref. 4) in an experiment over a rough surface showing that the non linear decrease of nadir reflectance with increasing amount of shadow is due to secondary reflections of the incoming radiation. Here, the studied soils show higher reflectance at longer wavelegths (Fig. 1).

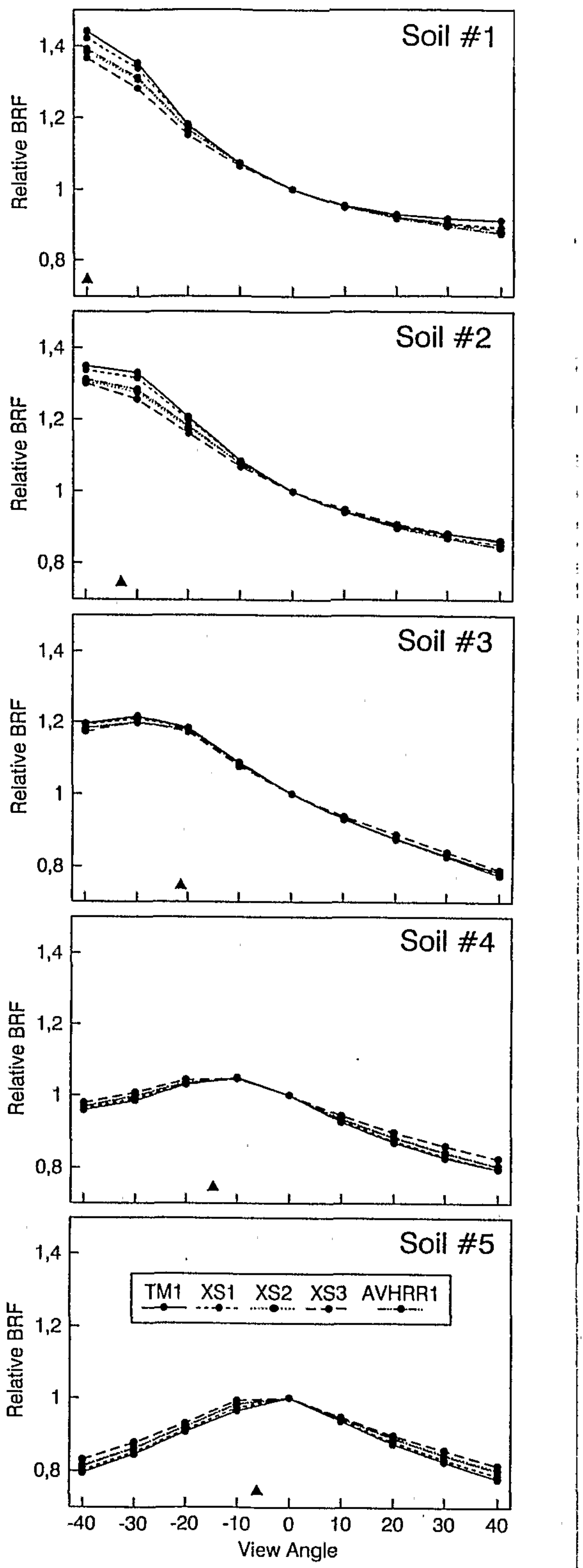

Figure 3. Bidirectional reflectance factors (BRF) relative to nadir, measured over the five studied soils. The marker shows the sun zenith angle at the time of the experiment.

In the corresponding bands, secondary reflections are stronger and conteract more significantly the effect of the shadows then in shorter wavelengths bands. When comparing the BRF in the visible bands (TM1 to TM3) relative to the near-infrared band (TM4), this phenomenon is clearly observed between -40° and nadir viewing (Fig. 4b).

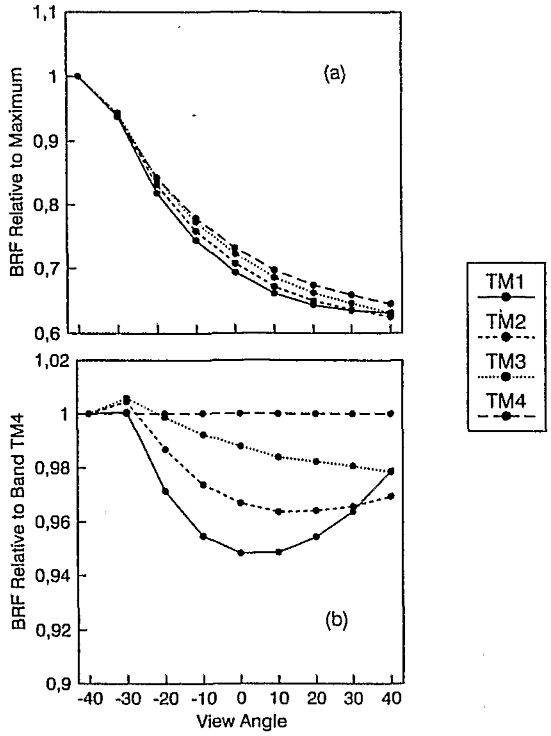

Figure 4. Relative bidirectional reflectance factors (BRF) measured over soil #1 using TM bands; a) relative to the maximum reflectance b) relative to band TM4.

However, in the forward scatter direction (positive view angles) the relative BRF is affected by a reverse trend, although the amount of shadow is still increasing. This is particularly noticeable in the blue band (TM1), suggesting an increased relative contribution of the diffuse solar radiation and a diminishing importance of secondary reflections when viewing the surface elements facets opposing the sun.

3.5 Color and spectral signature alterations

The x,y C.I.E. coefficients (Fig. 5) depict the 'apparent' color computed from the BRF measurements. Hue and saturation are a convenient way to express these coefficients in relation to the curve shape (Ref. 5). The third color component, the brightness Y, is not considered

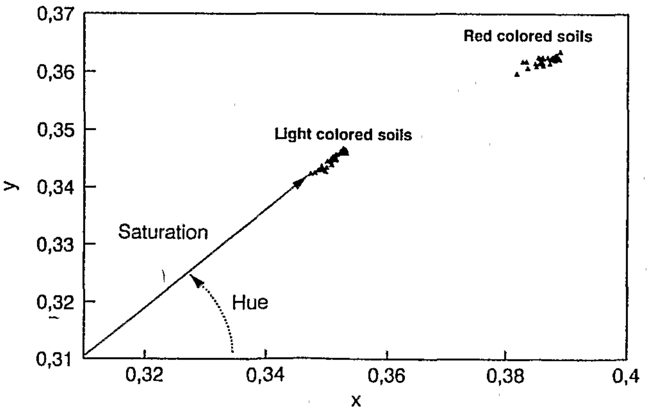

Figure 5. Color coordinates x and y computed from the set of BRF data (C.I.E., Standard illuminant C; the origin corresponds to coordinates of non-colored objects).

here. Two groups of points can be distinguished : one with high hue and low saturation (light colored soils) and the other one with lower hue and higher saturation (reddish soils). Within each group a certain variability can be observed.

More precisely, Fig. 6a shows that the hue is generally higher when a given soil is viewed in the antisolar direction. On the other hand, the color saturation is more pronounced at the nadir viewing angle in the case of reddish soils (1 and 2, Fig. 6b), while not significantly affected in the case of light colored soils (3, 4 and 5, Fig. 6b). This can be related to the slight spectral alteration caused by the non-linear effect of increasing shadow described above.

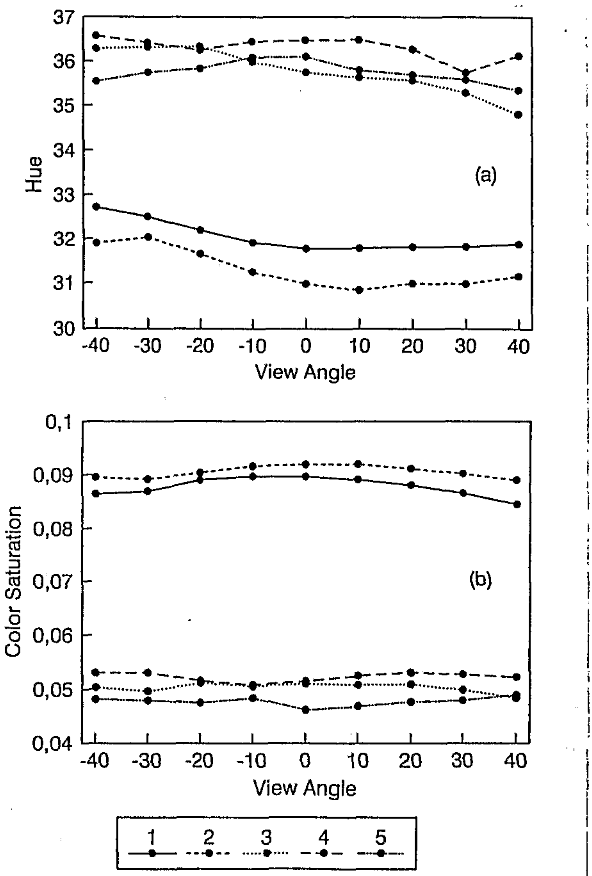

Figure 6. Color computed from spectral reflectance curves measured at different view angles over the 5 studied soils; a) hue b) saturation.

3.6 Effect of viewing geometry on indices

An interesting way to assess the variability of the spectral signature in the Red/Infrared domain is to compute vegetation indices which are combinations of these bands. Fig. 7 shows the variations in NDVI computed with reflectances simulated for TM and AVHRR for two soils (1, reddish and 5, light colored). The overall angular effect is significantly less than the variability due to sensor bandwith. The soil color is also a prominent source of variability as the redder soil results in higher magnitude NDVI values which could be falsely interpreted as a low density vegetation cover.

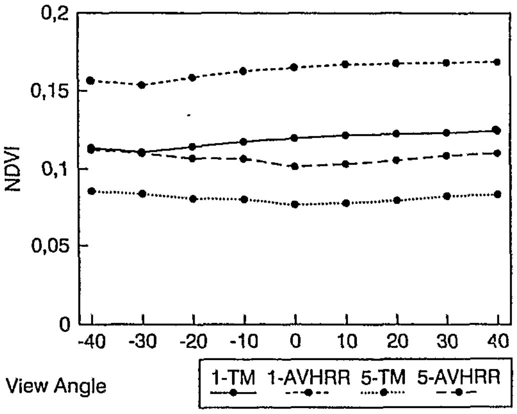

Figure 7. Normalized Difference Vegetation Index (NDVI) computed from BRF measurements over two different soils (#1, reddish and #5, light colored) simulating TM and AVHRR bands.

CONCLUSION

The five studied soils exhibited strongly anisotropic reflectance properties as expected from rough surfaces. When considering the shape of the spectra, a secondary source of variability was encountered. The more colored the soils, the greater was the effect of viewing geometry on the curve shape. This has been related to multiple reflections of radiation by the rough surfaces and higher relative contributions of diffuse light in the shadowed parts of the surface.

This alteration of the spectral signature could limit the use of ratios and indices for processing data involving different viewing geometries. The magnitude of this phenomenon, however, was found to be small in this experiment and may only be significant for very rough surfaces and reddish soils at low solar elevations. The variablity of the indices due to differences among soils and instrument bandwiths also exceed such variations. This last point as well as the influence of the atmosphere will need further study.

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