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REMOTE SENSING OF ARID SOIL SURFACE COLOR WITH LANDSAT THEMATIC MAPPER

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ABSTRACT

Recent laboratory results on the relationships between soil color notation using Munsell charts and soil spectral properties are here applied to Landsat TM data. Soil surface color and composition were described using a multilevel sampling technique for a series of ground test sites in Southern Tunisia. Munsell terrain data were converted into C.I.E. Red, Green and Blue color coordinates. The brightness effect was removed using a ratioing technique. The data of Landsat TM channels 1 to 3 were related with B, G and R, respectively. Soil colors displayed in the R,G,B color space are easily related with remote sensing data. Combined with the soil composition discrimination using the TM7 band, this approach allow the mapping of the soil surface types.

INTRODUCTION

Remote sensing of soil surface condition is an important and promising objective as the soil surface is the unique interface for energy, water and matter flows occuring in arid ecosystems.

In nadir viewing, the most apparent component of the arid landscapes are bare soils and rocks. Thus, the intensity and the spectral composition of the solar radiation reflected towards the sensors of the satellites depend essentially on the soils surface characteristics. As vegetation is generally scarce and non-green its effect is restricted to a decreasing of the signal in all the wavebands /1/. A similar shadowing effect is produced by the irregularities of the soil surface, i.e. the coarse elements or the furrows forming the microrelief. This soil surface roughness is a major variable for the interpretation of Landsat MSS data recorded over bare soil /2/.

Results from a study in Southern Tunisia showed that the soil surface color is another important variable, as its *chroma* is related to the MSS band5/band4 ratio. Both aspects were considered to distinguish several surface conditions on MSS images, according to their roughness and color /3,4/.

The aim of this study was to explore the improvement of the soil surface characterization allowed by the Landsat Thematic Mapper data. As the influence of roughness is purely a geometrical effect, which is rather well understood and modeled /5,6/, our study was focused on the soil spectral properties. Color is an important variable for soil characterization. Landsat Thematic Mapper featuring three visible bands is expected to allow a precise determination of surface color from space.

The Colorimetric Approach

Since the fifties soil color is systematically recorded by earth scientists on the field. This is done by visual comparison with specially designed color charts /7/. They are based on the Munsell system in which a sample color is designed by its *hue, value* and *chroma*.

According to the principles of colorimetry established in 1931 by the Commission Internationale de l'Eclairage, the color aspect of an object under given illumination conditions can be calculated from its visible spectral reflectance curve. In this case color is expressed in C.I.E. x,y,z coordinates /8/. This technique is most used in color industry and its application to soil samples has been recently reviewed by Fernandez and Schulze /9/. Tables published by Wiszecki and Stiles /10/ allow the conversion from this international system to the empirical Munsell notation system.

Generally, the spectral properties of an object cannot be infered from its color aspect. Namely, objects with very different reflectance curves can produce the same color sensation. This property of the human vision is known as *metamerism* and is widely used in color reproduction. But, recent results from Escadafal et al. based on laboratory measurements showed that metamerism is exceptional for soils /11/. This allowed modeling of the relationships between soil color and spectral properties. Moreover, R, G and B coefficients, derived from x,y,z notation using the C.I.E. equations, were found to be related to the reflectance in the corresponding red, green and blue bands.

In this paper this approach is applied to a Landsat TM scene of an arid area of Tunisia.

Location of the study area

The studied area is located in the presaharan part of Tunisia around the small city of Tataouine (35º56′ N, 10º27′ E). The mean annual rainfall is about 120 mm. Soils formed from sedimentary parent materials are composed by calcareous loam, stones and crusts, red quartzic sand and gypsiferous crusts. Landforms are dominated by tabular reliefs and wide plains. Except for the foothills, this area is rather flat. The vegetation is scarce and is mainly used for extensive ranging.

METHODOLOGY

After a reconnaissance of the different soil and surface types, based on photointerpretation and terrain investigations, 85 soil surface sampling sites were selected. Each studied site of about 1 ha was precisely located using triangulation techniques. In each site, the composition, and the Munsell color of the different surface constituents (i.e., bare soil, vegetation patches, sand sheets, gravel deposits,...) were noted on the field using the multilevel sampling technique described by Escadafal /12/.

The Munsell colors of each of the surface constituents were first converted into X, Y, Z, coordinates using the tables published for the C-type daylight illuminant /10/. The C.I.E equations (1) were then inverted to compute the R, G, B values.

$$\begin{aligned} X &= 2.7689\,R + 1.7519\,G + 1.1302\,B \\ Y &= R + 4.5909\,G + 0.0601\,B \\ Z &= 0.0565\,G + 5.5944\,B \end{aligned} \qquad (1)$$

Average data were obtained for each site by weighting the R, G, B values of each constituent by its relative abundance. As colors are represented by vectors in the C.I.E color space this procedure is rigourous. On the contrary, in the Munsell system colors are visually spaced and there addition or weighting have no physical significance.

The Landsat image selected has been acquired during the dry season under favorable atmospheric conditions (5 Aug 1984). Terrain data were collected during the same period. This image was registered to the map of the sampling sites location. For each site, the digit counts values of the band 1 to 3 were extracted and the means, TMi, were computed. In each band the maximum and the minimum digit values observed in the image were assumed to correspond to very bright (white) and very dark (black) targets. They are refered below as TMi_{max} and TMi_{min}, respectively. For each site the "stretched" radiance was then computed following the simple equation (2), where i is the band number:

$$TMis = \frac{TMi_{max} - TMi}{TMi_{max} - TMi_{min}} \qquad (2)$$

RESULTS and DISCUSSION

For this study concerning colors a subset of 10 sites was selected representing the whole range of surface colors observed. Table 1 summarizes the dominant Munsell color, weighted C.I.E color expressed in R,G,B and Thematic mapper stretched radiances (TMis). The surfaces of the studied area have reddish yellow to pinkish white colors. This corresponds to Munsell hues 5 YR and 7.5 YR, with values varying from 6 to 8, and chroma from 2 to 8.

TABLE 1 . Weighted Surface Colors expressed in Red, Green and Blue Coordinates and Landsat Thematic Mapper Stretched Radiances for a Series of Ten Arid Soils Surface Samples.

	surface type	dominant Munsell color	mean C.I.E. color			relative radiances		
			R	G	B	TM1s	TM2s	TM3s
1	s	5 YR 6/8	0.09038	0.04550	0.02031	0.266	0.403	0.500
2	sc	5 YR 6/8	0.08650	0.04633	0.02189	0.372	0.558	0.672
3	cs	7.5 YR 6/6	0.08134	0.04743	0.02401	0.468	0.610	0.703
4	c1	7.5 YR 6/6	0.07746	0.04825	0.02559	0.457	0.558	0.633
5	c2	7.5 YR 7/6	0.09427	0.06147	0.03487	0.490	0.584	0.648
6	c3	7.5 YR 7/4	0.09581	0.07224	0.05219	0.543	0.610	0.656
7	sg	7.5 YR 6/6	0.08339	0.05942	0.04043	0.521	0.610	0.672
9	l	7.5 YR 7/4	0.09339	0.07273	0.05497	0.564	0.623	0.664
9	gs	7.5 YR 8/2	0.09229	0.07617	0.06270	0.745	0.792	0.828
10	gy	7.5 YR 8/2	0.09615	0.08343	0.07235	0.713	0.714	0.727

surface type symbols : s , fine red quartzic sand ; sc, fine sand sheet on calcrete ; cs, calcrete with discontinuous sand sheet ; c1, reddish ancient calcrete ; c2, stony calcrete ; c3, clear calcareous crust ; sg, sand sheet over gypsiferous soil ; l, bare loamy soil ; gs, gypscrete partly covered with sand ; gy, eroded gypsiferous rock.

The brightness of a surface depends on its color value, but also on its roughness. To remove this brightness effect we considered the relative proportion of Red, Green and Blue, expressed by the chromaticity coefficients r,g,b :

$$r = \frac{R}{R + G + B} \quad \text{and similarly for g and b.} \tag{3}$$

As r + g + b = 1, these values are conveniently represented in a triangle (Figure 1). The center of this triangle corresponds to grey colors (equal proportion of r,g,b). From this center towards the edges the colors are more and more saturated along the axis WP. The Munsell chroma is similar to this saturation concept. The hue corresponds to the direction of this axis and is expressed by the angle h. For instance a green color would be displayed on the WG axis. The hue variation of our series is very slight and all the points are roughly on the same line.

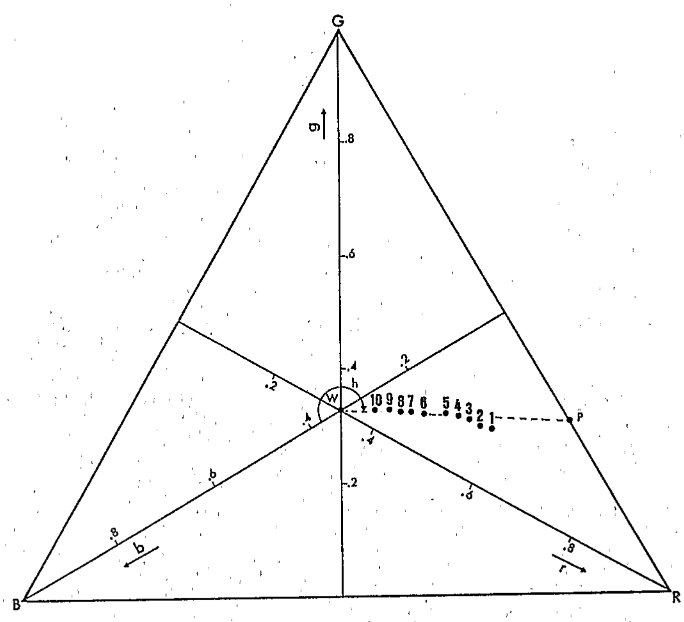

Fig. 1 Chromaticity coefficients r,g,b expressing the relative amount of red, green and blue of color estimated in the field for the studied soil surface samples series (see table 1).

Relative visible radiances measured by TM were expressed in the same way by tmi, where i is channel number 1 to 3 :

$$tmi = \frac{TMis}{TM1s + TM2s + TM3s} \tag{4}$$

The tmi values observed for the 10 surface types are displayed on Figure 2. The diagram obtained is similar to Figure 1, but the tmi gamut is narrower then the r,g,b gamut. This corresponds to a loss of contrast between the ground observations and the measurements from space. This atmospheric attenuation phenomenon is well known /13/. R,G,B values are not very accurate as they are derived from color *visually estimated* in the field. Nevertheless, the soil data and the satellite data are both ranked and oriented in the same manner. At this precision level, the correspondance observed between the two is satisfactory.

This first experiment of remote sensing of soil surface color shows that Munsell color can be related to Landsat TM radiances through the transformation into R,G,B coordinates. The relationships between the two systems are not simple as their geometry is different /10/. Basically, Munsell coordinates are cylindrical, whereas C.I.E are cartesian (Figure 3). In the R,G,B space, the Munsell plate displaying the different chips of a same hue can be represented by the plane OPW. Viewed in the WO direction this plane corresponds to the WP line appearing in Figure 1. In this plane the value is increasing from O to W, whereas the chroma varies as the distance to the achromatic axis OW. The succesive planes of the most frequent soil hues generate a volume, which can be referred as the "soil colors solid" (shaded on Figure 3). Assuming that R,G,B are related to the reflectance values in the red, green and blue bands of the sensors, this schema gives an efficient interpretation key of the relationships between soil color and remote sensing data. For instance, as the projection of this solid covers a larger surface on the R,B plane than on the others, Thematic Mapper band 3 and 1 are expected to be the less correlated visible channel pair. This is what is observed on the studied area /14/.

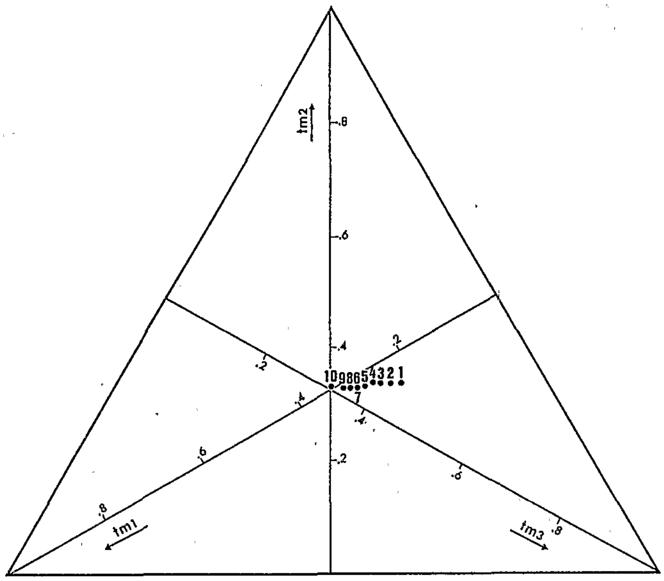

Fig. 2 Relative Thematic Mapper radiances (tmi = bandi / band1 + band2 + band3) for the studied soil surface samples series (see Table 1).

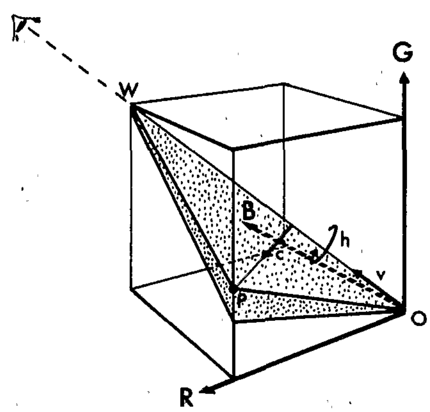

Fig. 3 Scheme of the relation between the Munsell coordinates (h:hue, v:value, c:chroma) and the R,G,B coordinates. The "soil colors solid" is represented by the shadowed volume.

CONCLUSION

Converting the Munsell color into C.I.E. Red, Green and Blue components allows a new approach of the relations between remote sensing data and soil surface color. The hue range of the samples observed here is narrow, but the principles developed are applicable to the whole range of soil colors.

Soil color is an important variable for earth scientists, largely available in soil maps and data banks. Our results allow to use this information to estimate soil spectral properties. These estimates can help to compute better vegetation indices for incomplete canopies, where Huete and Jackson /15/ have stressed an important soil background effect.

Further development towards absolute color determination from space will require exposition and atmospheric corrections and also separate measurement of roughness, with radar data, for instance.

At present, Thematic Mapper data allow arid soil surface types discrimination, based on visible and infrared bands. Maps characterizing this soil-atmosphere interface over large areas can be produced by supervised classification /14/. Their application for hydrological modeling and desertification monitoring is a promising arid land resources management technique.

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