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Spectral signature of selected soils

Assinatura espectral de alguns solos

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***Abstract** - Soils comprise a considerable portion of the land surface. Therefore, measurements of soil reflectance in the visible (VIS), near infrared (NIR), and middle infrared (MIR) regions of the electromagnetic spectrum are important for remote sensing the land surface. Soil reflectance may also play an important role in identification, chemical composition, and mapping of soils. The objective of this study was to quantify the spectral signature of some agricultural soils in dry and wet conditions. Two laboratory experiments were conducted inside a room with walls, floor, and ceiling all painted black at the Center for Advanced Land Management Information Technologies, University of Nebraska – Lincoln, Lincoln, Nebraska, USA. Three different soil types were used in this study: sand used in construction projects, a dark gray soil from a wheat field at Lincoln, Nebraska, USA, and a dark soil from a rural Codington County, South Dakota, USA, agricultural field. The results showed that spectral signatures of soils are unique and can be used to identify soil series. Water decreased the reflectance of soils in all wavelengths.*

***Key words:** soil color, reflectance, remote sensing.*

***Resumo:** Solos compreendem uma considerável parte da superfície terrestre. Por isso, a medida da refletividade na faixa do visível, infra-vermelho próximo e infravermelho médio do espectro electromagnético é importante no sensoriamento remoto da superfície terrestre. A refletividade do solo também é importante na identificação, composição química e mapeamento de solos. O objetivo deste estudo foi quantificar a assinatura espectral de alguns solos agrícolas na condição seca e úmida. Foram conduzidos dois experimentos de laboratório no Center for Advanced Land Management Information Technologies, University of Nebraska – Lincoln, Lincoln, Nebraska, USA. Três diferentes solos foram usados: areia de construção, um solo escuro oriundo de uma lavoura cultivada com trigo em Lincoln, Nebraska, USA e um solo preto oriundo de uma área rural no município de Codington County, South Dakota, USA. Os resultados mostraram que a assinatura espectral é específica para cada tipo de solo e condição de umidade, o que permite a diferenciação de séries de solos com esta técnica. A presença de água nas amostras de solo diminuiu a refletividade em todos os comprimentos de onda do visível ao infravermelho médio.*

***Palavras-chave:** cor de solo, refletividade, sensoriamento remoto.*

Introduction

Soils constitute a major portion of the land surface of the Earth, and consequently, soils influence the reflectance of the composite land surface. Therefore, observations of soil reflectance in the visible (VIS), near infrared (NIR), and middle infrared (MIR) regions of the electromagnetic spectrum are important for remote sensing the land surface.

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Soil reflectance is a function of material properties, such as soil texture (percent of sand, silt, and clay), soil moisture (dry, moist, saturated), organic matter content, iron-oxide content, and surface roughness (JENSEN, 2000). Consequently, soil spectra curves or signatures are unique for each soil and remote sensing can play an important role in identification, chemical composition, and mapping of soils (BAUMGARDNER et al., 1985; IRONS et al., 1989; JENSEN, 2000). The quantification of soil spectra is also important for remote sensing agricultural areas as reflectance from the soil comprises a considerable amount of the signal during the period from sowing to complete canopy closure (JENSEN, 2000).

The objective of this study was to quantify the spectral signature of some agricultural soils in dry and wet conditions.

Material and Methods

The research summarized in this paper is based on two laboratory experiments conducted inside a room with walls, floor, and ceiling all painted black at the Center for Advanced Land Management Information Technologies (CALMIT), University of Nebraska – Lincoln, Lincoln, Nebraska, USA. The lighting was provided by two 650-watt tungsten halogen lamps, one supplying direct and the other diffuse irradiance.

Three different soil types were used in this study (Table 1). The sand was a washed sand that is typically used in construction projects, and came from a sand and gravel pit near Ashland, Nebraska. The pit is located in an area of Sarpy loamy fine sand, frequently flooded (mixed, mesic Typic Udipsamments). The sand was excavated from the subsoil material made up of stratified very dark grayish brown and dark grayish brown fine sand, loamy fine sand and very fine sandy loam. The sand was washed to remove the finer particles. The dark gray soil sample was collected from a wheat field at the Havelock Farm, Department of Agronomy and Horticulture, University of Nebraska-Lincoln, Lincoln, Nebraska, USA, in July 2000 from the upper 10 cm of soil (AP horizon). This soil is a Butler silt loam (fine, montmorillonitic, mesic Abruptic Agriaquoll) with 22% clay, 68% silt, and 10% sand in the AP horizon (NATIONAL SOIL SURVEY CENTER - http://vmhost.cdp.state.ne.us:96/). The darker soil sample was collected from a rural Codington County, South Dakota, USA, agricultural field in the summer of 2000 from the upper 10 cm of soil. This soil is a Vienna silt loam (fine-loamy, superactive, frigid, Calcic Hapludolls) with 26% clay, 57% silt, and 17% sand in the AP horizon (NATIONAL SOIL SURVEY CENTER - http://vmhost.cdp.state.ne.us:96/). Several soil cores were collected in the sampled area, pooled, and air dried.

In the laboratory, soil samples were placed in circular, black containers (44 cm in diameter at the top, 36 cm in diameter at the bottom and 11 cm in height). Each container was half filled with soil. Six backgrounds for data collection were obtained by water spraying the surface of each dry soil sample. Munsell colors of the soil backgrounds are presented in Table 1. An Analytical Spectral Device (ASD), Field Spec FR spectroradiometer (Boulder, CO) was used to measure the reflectance of each soil. The ASD measures the irradiance from 350 nm to 2500 nm with a spectral resolution of 1 nm. The sensor was positioned at nadir, the angle of the optic was 18°, and the distance from the optic to the background was 65 cm, yielding an instantaneous field of view of 21.1 cm (Figure 1). A bright white Spectralon panel was used to measure the downwelling radiation for use in calibrating target scans. Background reflectance of the dry soils was measured using the ASD and scans were taken again on the same background sample after spraying water on the surface that completely moistened the surface without run-off. The experiment was conducted twice, first on 29 September 2000. The soil samples were then air dried again and the experiment was replicated under the same conditions on 19 December 2000.

Results and Discussion

The spectral profiles for the soil backgrounds

Table 1. Munsell colors of the soil used in the study.

Soil	Condition	Identification	Munsell Color
Sand	Dry	Soil A	10YR 6/2
	Wet	Soil B	10YR 3/3
Dark gray	Dry	Soil C	7.5YR 4/1
	Wet	Soil D	10YR 2/2
Dark	Dry	Soil E	10YR 4/1
	Wet	Soil F	10YR 2/1

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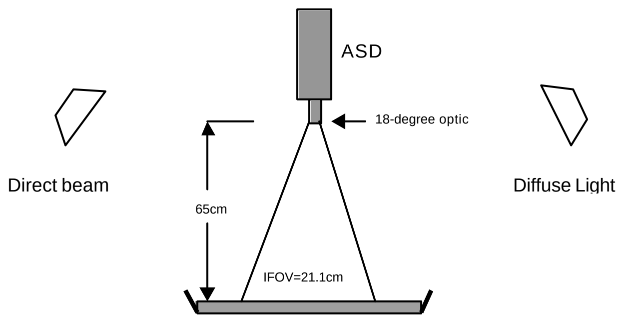

Figure 1. Experimental setup.

(soils A, B, C, D, E, and F) are presented in Figure 2, with each curve being the average of the two replicates. Note that signatures are distinct among soil types and moisture conditions.

The dry soils (soils A, C, and E) show a consistent characteristic signature, i.e., an increasing reflectance with increasing wavelength in the VIS, NIR, and MIR. Three narrow troughs in the MIR centered at about 1400 nm, 1900 nm, and 2200 nm are evident in the dry soil signatures, corresponding to the hidroxyl and clay absorption bands of soils (BAUMGARDNER et al., 1985; JENSEN, 2000). Dry sand (soil A) had the highest reflectance throughout the entire spectrum, with about 20% more reflectance than the other dry soils (soils C and E) . The highest reflectance of the sand is because it is composed by quartz, which has high reflectance in VIS, NIR, and MIR compared to agricultural soils that are composed by other minerals such as feldspats, micas, montmorillon, and kaolinite, minerals that absorb more radiation in this waveband (IRONS et al., 1989). Comparing the two agricultural soils (soils C and E), the reflectance of the Soil C is consistently

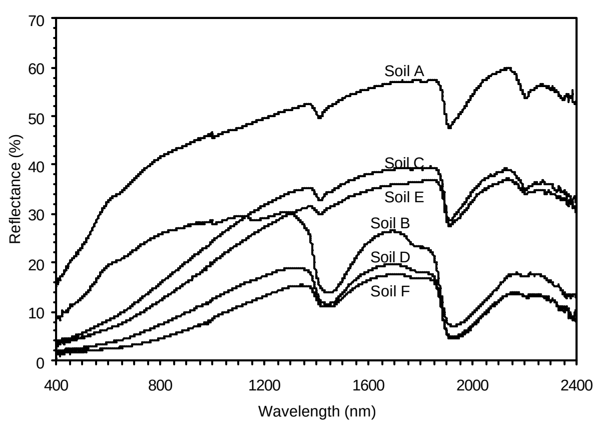

Figure 2. The spectral signature of the soils.

greater than the reflectance of soil E in all wavelengths, indicating that they can be distinguished using remote sensing in a large range of wavelengths.

After watering the surface of the soil samples (soils B, D, and F), water absorbed significant amounts of incident radiation in all wavelengths and especially in the water absorption band in the MIR centered at 1450 nm and 1940 nm (JENSEN, 2000). The result is a dampening of the entire spectral response of the wet soils compared to the dry soils, with two deeper and wider troughs at the water absorption bands. Note that in dry conditions, sand (Soil A) can be easily distinguished from the other two soils (Soils C and E) in all wavelengths. This was not the case when the samples were wet, where the wet sand (soil B) had similar reflectance to the other wet soils (soils D and F) in the MIR as a result of strong water absorption at wavelengths greater than 1300 nm. Comparing the two agricultural soils in wet conditions (Soil D and F) results in Figure 2 show that these soils can still be distinguished as the reflectance of soil D was consistently higher than soil E.

The spectral signature of soils has been measured on a number of studies (e.g. BOWERS & HANKS, 1965; CONDIT, 1970; MATHEWS et al., 1973; STONER et al., 1980). The spectral signature of a soil is a function of several characteristics including soil texture (percent of sand, silt, and clay), soil moisture (dry, moist, saturated), organic matter content, iron-oxide content, and surface roughness (JENSEN, 2000). Iron is one of the most widely spread soil component, and absorption features in spectral signatures of soils are largely caused by either crystal field effects or charge transfers involving some form of iron (BAUMGARDNER et al., 1985). A major effect of iron on soils spectral signature is the steep decrease in reflectance towards the blue and ultraviolet wavelengths (BOWERS & HANKS, 1965), which is evident in our results (Figure 2).

Another important soil component is the organic matter content, which also has a strong influence on soil reflectance. STONER & BAUMGARDNER (1981) measured the spectral signatures of 240 soil series, including samples of tropical soils from Brazil, and proposed that all soils can be resembled in one of five curves. In STONER & BAUMGARDNER (1981) classes, when the organic matter content is greater than 5%, the spectral signature has a concave shape between 500 nm and 1300 nm, compared to the convex shape of spectra of soils with lower organic matter content in this waveband. The dark gray and darker soils used in this study presented a concave shape in this region of the spectra both in dry (soils C and E) and wet (soil D and F) conditions whereas the sand (soil A and D) showed a convex shape (Figure 2). The sand samples had no organic matter, and therefore the convex shape of the spectral signatures of dry (soil A) and wet (soil D) sand agrees with the findings by STONER & BAUMGARDNER (1981). We did not measure organic matter content in the samples used in this study. However, as the dark gray and darker soil samples were sampled from agricultural areas which had lots of plant material covering the soil, we expected these samples would have a high organic matter content, which would then lead to the concave shape of the spectral signatures below 1300 nm.

Conclusion

Spectral signatures of soils are unique and can be used to identify soil series. Water has a profound effect on spectral signature of soils, decreasing the reflectance in all wavelengths of the visible to middle infrared region of the electromagnetic spectrum.

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