Quantitative Mapping of the Soil Rubification Process on Sand Dunes, Using Field and Airborne Sensors

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1.0 INTRODUCTION

Remote sensing of soils plays a major role in both soil survey and soil mapping applications. Traditional methods such as air photos and satellite images suffer from low spectral resolution and, thus, provide only limited spectral information about the targets explored. For soil survey applications, high-resolution imaging spectroscopy may be a key factor in implementing accumulated spectral-soil knowledge. Because the IS technology provides a near-laboratory-quality reflectance and emittance spectrum for each single picture element (pixel), it allows the identification of objects based on the spectral absorption features of the chromophores (Goetz et al. 1985, Clark and Roush 1984). In this regard it can be used to assess mineral changes on the soil surface and to better provide spatial view of pedogentic processes. One of the fundamental pedogenesis processes taking place along the coastline of Israel is the soil rubification of the sand dunes. The soil rubification is defined as a pedogenesis stage in which iron is released from primary minerals to form free iron oxides that coat quartz particles with a thin reddish film (Buol et al., 1973). The Fe in the free iron oxides is active across the VIS-NIR region via the electron transition of (6A1→4T1g between 0.75-0.95μm and 6A1→4T2g between 0.55-0.65μm) and is responsible for the red soil color. We thus applied a careful study to account for the iron oxides content on the sand dune surfaces using spectral information both from laboratory and airborne sensors. This was done in order to demonstrate that rubification processes on costal environment can be done using imaging spectroscopy technology.

2.0 MATERIALS AND METHOD

In October 1999 the CASI 48 channel sensor (covering the VIS-NIR) was mounted onboard an Piper Aztec two-engine aircraft and acquired data from an altitude of 10,000 feet over the area of Ashdod City, Israel. Two flight lines were acquired from south to north, each having a spatial swath of 1.2 km and ground resolution of about 2 meters. During the flight coverage, ground truth data were collected. These data included atmospheric conditions (optical depth, humidity and water vapor content) and soil sample collections for laboratory measurements. The soils were dried and measured for reflectance in the laboratory, using a LICOR spectrometer. For each soil sample, two replications were used for the DCB extraction (Mehra and Jackson 1960). The radiance CASI data were atmospherically rectified into reflectance using the EL calibration method (Roberts et al., 1985), using 5 selected targets. Validation of this correction was performed using samples that were not incorporated in the EL process, and by comparing the similarities between the imaging spectra and the laboratory spectra. Geometrically correction took place using image the image correction technique that extract about 160 GCP from ortho-photo of the area.

3.0 RESULTS AND DISCUSSION

a. General

The sand material is brought to the Israeli coast from the Nile delta by the west-east circle stream along the east bank of the Mediterranean Sea. The study area located near the city of Ashdod, consists of a dune mass of about 350,000 m^3/year as received from the above stream. The resulting dune strip at the selected areas is about 5 km in width. Viewing historical air photos (taken over the past 60 years) shows that a significant diminishing of dune area coverage is occurring. These changes, significantly observed in the north, are due to the massive urbanization activity. Careful measurements of the entire sand dune area show that the sand dunes occupied an area of about 40 km^2 in 1945 and diminished to 25 km^2 in 2001. The sand motion envelope as identified by the 60-year air photo archive showed that the dune masses have tended to significantly diminish over the years, from 2.7 m/year in 1945 to 0.6 m/year in 1997. Based on this finding, we selected soil samples (for spectral and chemical analyses) that were allocated on the cross section that best represents the southwest to northeast dune development. As can be observed from both the satellite image and the ground observations, no significant natural reddish chrome occur at the selected west–east cross sections, except in several discrete pockets (vegetation surrounding area). For the most part, the absence of a reddish color on the rest of the dune area is based on the fact that the dune stabilization process is rather young (about 50 years) and the climate conditions (500 mm of annual precipitation) do not effectively permit a massive extraction of free iron oxides in those areas during this time period. The free iron oxide content (DCB-Fe) that was chemically measured in the laboratory, showed relatively low iron oxides amount (0-0.03 %) that agrees with the previous observation that showed no red color sequence in the study area. The first step toward adopting the spectral information to account for the DCB-Fe content was to examine the laboratory spectral information and then to apply it on the image data.

b. Laboratory (Field) Dune Spectra

In this stage, the original laboratory spectra was resampled into the CASI spectral configuration (consisting of 48 bands) and then used to extract the iron absorption parameters after applying the continuum removal (CR) algorithm. As can be seen in Figure 1a,b, a spectral sequence exists between the selected samples (for both laboratory (a) and air (b) domains), which calls for the extraction of the quantitative relationship between the entire DCB-Fe sand sample, using spectral parameters. The two selected spectral parameters were 1) the slope between 590 and 511 nm (termed as [SLOP] and 2) and the absorption peak at 499 nm after applying the CR treatment (termed as ABS). The above-mentioned spectral parameters provided correlation values (r) of 0.79 for the SLOP 0.88 for the ABS parameters. Examining the slope and aspect effects showed that significant variation occur within close areas as a result of the micro-topography variation. Also, non-lambertian effects, especially in the low incidence angle, were found to be significant. Correction for those effects (using DEM and Minnaret correcting factor respectively) still provided errors in the spatial domain, suggesting that BRDF effects may be introduced within the data. To remove these effects, a second polynomial curve fit, between the spectral differences of the laboratory and the image reflectance data, for each ground point, across the entire spectra region, was employed. As the ground sampling were taken across track the flight lines, the correction for the BRDF effects was found to provide a sufficient solution for the entire sensor's FOV. Validation data confirmed the previous corrections, allowing us to move forward to the next quantitative stage.

c. Quantitative Mapping of the Rubification Process using the Image Spectra

Assuming that each spectral parameter describes a different mechanism, and that all of the external effects were removed, we prepared a multiple correlation using both SLOP and ABS parameters to extract the following equation:

$$Fe = 0.80929 + 0.00975(SLOP) - 0.86681\,(ABS) \qquad r2=0.88 \tag{1}$$

Applying this equation on a pixel-by-pixel basis produces a gray scale image, in which the intensity level of each pixel refers to the iron concentration. Figure 2 shows the two georectified flight lines after applying the above equation and after the gray scale image was encoded with a color table that represents the iron oxide occurrences in a natural view, i.e., reddish pixels represent high, and white pixels represent low DCB-Fe content. In contrast to the manipulated DCB-Fe image, areas in the gray scale image that are not characterized as dune or soil were not encoded with the selected color table, because their calculated values lie outside the DCB-Fe calibration scale. From the DCB-Fe images, it can be seen that the reddish chroma increase while going from the coastline (west) toward the inner land (east), whereas the greatest amount of reddish chroma occurred at the southeastern boarder of the sand dune area. Because the direction of the wind regime in the study area is WSW to ENE, and there is a decreasing wind gradient toward the east, sand particle movement decreases while going east, resulting of sand stabilization processes. At the reddish locations, the sand particles are more stable and are exposed more to soil-forming factors than at the light locations, forming the free iron oxides that coat the quartz particles. It is interesting to note that the reddish spots observed previously (exposed paleosol and vegetation pockets) were also encoded a strong red in the processed DCB-Fe image.

4. SUMMARY AND CONCLUSIONS

Reflectance spectroscopy offers new insight into the pedogenesis process, long before it is visible to the naked eye. The imaging spectroscopy technique, which provides near-laboratory-quality reflectance information, also has the capability to observe nonvisible information and thus to produce a special view of the pedogenesis processes in large areas. Caution must be paid however to micro topographic and non-lambertian effects as well as to BRDF effects in spectral imaging sand dunes ecosystem. We can conclude that spectral information from field or air domains can provide valuable information regarding the premature stages of the rubification process. This information can also shed light on sand dune stabilization as well as on possible obstacles that might control dune development.

5. REFERENCES

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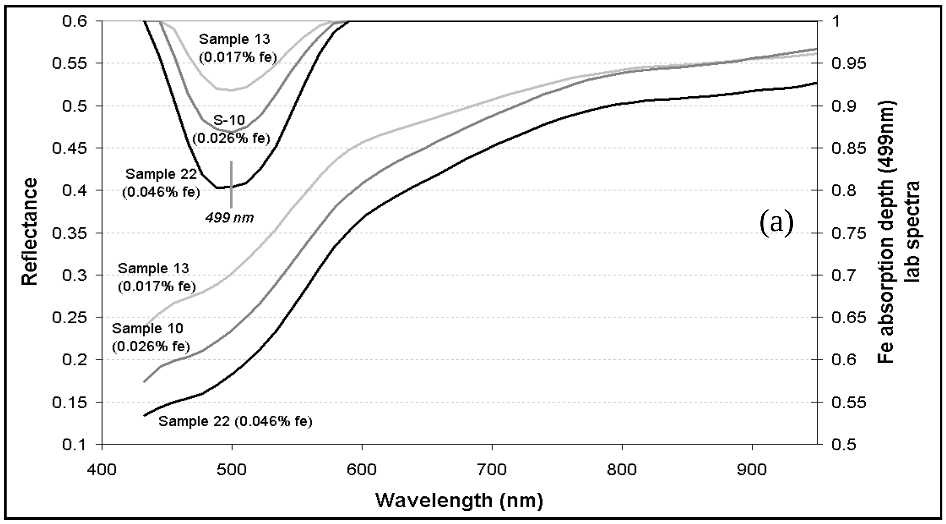

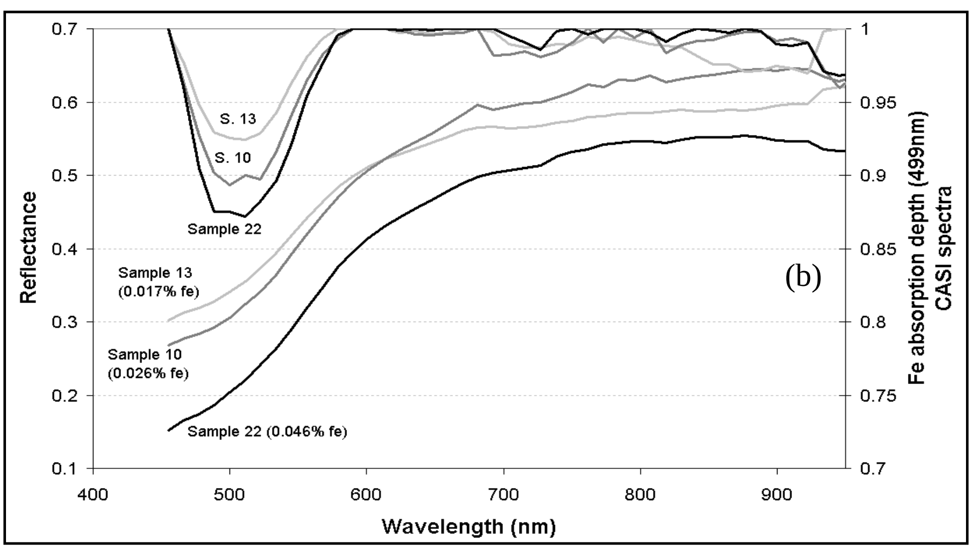

Figure 1: The reflectance spectra of three selected sand samples, with relative high, moderate and low DCB-Fe content before and after applying the continuum removal algorithm. Both the field (a) and airborne (b) measurements are provided.

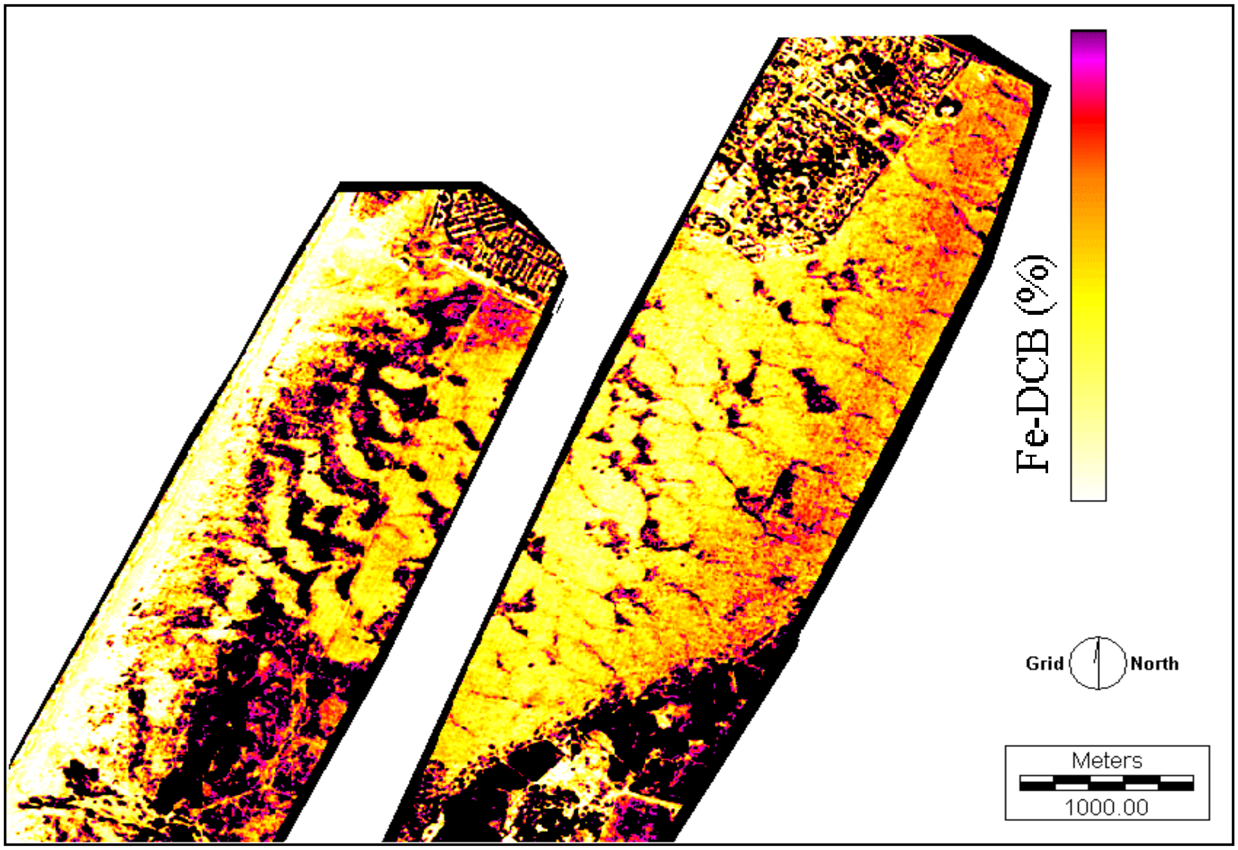

Figure 2: The DCB-Fe image as obtained after applied equation 1 on a pixel-by-pixel basis on the CASI 48 atmospherically rectified image