SPECTRAL DETECTION OF INORGANIC CARBON CONTENT ALONG A SEMI-ARID TO HYPER-ARID CLIMATIC GRADIENT IN THE JUDEAN DESERT (ISRAEL)

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ABSTRACT

Along a hypsometric rainfall gradient from Jerusalem covering the semi-arid and arid climate and extending to the east to the hyper-arid area at the Dead Sea rift soil samples have been collected and analysed for different chemical parameters. In addition to soil chemical laboratory analysis the spectral reflectance of the soil samples has been measured in the range of 0.35 and 2.5 µm. These reflectance measurements have been normalised to derive individual absorption features employing a convex-hull function, and the spectra were used to calculate colour parameters according to the Commission Internationale de l´Eclairage (CIE) colour scheme. The depth and area of the convex-hull normalised carbonate absorption band in the near infrared around 2.35 µm and the CIE-chromaticity coordinates were tested for their significance to predict the inorganic carbon content. In this way, a method for spectral detection of inorganic carbon content was generated based on statistical analysis.

1   INTRODUCTION

Soil loss resulting from a combination of physiographic and human factors is a sign of degradation. The inorganic carbon content in soils on carbonatic bedrock in semi-arid and arid environments is one major indicator of soil development. High inorganic carbon contents point to an almost undeveloped soil or to a degraded soil. Since the spatial detection of inorganic carbon has a great importance in the context of monitoring land degradation and sub-recent morphodynamics with remote sensing, it is necessary to develop an approach for spectral determination of inorganic carbon content.

The spectral reflectance of soils is affected by the inherent spectral characteristics of varying combinations of mineral components, organic matter and the soil moisture (Baumgardner et al. 1985). The relations of spectral reflectance and soil properties, like grain size distribution, soil moisture, iron oxides, carbonate content or organic matter, have been outlined in many studies. Relationships between soil reflectance and carbonate content have been established using statistical methods such as multiple regression analysis (Ben-Dor & Banin 1990, 1994).

In this study an analysis of the relationship between spectral measurements and inorganic carbon content is accomplished based on characteristic absorption features of carbonate. Based on statistical analysis, a method for spectral detection of inorganic carbon content is generated.

2 STUDY AREA

Research was conducted along a transect following a hypsometric rainfall gradient from east of Jerusalem covering the semi-arid and arid climate zone and extending to the east towards the hyper-arid area at the lower part of the Dead Sea rift. The transect shows a strong decrease in elevation, ranging from 650 m in the Judea-Samaria mountains to 60 m below sea level in the Judean Desert. Mean annual rainfall decreases on a distance of only 25 km from 500 mm in the west to about 120 mm at the Kalia cliff (Lavée et al. 1998).

All test sites are located on limestone bedrock and according to the amount of rainfall the soils vary from brown and pale renzinas in the semi-arid and arid areas to desert lithosols and bare rocks at the eastern edge of the transect.
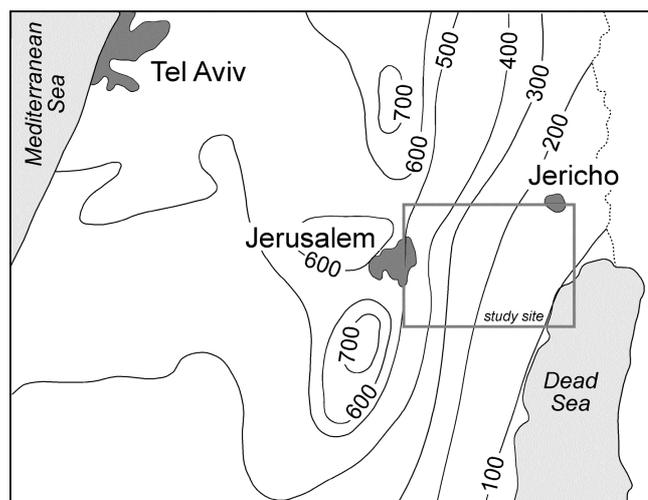
Figure 1: Location of the study site and mean annual rainfall in Israel (modified after Atlas of Israel 1985)

3 MATERIAL AND METHODS

Sampling of the surface soil material (upper 2 cm) was conducted along slope transects located on limestone bedrock covering north- and south- facing slopes and valley bottoms. In total 45 samples were collected along the transect.

The soil samples were air-dried and gently crushed in order to pass a 2mm-sieve. Subsamples were carefully homogenised for an enhancement of spectral features and to allow better reaction with the chemical reagents. Organic and inorganic carbon content for all samples was analysed by an infrared cell in a high-frequency induction oven (LECO). The content of inorganic carbon varies between 1.57 and 9.24 percentage (see table 1). Carbonate content was determined for a subset of the soil samples using a volumetric calcimeter. For a second set of samples only inorganic carbon measurements have been

Table 1: Descriptive statistics of the laboratory analysis of the soil samples

	n	minimum [%]	maximum [%]	mean [%]	std.-dev. [%]
C_{inorg}	45	1.569	9.239	5.545	2.004
C_{org}	45	0.687	2.787	1.525	0.536
Carbonate	8	27.79	72.74	43.249	15.447

available. However, since a high correlation between inorganic carbon and carbonate content for this subset of the investigated soils was found ($r^2 > 0.95$; n = 8), further analysis was conducted based on the inorganic carbon laboratory results only.

Spectral reflectance measurements of homogenized soil samples were acquired in the laboratory with an ASD FieldSpec II spectroradiometer in 1 nm steps between 350 and 2500 nm using a reflectance standard of known reflectivity. The optical head of the spectroradiometer was mounted on a tripod in nadir position with a distance of 10 cm to the sample. A 1000 W quartz-halogen lamp set in a distance of approx. 30 cm and an illumination angle of 30 degrees was used to illuminate samples and reference panel.

Individual absorption features like maximum absorption depth at typical wavelengths and area integrals for specific wavelength intervals were calculated using a convex-hull function.

For the calculation of colour parameters, the reflectance measurements were converted into trichromatic specifications, and then expressed in terms of the „Commission Internationale de ´Eclairage [C.I.E.]" colour notation (Y, x, y) from 1931. In this colour system the colour intensity is characterised by the luminance "Y", which represents the brightness of colour while "x" and "y" are the chromaticity coordinates (Wyzecki & Stiles 1982). The C.I.E. colour coordinates were already found to contain substantial information for spectroradiometric detection of soil properties (Jarmer & Schütt 1998, 1999).

4   RESULTS

Carbonates show strong diagnostic absorption bands in the Near Infrared at 2.30 - 2.35 µm (figure 3 & figure 4) and at 2.50 - 2.55 µm. Three weaker bands occur at 1.85 - 1.87 µm, 2.12 - 2.16 µm and at 1.97 - 2.00 µm. The band positions vary with the composition of different carbonates in the soils (Hunt & Salisbury 1971; Gaffey 1986). With increasing content of Mg-carbonate the wavelength position of maximum absorption is shifted to the shorter wavelength (Van der Meer 1996; Clark 1997). A comprehensive collection of spectral measurements of different carbonates can be found in Hunt & Salisbury (1971).
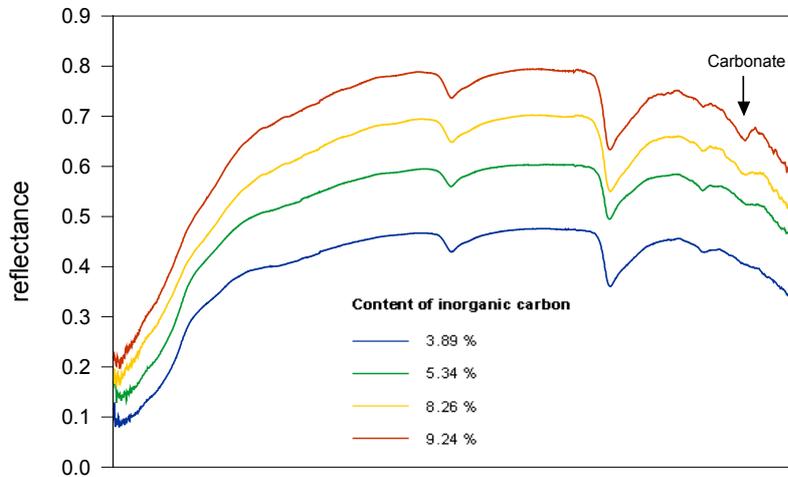
Figure 3: Reflectance spectra of soil samples with different content of inorganic carbon
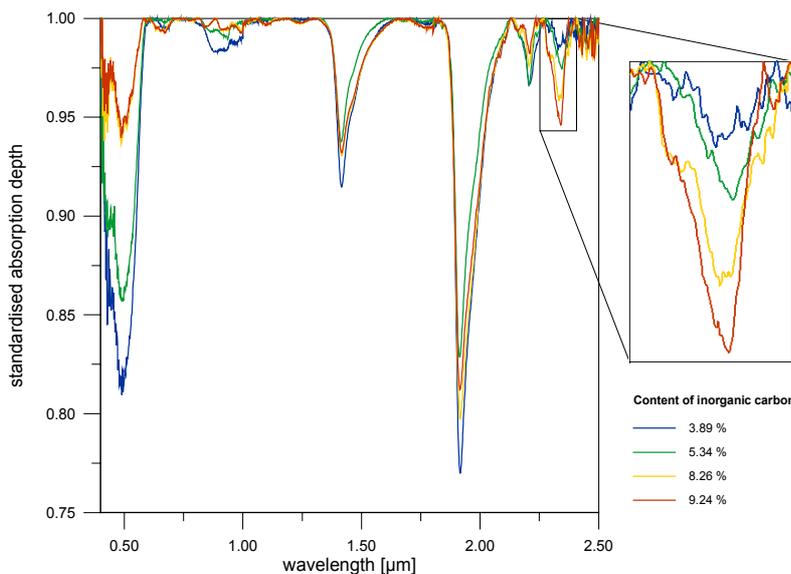
Figure 4: Convex-hull standardised reflectance spectra of soil samples with different inorganic carbon content

Thus, based on the convex-hull standardised reflectance spectra the maximum absorption depth and the area integral in the wavelength interval in the spectral range 2.33-2.37 µm was employed in this study. This range was discovered to show highest correlation with the inorganic carbon content. In a first approach the inorganic carbon content was modelled based on linear regression with the "maximum absorption depth$_{[2.33-2.37]}$" and "area$_{[2.33-2.37]}$". The best result with these variables was obtained in the case of using the "maximum absorption depth$_{[2.33-2.37]}$" (ad. r² = 0.719).

Since the relative amount of carbonate in soils influences soil brightness substantially (Ben-Dor & Banin 1994; Udelhoven et al. 2000) it was decided to integrate C.I.E. colour values in model finding. It was expected that the integration of the luminance "Y" representing the soil brightness would improve the modelling result substantially.
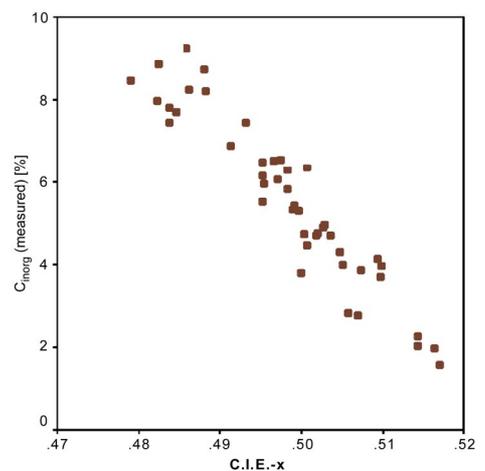
Figure 5: Relation between C.I.E. chromaticity value "x" and the content of inorganic carbon

However, it was found that the integration of "Y" did not have a positive effect on the modelling results while a regression based on the C.I.E. chromaticity value "x" yielded a significantly higher fit (ad. r² = 0.894) (see also figure 5).

Further, multiple regression was calculated based on the derived absorption features "maximum absorption depth$_{[2.33-2.37]}$", "area$_{[2.33-2.37]}$" and die C.I.E. colour values "x", "y" and "Y". The best model to determine the inorganic carbon content was defined by an integration of the variables "area$_{[2.33-2.37]}$" and chromaticity value "x". This model results in an ad. r² of 0.9538 for the cross validation (figure 6).

$n = 45$; $r = 0.977$; ad. $r^2 = 0.9538$

$C_{inorg} = f \{x; area_{[2,33;2,37]}\}$

Figure 6: Scatterplot for cross validation of the generated model for predicting the inorganic carbon content

5   CONCLUSIONS

The spectral detection of inorganic carbon led to satisfying results. While the use of derived absorption features of the characteristic carbonate absorption band around 2.35 μm was not convincing, the integration of C.I.E. chromaticity values leads to a distinct improvement of the results.

Based on these promising results the developed model will be transferred to hyperspectral data. Beside this, a modification of the approach for operational satellite systems is intended and the approach has to be validated and adapted for other geographic regions under similar climatic conditions.

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