



Short communication: Laboratory imaging spectroscopy of soil profiles

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An imaging spectrometer in a laboratory rack was used to examine soil profiles. Images in the 400–1000 nm range with 4 nm spectral resolution and less than 0.1 mm spatial resolution of the top 30 cm of the soil were acquired. These images can be used to analyse the spatial distribution of chemical and physical soil characteristics and for discrimination and classification of horizons and inclusions. Three-dimensional characterisations of soil properties are possible by recording images of series of parallel slices.

Keywords: hyperspectral imaging, proximal sensing

Introduction

In remote sensing, imaging spectroscopy, also known as hyperspectral imaging, is usually performed using air- or spaceborne sensors.^{1,2} Laboratory and field spectroscopy on the other hand is usually applied at few points only, but without acquiring images. In this study we combine both techniques by using an imaging spectrometer in the laboratory.

Imaging spectroscopy is a well-established technique for studying the properties of soils.³ Soils are usually imaged from above, showing only the soil surface, or homogenised samples from different horizons are taken and spectrally measured using a field or laboratory spectrometer. The vertical heterogeneity of soil profiles is usually not taken into account when remote sensing techniques are used, except for photographs of soil profiles. Many soil horizons are obviously heterogeneous and show clear patterns with widely varying physical and chemical properties on small spatial scales, e.g. oxidised and reduced areas in temporarily water-logged stagnic horizons. With an image of the soil profile the area size of different domains can be assessed. Ben-Dor *et al.*⁴ introduce a method for taking several spectral measurements of the soil profile in

different depths of drilling holes in the field using a spectrometer, but it does not produce images of the profile. Viscarra Rossel *et al.*⁵ also show spectral point measurements at different profile depths. In geology, laboratory or field imaging spectroscopy of vertical profiles has been used for the identification and mapping of minerals (Kruse),⁶ for the detection of sulfide (Bolin and Moon)⁷ and for the ore identification in the field (McHugh *et al.*).⁸

Spectroscopy has been successfully applied in soil remote sensing for a long time. For example, Stoner and Baumgardner⁹ studied the characteristic variations in soil reflectance, showing the influence of organic matter, iron content and texture, among others. Udelhoven *et al.*¹⁰ obtained reliable estimations of Ca, Mg, Fe, Mn and K. Kemper and Sommer¹¹ used multiple linear regression and artificial neural networks to predict the concentration of six heavy metals after a mining accident using reflective spectroscopy. Vohland *et al.*¹² were able to assess trace heavy metal contents using soil spectroscopy although they have no absorption bands in the wavelengths considered.

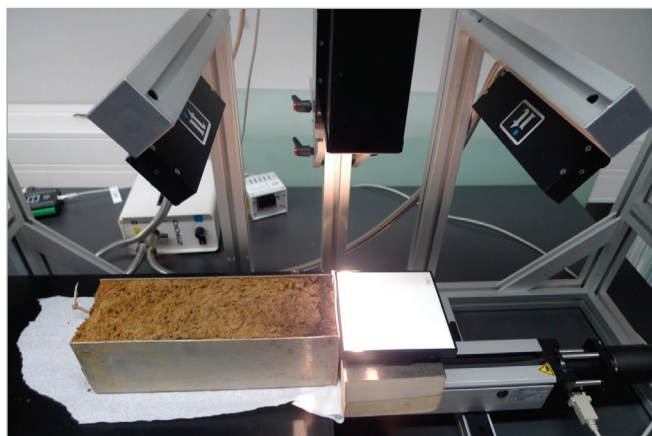


Figure 1. Laboratory imaging setup. The sample is illuminated by two diagonal light sources, the camera can be seen in between. The soil block in its metal case and the white reference panel are moved to the right by the translation stage.

In this study, we tested the potential of a laboratory hyperspectral scanner to assess soil properties of a complete soil profile with a spatial resolution on the aggregate scale.

Material and methods

Study site and soil sampling

The sampling site was situated near Freising (South-East Germany), approximately 35 km north-east of Munich. The soil was classified as a stagnic Luvisol, siltic¹³ derived from quaternary aeolian sediments (Loess) overlying tertiary clayic sediments under a Norway spruce (*Picea abies*) monoculture. The climate was classified as a moist continental climate (Cfb) with mean annual temperature of 7.3°C and a mean annual precipitation of 814 mm.

The soil profile was sampled with a custom-made stainless steel box (100 × 100 × 300 mm; Figure 1). The steel box was gently hammered vertically into the soil from the surface after the litter was removed. The soil core was dried in the stainless steel box at 30°C for 24 h.

Imaging setup

Hyperspectral images of the soil core were taken at the Remote Sensing Department at the University of Trier. After one image was taken, a layer of approximately 15 mm was removed, the new surface carefully smoothed, the camera

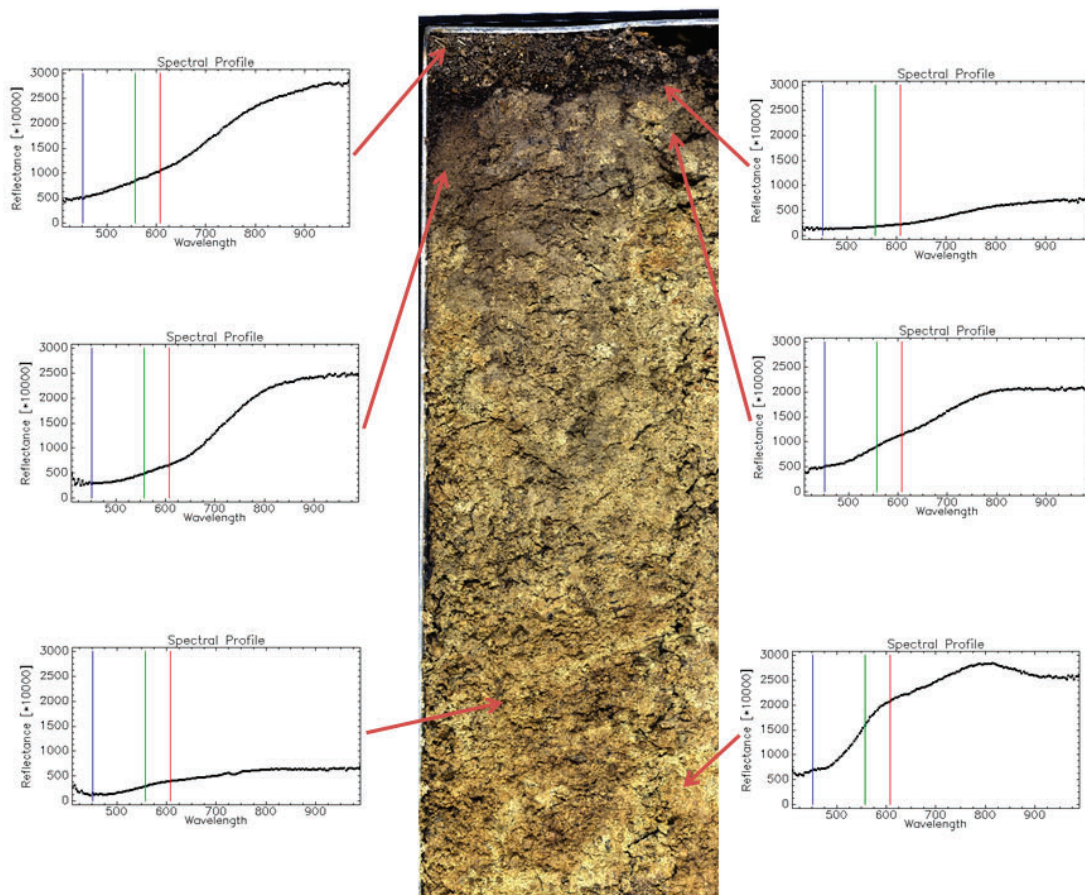


Figure 2. A natural colour depiction of the soil profile with six pixel spectra. The displayed wavelengths are marked with red, green, and blue lines in the spectra.

height was adjusted to its focal plane and the next image was taken. The dry soil had a non-sticky, silty texture that could easily be worked with using a long knife. In total seven images of the soil profile were acquired, so that a three-dimensional characterisation of the soil was possible.

The images were recorded using a HySpex VNIR-1600 hyperspectral camera (Norsk Elektro Optikk, Norway), a push-broom sensor covering the visible and near infrared spectral regions. The camera was equipped with a 30 cm focal lens for laboratory use and set up in a frame with two tungsten halogen light sources illuminating the sample from about 45° in front of and behind the camera. The light sources were mounted about 35 cm from the sample, casting light on a narrow strip on the sample under the camera aperture. The reflected light passes through a

transmission grating that separates the different wavelengths. The camera uses a two-dimensional CCD sensor array of 1600 × 1200 silicon detectors. One dimension is used for spectral separation and the second dimension is used for imaging in one spatial direction. The second spatial dimension is covered by movement of either the sensor or the sample. In our case, the sample was placed on a translation stage (Figure 1) moving the sample under the camera. The camera records 1600 pixels across track with a total field of view of 17°. The pixel instantaneous field of view is 0.18 mrad across track and 0.36 mrad along track. The speed was adapted so that an image with square pixels is formed out of the single lines the camera recorded. The area recorded from the 30 cm distance was 10 cm wide, so that a single pixel is about 62.5 μm wide. A soil profile of 30 cm length

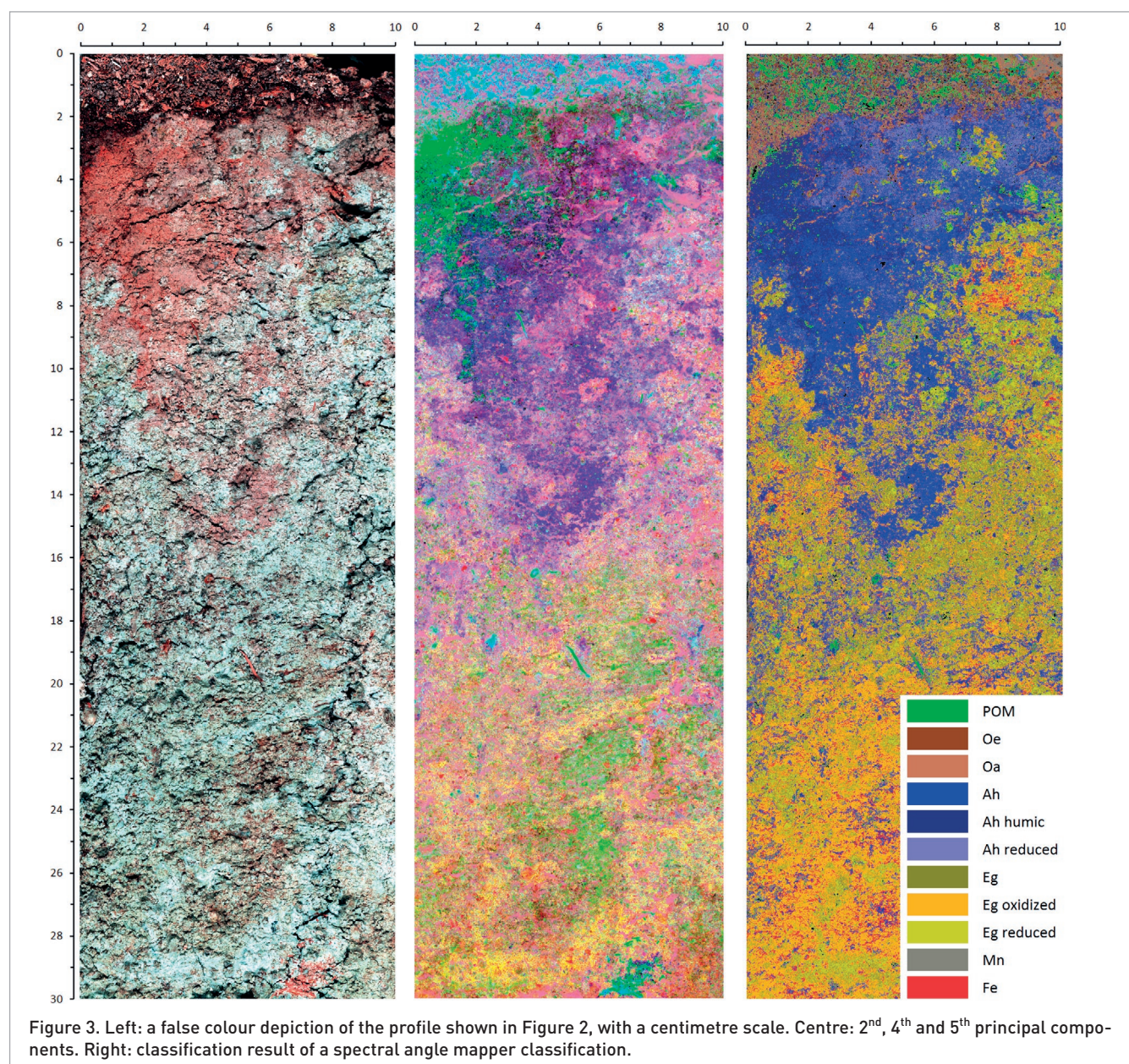


Figure 3. Left: a false colour depiction of the profile shown in Figure 2, with a centimetre scale. Centre: 2nd, 4th and 5th principal components. Right: classification result of a spectral angle mapper classification.

consists of 4800 image lines. By binning of the 1200 sensor pixels in the spectral direction, 160 spectral bands were recorded in the spectral range of 410–990 nm with a spectral sampling distance of 3.7 nm. Data was recorded in 12 bit radiometric resolution.¹⁴

Comparable hyperspectral laboratory imaging systems have also been used to show bruised skin¹⁵ and to examine fish fillet quality.¹⁶

Image processing

Because the hyperspectral camera was used in the laboratory, radiometric processing is fairly easy. A SpectralonTM certified reflectance standard white reference panel of known reflectivity was recorded with each image. Because the illumination was not perfectly uniform, the object reflectance ρ_{obj} was calculated for each image line (along track) separately following Equation (1):

$$\rho_{\text{obj}} = \frac{L_{\text{obj}}}{L_{\text{ref}}} \times \rho_{\text{ref}} \quad (1)$$

where L_{obj} is the measured radiance from the object in camera units, L_{ref} is the measured radiance from the white reference and ρ_{ref} is the reflectance of the white reference panel.¹⁷ No geometric correction was applied to the images.

Results

Using the setup described we were able to obtain high-quality hyperspectral images of soil profiles. Remaining surface roughness after smoothing was negligible (<3 mm) so that all resulting images were acceptably sharp. Figure 2 shows the first image of the stagnic luvisol profile in a real-colour composite (RGB: 608, 557 and 451 nm). Six spectra of typical regions in the image are shown next to the image. The soil horizons, Oe at the top, Ah below and Eg in the lower parts, can be well recognised. In the top and left regions of the image parts of the metal frame are visible. No distinct absorption bands are present in the soil at the considered wavelengths except for iron oxide features in the blue and green region of the spectrum around 500 nm.

A supervised spectral angle mapper¹⁸ classification based on visually selected training areas was conducted on the images. We selected training areas representative of the classes we wanted to detect and some background areas on the Spectralon and the metal frame. The spectral angle mapper is insensitive to shadow in the image and was thus deemed an adequate simple classification algorithm. Figure 3 shows a false-colour composite (RGB: 819, 608 and 557 nm), a composite of principal components (PC) (RGB: 2nd, 4th and 5th PC, chosen for best visual impression), and the classification result with centimetre scales. The different horizons, particularly organic matter (POM), iron and manganese inclusions and oxidised and reduced areas could be well discriminated. A detailed accuracy assessment was not conducted, but the results coincide well with the visual impression of the spatial

class distribution. All seven layers were classified using the same training areas, with comparable results.

Discussion

The proposed method of laboratory imaging spectroscopy of soil profiles is a novel approach of mapping the heterogeneity of soils. Instead of imaging the soil surface or of taking only a limited number of samples from different depths, complete profiles are imaged hyperspectrally. By removing thin layers of the soil body, three-dimensional information can be collected. The hyperspectral images of the profile can be used for various characterisations of the soil like horizon classification, mapping the chemical composition or analysing the small-scale heterogeneity.

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