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Spectral pedology: A new perspective on evaluation of soils along pedogenetic alterations

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ABSTRACT

There is still a lack between pedology and the knowledge of what is the perspective of spectroscopy in this science. Thus, it is important to describe how soil sensing can assist these pedologists on their studies. This work aims to show the perspective of proximal and remote sensing (VisNIR) on the evaluation of pedogenetic processes and parent material alterations along a toposequence and to estimate their mineralogical content. Eight soil classes from different taxonomic units were studied. Soil samples were submitted to physicochemical, mineralogical, and reflectance spectroscopy analyses. Reflectance data were acquired in laboratory conditions using a spectroradiometer (400–2500 nm). Hierarchical clustering analysis was applied to discriminate soil classes and their properties were assessed by multiple linear regression. Variations in spectral behavior in depth (absorption features and reflectance intensity) enabled the characterization of the soil classes. Reflectance data associated with clustering analysis allowed distinguishing the soils according to their weathering levels and parent materials. The clay mineral contents were estimated with a reasonable accuracy level. Soils along a toposequence can be detected by reflectance spectroscopy through variations in reflectance intensity and absorption features mainly in terms of the texture and mineralogical composition, respectively. Different weathering levels and, consequently, soil formation processes alter the soils along the toposequence which reflect on their spectral behavior, thus leading to a new site for soil visualization: the spectral pedology.

1. Introduction

Soils have been largely studied for their fundamental pedogenetic information. From time to time, technologies have been incorporated by pedologists to improve the comprehension of soil distribution in landscapes. As an example of these technologies we have remote sensing by aerial photographs that started to be applied in the 1960s (Buring, 1960). Remote sensing showed its importance as it displays the landscape relief directly to the user, which is a soil formation factor (Jenny, 1994). This technology allows visualizing land surface by stereoscopy (third dimension) in an aerial photograph. This has been very useful for pedologists as an important tool for soil survey and mapping. Its importance has rendered the term "photopedology", which has been largely used by soil researchers (Demattê et al., 2012).

Another type of useful technology for soil science concerns reflectance spectroscopy where soil information is extracted by its reflected electromagnetic energy with no contact. This information started to be used in the 1960s and 1970s by Bowers and Hanks (1965) and Hunt and Salisbury (1970) at the laboratory level. At that time, descriptive analyses of the spectral behavior of a soil sample could indicate the existence of significant variation by their intrinsic properties. In the mid 1980s, studies began to seek additional information beyond qualitative variations and started to observe the importance of spectral data in the quantitative analyses (Stoner and Baumgardner, 1981). As sensors improved their signal-to-noise ratio, and spectral and spatial resolutions, onboard aerial and orbital platforms could be applied outside the laboratory environment, being called imaging spectroscopy. Thus, soil monitoring could be performed by spectral remote sensing at a large scale (Ben-Dor et al., 2008b; Ben-Dor et al., 2009). Thereafter, researchers started using appropriate statistical and mathematical methods, such as multiple correlation and regression analyses, to treat and process spectral data to extract more accurately quantitative information of soils (Coleman et al., 1991; Cozzolino and Morón, 2003; Nanni and Demattê, 2006).

Currently, soil spectral sensing has been gradually absorbed by the scientific community due to its benefits regarding efficiency in attribute quantification (Viscarra Rossel et al., 2006a); in designing surveys and mapping, and classifying soils (Ben-Dor et al., 2008a; Demattê et al. 2004), as well as in management practices (Morris et al., 2008). However, even after several papers have produced vast scientific background, the intimate interaction between soil properties and reflected energy are restricted to research, and records of these practical activities conducted at a large scale have not been found. A possible explanation

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can be the necessity of more pedologists to understand how to use this technology and to interpret its data, requiring more research with clear methodologies.

Variations of soil survey and mapping can be evaluated from three perspectives: spatial/multiple directions, longitudinal/one direction (toposequence) and punctual. Spatial variation uses remote sensing by aerial photos and imaging spectroscopy and has great importance given that these technologies brought information about landscape relief and soil properties from surface layers of bared areas, respectively. Differently, reflectance spectroscopy can be very useful in the assessment of punctual soil variations—in depth (from different layers and/or horizons) due to the interaction of light with soil properties reflecting intrinsic data related with them. Spectral punctual information started to be evaluated in the laboratory (Bowers and Hanks, 1965), and some field studies using reflectance spectroscopy have already been observed (Ben-Dor et al., 2008a).

The basic and traditional method for soil survey and mapping involves several important steps to determine information related to soil classification, and to represent the spatial variation of each soil class. The most important is to detect the soil class limits in the landscape. This is based on the recognition of soil changes along a toposequence, in other words, longitudinal visualization of its variations. This leads to several field observations to determine soil property changes (soil texture and mineralogy, for example) indicating it in the map. Alterations on soils are mostly related with the pedogenetic processes. This raises the question of whether a spectral sensor would be able to determine the weathering indexes or soil properties that differentiates them along a toposequence. Could the soil spectral behavior assist pedologists on the recognition of soil information related to their pedogenetic information? Many papers have indicated the advantages of spectral sensing compared to conventional methods to study soil properties, such as optimization of soil analyses by reducing time and costs of analyzing samples. Besides, spectral sensing does not need reagents or produce waste. However, there is a lack of knowledge about how to directly apply spectral sensing to soil survey and mapping and how this spectral data can be used. Therefore, combining spectral information to detect soil spatial extent (soil limits) to map an area requires special strategies of interpretation and use of different information sources. Despite the importance of spectral sensing for soil application, the knowledge of its features is far away from the background of pedogenic basis. This technology will only advance with further research and clearer methodologies for its application.

Thus, this study aimed to evaluate the potential of the VisNIR (400–2500 nm) spectral sensing to detect soil differences along a toposequence, as a basic methodology for application by pedologists. For that purpose, we considered that soils developed on a toposequence show changes in their intrinsic properties (physicochemical and mineralogical) due to pedogenetic processes reflecting on the weathering level. We also expected that spectral information allows the detection of these variations in order to identify different soil classes and specifically to assist in the identification and estimation of clay minerals.

2. Material and methods

2.1. Characterization of the study area

The area is located in the municipality of Piracicaba, São Paulo State, Brazil, with its center at coordinates 22°42′S (latitude) and 40°37′W (longitude) (Fig. 1). The climate of the region is Cwa (Koppen) with dry winters and rainy summers, annual average temperature of 21.6 °C and average annual rainfall of 1415 mm.

Geologically, the area is situated at the top of an interfluve formed by the Piracicaba River on predominantly sandy deposits correlated with the Rio Claro Formation that top the material of the Irati (the Piracicaba River course) and Estrada Nova Formations. The local stratigraphy is disrupted by intrusions of basic rocks (diabase) related to the Serra Geral Formation (Cooper and Vidal-Torrado, 2000). The relief on the highest part of the site is gently undulated to flat sloping as it approaches the hillside areas, with predominantly diabase rocks. From there, there is the formation of two terrains, one of flatter topography with a slight slope and another with the presence of other parent materials of the Irati and Estrada Nova Formation ending at the river channel (Fig. 2).

According to Cooper and Vidal-Torrado (2000), the position of the studied soil classes in the landscape (toposequence) shows the occurrence of soils derived from diabase rocks such as Hapludox (Latossolo Vermelho-Amarelo), in the highest positions and over smooth to gently undulated relief, and Kandiudox (Nitossolo Vermelho) nearby the shoulder of the first hillside with a slope around 12% (Fig. 2). In the second part of first hillside, with steeper topography (from 25 to 30% of slope), the previous soil class changes into the class of shallow soils, such as Eutrustept (Cambissolo Háplico) of common occurrence in this area. At the foothill, there is the Argiudoll (Chernossolo Argilúvico), derived from diabase associated with shales, which becomes Hapluderts

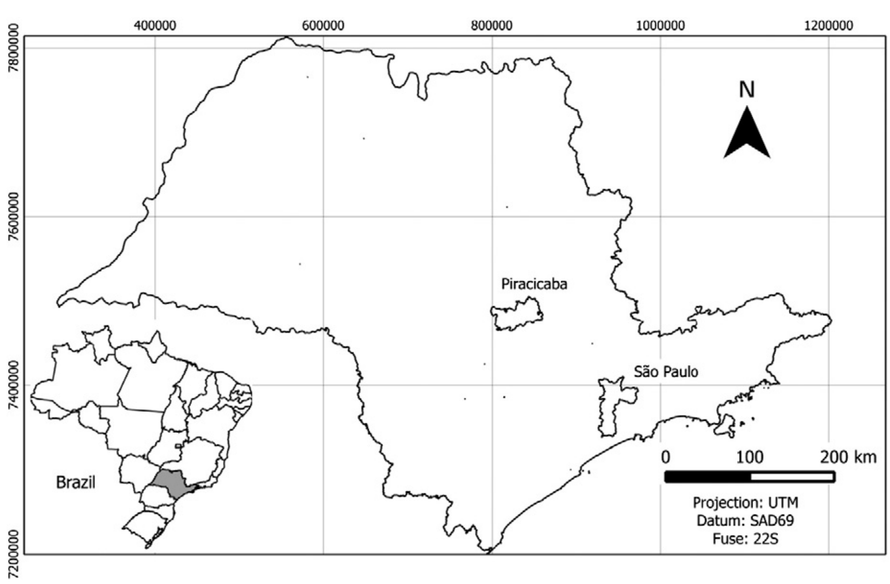

Fig. 1. Location of the study area.