



## Prediction of soil properties using imaging spectroscopy: Considering fractional vegetation cover to improve accuracy



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### ABSTRACT

Spectroscopic techniques have become attractive to assess soil properties because they are fast, require little labor and may reduce the amount of laboratory waste produced when compared to conventional methods. Imaging spectroscopy (IS) can have further advantages compared to laboratory or field proximal spectroscopic approaches such as providing spatially continuous information with a high density. However, the accuracy of IS derived predictions decreases when the spectral mixture of soil with other targets occurs. This paper evaluates the use of spectral data obtained by an airborne hyperspectral sensor (ProSpecTIR-VS – Aisa dual sensor) for prediction of physical and chemical properties of Brazilian highly weathered soils (i.e., Oxisols). A methodology to assess the soil spectral mixture is adapted and a progressive spectral dataset selection procedure, based on bare soil fractional cover, is proposed and tested. Satisfactory performances are obtained specially for the quantification of clay, sand and CEC using airborne sensor data ( $R^2$  of 0.77, 0.79 and 0.54; RPD of 2.14, 2.22 and 1.50, respectively), after spectral data selection is performed; although results obtained for laboratory data are more accurate ( $R^2$  of 0.92, 0.85 and 0.75; RPD of 3.52, 2.62 and 2.04, for clay, sand and CEC, respectively). Most importantly, predictions based on airborne-derived spectra for which the bare soil fractional cover is not taken into account show considerable lower accuracy, for example for clay, sand and CEC (RPD of 1.52, 1.64 and 1.16, respectively). Therefore, hyperspectral remotely sensed data can be used to predict topsoil properties of highly weathered soils, although spectral mixture of bare soil with vegetation must be considered in order to achieve an improved prediction accuracy.

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### Introduction

Vis–NIR–SWIR reflectance spectroscopy has been proposed as a valuable technique to describe soil properties variability, assisting methods conventionally used for this purpose (i.e., soil sampling and wet-chemistry analysis), with potential reductions in costs, amount of labor needed, time demanded and environmental impacts of these conventional methods (Ben-Dor, 2011; Gomez et al., 2008b).

Research has highlighted Vis–NIR–SWIR spectral data as a rich source of information about soil organic and mineral components, as well as on its physical properties (Demattê and Garcia, 1999;

Demattê and da Silva Terra, 2014; Mulder et al., 2011; Stenberg et al., 2010). Although reflectance spectroscopy using prepared soil samples (i.e., which are dry and sieved) and laboratory-derived spectral data is becoming a well-established technique, soil spectra obtained using airborne and space borne imaging spectroscopy (IS) has not yet been completely integrated in the assessment of soil properties (Ben-Dor et al., 2009, 2008; Gomez et al., 2012).

While in proximal soil sensing, performed in laboratory or field, spectral measurements correspond to point based data, IS can be used to perform spatially continuous mapping with high spatial-resolution providing information in a great density, reducing errors caused by data interpolation and making it easier to describe soil spatial patterns (Gomez et al., 2012; Hively et al., 2011; Lagacherie et al., 2013; Mulder et al., 2011).

However, there are some drawbacks concerning IS approaches that can affect accuracy of soil properties predictions, such as

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atmospheric effects, variation in soil roughness and humidity, low signal-to-noise ratio of sensors, and spectral mixture of bare soil with other materials such as photosynthetic and non-photosynthetic vegetation (Hbirkou et al., 2012; Lagacherie et al., 2008). In the literature, variable mixing of photosynthetic and non-photosynthetic active vegetation with bare soil, from high (such as 40%) to considerable small values (as 5%), are indicated as hampering accurate prediction of soil properties using IS (Bartholomeus et al., 2011, 2007; Chabrilat et al., 2002; Hbirkou et al., 2012).

Considering the small number of studies on the use of hyperspectral remote sensors to predict soil attributes (Gomez et al., 2012), especially concerning the spectral mixture of soil with other targets, there is clearly a need for research to evaluate the potential use of data from these sensors under different environments and for multiple purposes.

In this context, this study evaluates the prediction accuracy of airborne-derived hyperspectral data in order to quantify properties of highly weathered soils (i.e., Oxisols) in Brazil. Special attention is given to the assessment of bare soil fraction, in contrast to photosynthetic and non-photosynthetic active vegetation fractions. An approach to select optimal spectral datasets for estimation of soil properties is implemented and evaluated, considering increasing thresholds from the maximum bare soil value for each sampling point in a moving window-wise methodology. This method aims to find an optimal trade-off between bare soil fraction maximization and mitigation of other factors affecting prediction accuracy, such as geo-referencing errors, noise in the spectral data and inaccuracies of the unmixing approach itself (Bartholomeus et al., 2011; Casa et al., 2013). Comparison of prediction performance with the conventional IS approach (without spectral data selection, i.e., considering only co-geolocated pixels with soil sampling sites) allowed to assess if the proposed method provides real accuracy improvement.

## Material and methods

### Description of the study area

The study area is located between the cities of Paulínia and Campinas, São Paulo state, Brazil (22°48'13"S and 47°06'44"W, Datum WGS84), and is composed by land forms that vary from predominantly plain to smoothly sloping (up to 8% declivity) and with soils classified as Rhodic Hapludox (Oliveira et al., 1977; Soil Survey Staff, 2010). This soil class is generally characterized by intense weathering and mineralogical composition of iron and aluminum oxides, hydroxides and oxi-hydroxydes (hematite, goethite and gibbsite), as well as kaolinite as the main 1:1 phyllosilicate (Fontes and Weed, 1991). The climate is defined as humid subtropical, without dry season, with hot summer (Cfa), according to the Köppen classification (Alvares et al., 2013).

### Airborne spectral data acquisition and processing

Two aerial hyperspectral images are obtained on June 2010 using the ProSpecTIR V-S sensor (SpecTIR LLC), which consists of two imaging sensors (AISA Eagle-Hawk; Specim), one taking measurements from visible to near-infrared wavelengths (Vis-NIR, from 400 to 970 nm) and another capturing shortwave-infrared wavelengths (SWIR, from 970 to 2500 nm). The spectral data are obtained with a spatial resolution of 1 m and a spectral resolution of 4.6 nm in Vis-NIR and 5.3 nm in SWIR, resulting in 357 spectral bands per image.

Raw data are converted into radiance using the calibration files generated during the radiometric and wavelength calibration, created before and after sensor mobilization. The data are further

transformed into surface reflectance values, using the radiative transfer model MODTRAN4 incorporated into the ATCOR-4 computer program (Berk et al., 1999; Richter and Schläpfer, 2012).

Spectral bands influenced by the absorption of electromagnetic energy by water vapor in the atmosphere (from 1300 to 1500 nm and from 1800 to 1950 nm) are removed from the dataset yielding a new dataset with 282 spectral bands. A mosaic of the two scenes, covering approximately 100 ha, is made to the study area.

### Soil sampling and analysis

Soil cores are sampled from 6 agricultural fields without crops, distributed over the study area and covering together approximately 2 ha. A total of 89 samples are collected from the surface layer (0–20 cm depth) and at variable distances between sampling points (ranging from 5 to 30 m, considering samples within the same field) in order to adequately represent variability of soil fertility over the bare areas. The sampling sites are georeferenced using a GPS Trimble PRO-XRS receiver, with a post-processing accuracy of approximately 1 m. Fig. 1 shows the location of sampling points in fields with exposed soil.

The soil samples are dried at 45 °C for 24 h, grinded, sieved (<2-mm), and analyzed for soil particle size distribution and chemical properties. Soil sub-samples are chemically dispersed to assess their granulometric distribution using a solution (250 mL) with sodium hydroxide (4 g L<sup>-1</sup>) and sodium hexametaphosphate (10 g L<sup>-1</sup>). This mixture is shaken mechanically for 16 h at 120 rpm (in 500 mL vessel). The sand content is determined by sieving (0.053 mm mesh) and drying (105 °C for 24 h) the retained material. The remaining material in suspension is collected in a 1 L measuring cylinder and filled to 1 L with distilled water. The solution is then homogenized for 30 s, allowed to stand for 24 h and the clay fraction was estimated using a hydrometer, as described in Bouyoucos (1962). Finally, the silt fraction is assessed by subtracting the clay and sand content from the total sample weight.

The soil chemical properties are determined using the methods described by Raji et al. (2001) and EMBRAPA (1997) including: pH in water; phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg) contents, which are extracted using an ion-exchange resin; exchangeable aluminum (Al) extracted using a potassium chloride solution (1 mol L<sup>-1</sup>); potential acidity (H + Al) extracted using a calcium acetate solution (1 mol L<sup>-1</sup>) at pH 7; and organic matter (OM) content estimated indirectly by oxidation using potassium dichromate (0.1667 mol L<sup>-1</sup>). From these results, the sum of bases (SB), cation-exchange capacity (CEC), CEC saturation by bases (V%) and aluminum (m%) are calculated according to Raji et al. (2001).

### Laboratory spectral data

Laboratory reflectance measurements of dried and sieved soil samples are acquired using a FieldSpec Pro (Analytical Spectral Devices, Boulder, Colorado, USA) spectroradiometer. This instrument performs measurements from 350 to 2500 nm and yields spectral data with a 1 nm interval. The soil samples are placed in 9 cm diameter and 1.5 cm height Petri dishes, and had their surface leveled in order to standardize the measurement conditions. The fiber optic is positioned at 8 cm distance from the sample. Two 50-W external halogen lamps are used as light sources, placed at a 35 cm distance from the sample support platform at a 30° zenith angle. For spectral calibration a white Spectralon® panel is used. Three spectra are acquired for each sample, rotating the Petri dish about 120° before each measurement. The average spectra are used for further analysis.

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