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Soil texture and organic carbon mapping using surface temperature and reflectance spectra in Southeast Brazil

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A B S T R A C T

The generation of soil attributes maps is crucial for proper field management, especially in tropical countries where agriculture plays a major role in economy, such as Brazil. The Land Surface Temperature (LST) derived from thermal infrared wavelength can be related with soil properties, particularly texture. The availability of LST data on a regular basis, with good spatial resolution to cover extensive agricultural regions and also integrated with reflectance data enhances its use in soil attributes mapping. The objectives of this research were to verify the relationships between soil attributes texture and organic carbon (OC) with the remote sensing (RS) products LST and surface reflectance and perform maps of classes of such attributes based on these variables. The study area (473 ha) is located near the municipality of Barra Bonita, southeast of São Paulo State, Brazil. A regular sampling grid with 100 × 100 m^2 and with sampling density of one sample per hectare was established on the study site, from where surface samples (0–0.2 m) were collected via auger and had their contents determined by wet chemistry analysis. Images from Landsat 5 were obtained for extraction of LST and reflectance. The algorithm Spectral Angle Mapper (SAM) was applied for soil attributes mapping using 55 toposequences samples and considering (a) three LST images; (b) only reflectance from one Landsat scene and (c) reflectance + LST from the same scene as in (b). Besides this, maps were performed using only one LST image with a histogram-based classification. The weighted kappa (k_w) was calculated with validation samples and indicated the classification accuracy. Mapping of texture and OC through SAM algorithm produced better results than the classification of LST, regardless of the variables being considered. For both attributes, the best map was produced using reflectance + LST, with substantial agreement for texture and moderate for OC. The use of LST for mapping soil attributes concomitantly with reflectance spectra improved the mapping accuracy.

1. Introduction

The generation of soil attributes maps is crucial for proper field management, especially in tropical countries where agriculture plays a major role in economy. Besides that, soil quality must be endured, and knowing the soil conditions and characteristics is an important step in land use planning and natural resources conservation. The use of remote sensing (RS) information from Visible (Vis), Near Infrared (NIR) and Shortwave Infrared (SWIR) wavelengths, allied with the development of new technologies helps in providing up-to-date and reliable soil information, and its availability to the community in a timely manner is one of the goals of digital soil mapping (DSM).

Unlike RS-Vis, RS-NIR and RS-SWIR, the use of thermal infrared (TIR) RS for soil attributes mapping has received little attention in literature. All ground targets with temperature above absolute zero emit electromagnetic radiation (Sabins 1997) mainly in the wavelength around 10 μm, located in the TIR domain. Sensors operating in this region capture this energy emittance, from which it is possible to derive the product Land Surface Temperature (LST), representing target's radiometric temperature (Kuenzer and Dech 2013). There are many algorithms developed for the derivation of LST, which produce accurate results that usually differ around 1–2 °C from the in-situ measured ground surface temperature (Li et al. 2013).

Differences in LST patterns are expected to occur following variations in soil constituents, which present distinct thermal properties such as thermal conductivity and thermal inertia. The water content of soil can also expressively influence on its thermal properties (Bonn and O'Neill 1993). Special attention has been given to the prediction of soil texture (Sayão et al. 2018; Müller et al. 2016; Wang et al. 2015a; Wang et al. 2012; Chang et al. 2003; Chang and Islam 2000) and organic carbon (OC) content (Sayão et al. 2018; Zhao et al. 2014) through LST, and only the work of Sayão et al. (2018) was developed in a tropical region (southeast of Brazil), where the availability of soil information is crucial considering the agribusiness magnitude. In fact, soil attributes maps are essential for proper field management in a timely manner, which is being promoted by precision agriculture (PA).

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Given this context, the objectives of this research were to verify the relationship between soil attributes texture and OC with RS products LST and surface reflectance, and perform maps of classes of such attributes based on these variables. The idea is to compare the mapping accuracy of different variables, first considering only LST (a single image and multitemporal images) and only Vis-NIR-SWIR reflectance, and then these variables together. We expect that LST can be used in the mapping of soil attributes in the same way as surface reflectance.

2. Materials and methods

2.1. Study area

The study area (Fig. 1a) is located near the municipality of Barra Bonita, southeast of São Paulo State, Brazil; it is delimited by the coordinates 22°26′2.37″–22°23′16.53″ south and 48°31′24.22″–48°27′51.77″ west. It has approximately 473 ha, with subtropical mesotermic climate according to Köppen classification, and was previously studied by Fiorio et al. (2003). The land use has been sugar cane cultivation for the last 30 years. The area is dominated by sandstone parent material (Itaqueri formation) intercalated with intrusive basalts (Serra Geral formation). Altitude was obtained from the digital elevation model (DEM) SRTM (Shuttle Radar Topography Mission, with 30 m spatial resolution) and varies from 605 to 726 m (Fig. 1b). The terrain is gently rolling to flat, with slope varying between 0 and 34%. The main soils that occur in the study site using the nomenclature of World reference base for soil resources (IUSS Working Group WRB 2015) are Arenosols, Ferralsols, Nitisols, Lixisols and Cambisols. For Arenosols, quartz is the predominant mineralogy; for the other soil types, there are mainly kaolinite and oxides (Fiorio et al. 2003).

A regular sampling grid with 100 × 100 m^2 was established in the study site, having a sampling density of one sample per hectare, comprising auger points from 0 to 0.2 m, resulting in 458 samples (Fiorio et al. 2003). The soil samples were oven-dried for 24 h at 45 °C, ground and sieved (2 mm mesh). Analysis of soil particle size distribution was performed using the hydrometer method, in which sodium hydroxide (4 g L^{-1}) and sodium hexametaphosphate (10 g L^{-1}) were employed as dispersing agents (Camargo et al. 1987). Soil texture (Fig. 2) was obtained based on the texture triangle classification developed by the United States Department of Agriculture (USDA) in R environment (R Core Team 2017), using the soil texture package (Moeys 2016). OC content was determined following an adaptation of the Walkley-Black wet oxidation method (van Raij et al. 1987).

2.2. Landsat image acquisition

Images from the satellite Landsat 5 were downloaded on the Earth Explorer platform, maintained by the United States Geological Service (USGS). This satellite has the thematic mapper (TM) imaging system and the multispectral scanner (MSS). The TM was used in this research, with spatial resolution of 30 m in the Vis-NIR-SWIR and 120 m in the TIR. The latter is resampled and already downloaded with a 30 m spatial resolution as well. Landsat 5 has seven bands that comprise the following wavelengths (μm): 0.45 to 0.52 (band 1, B1 – blue); 0.52 to 0.60

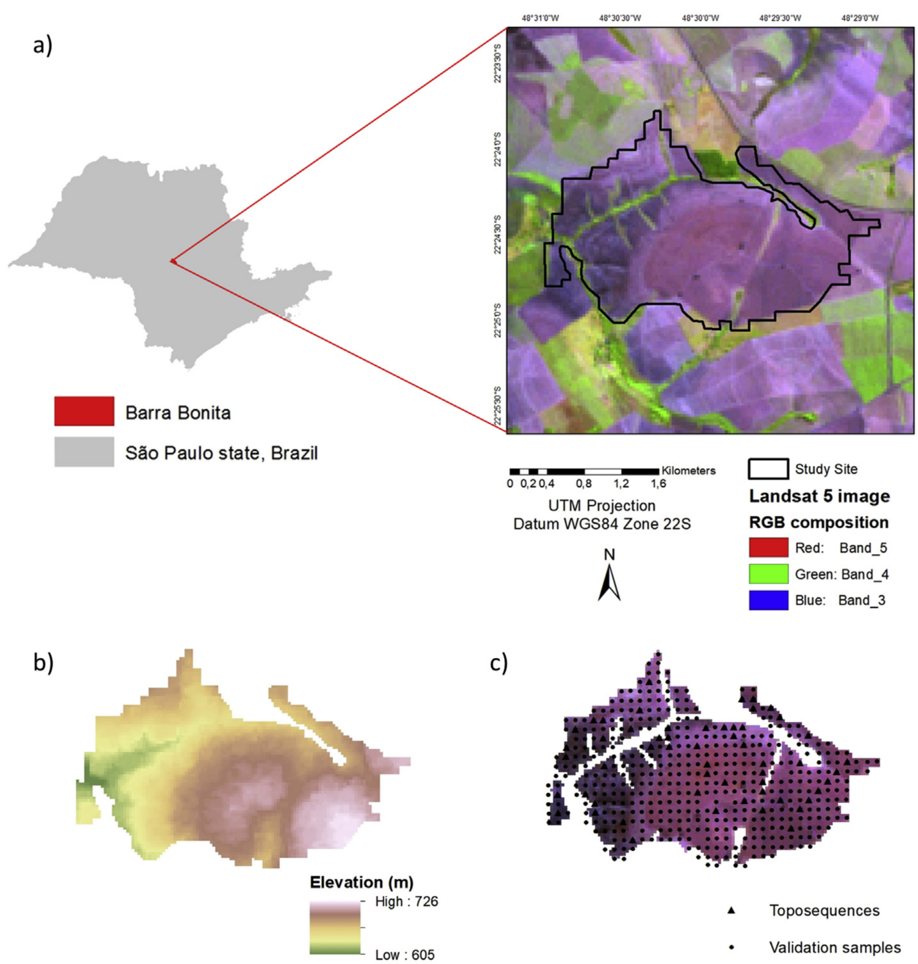

Fig. 1. a) Study site location, with an inset of a false-color composite (Red = SWIR 1; Green = NIR; Blue = Red); b) Elevation (m) extracted from the digital elevation model SRTM (Shuttle Radar Topography Mission); c) Bare soil mask (false-color composite) with toposequences (calibration) and validation samples. Samples placed outside the bare soil mask were not used. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

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