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Research article

Genesis and properties of wetland soils by VIS-NIR-SWIR as a technique for environmental monitoring

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A B S T R A C T

Wetlands are important ecosystems characterized by redoximorphic environments producing typical soil forming processes and organic carbon accumulation. Assessments and management of these areas are dependent on knowledge about soil characteristics and variability. By reflectance spectroscopy, information about soils can be obtained since their spectral behaviors are directly related to their chemical, physical, and mineralogical properties reflecting the pedogenetic processes and environment conditions. Our aims were: (a) to characterize the main soil classes of wetlands regarding their spectral behaviors in VIS-NIR-SWIR (350–2500 nm) and relate them to pedogenesis and environmental conditions, (b) to determine spectral ranges (bands) with greater expression of the main soil properties, (c) to identify spectral variations and similarities between hydromorphic soils from wetlands and other soils under different moisture conditions, and (d) to propose spectral models to quantify some chemical and physical soil properties used as environmental quality indicators. Nine soil profiles from the Pantanal region (Mato Grosso State, Brazil) and one from the Serra do Espinhaço Meridional (Minas Gerais State, Brazil) were investigated. Spectral morphology interpretation allowed identifying horizon differences regarding shape, absorption features and reflectance intensity. Some pedogenetic processes of wetland soils related to organic carbon accumulation and oxide iron variation were identified by spectra. Principal Component Analysis allowed discriminating soils from wetland and outside this area (oxidic environment). Quantification of organic carbon was possible with R^2 of 0.90 and low error. Quantification of clay content was masked by soils with organic carbon content over 2% where it was not possible to quantify with high R^2 and low error both properties when dataset has soil samples with high organic carbon content. By reflectance spectroscopy, important characteristics of wetland soils can be identified and used to distinguish from soils of different environments at low costs, reduced time, and with environmental quality.

1. Introduction

According to functional-factorial model proposed by Dokuchaev (1883), Shaw (1930), and Jenny (1994), soils are formed from environmental factors such as parent material (rocks, mineral and organic sediments), climate, relief, organisms, and time. For a

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particular relief (landscape position), the interaction between parent material and climate determines the presence of organisms, which acts over time and occur soil formation (pedogenesis). Thus, soils represent the result of a set of natural resources interaction, and for that reason, it can be considered one of the best ecosystem components for environmental stratification.

Soils are considered the base of terrestrial ecosystems and wetlands plays several environmental functions. Wetlands are ecosystems with permanent or seasonal flooding where soils remain saturated to the surface long enough to allow physical, chemical, and biological processes typical of anaerobic environments (National Research Council, 1995). Their ecological functions are essential for regulation of hydrological and biogeochemical cycles with fauna, flora and soil characteristics (Ramsar Convention Secretariat, 2013).

Wetland soils have been developed under strong influence of redoximorphic processes, which cause Fe and Mn redistribution and organic carbon accumulation. Properties of these soils are rather distinct from those developed under other hydrological conditions, and the chemical and mineralogical features are associated to the typical pedogenetic processes, such as: paludization, redoximorphism, and bissialitization. These features are able to be identified by spectral behavior and are directly related to their chemical, physical, and mineralogical composition and environment conditions.

In Brazil, some tropical wetlands are located in the Pantanal and in the Serra do Espinhaço Meridional, which are internationally recognized for their ecological importance and considered biosphere reserves by United Nations Educational, Scientific and Cultural Organization (UNESCO) and Ramsar Convention on Wetlands (Ramsar Convention Secretariat, 2013). In particular, Pantanal has around 195.000 km^2 of this important ecosystem, and information about wetland soils become essential for environmental studies to develop management plans and carry out impact analyses in these protected areas.

Reflectance spectroscopy is one part of the remote sensing techniques where information about properties of objects (soils, for instance) have been obtained by reflected electromagnetic radiation. There are many reasons to use this technique as an analytical method in soil analysis, as minimal samples preparation, rapid analysis, no waste, and simultaneous estimation of many soil properties (Viscarra Rossel et al., 2009). Reflectance spectroscopy is a non-destructive method that does not use toxic chemicals elements to humans and environment and it allows estimating results equal to conventional wet chemical analyses (Cohen et al., 2007). The graphic representation of reflectance data of objects along wavelength is known as curves behavior (or spectral signatures) and it is dependent on their inherent characteristics (Jensen, 2009). Soil spectral behavior is directly related to its chemical, physical, and mineralogical properties reflecting the pedogenetic processes and environment conditions.

Although many studies are related to quantitative spectroscopy to model soil properties (Soriano-Disla et al., 2014), qualitative assessments to investigate shapes and features of spectral behaviors are also important for a rapid and efficient identification of soils based on standards. Tropical wetland soils have not been appropriately studied in terms of reflected energy yet. Indeed, there are not enough information about spectral behaviors of soils from redoximorphic environments in Brazil. In this country, some spectral libraries have been developed in order to establish standards of spectral behaviors of typical tropical soil classes from oxic environments (Terra et al., 2015; Demattê and Terra, 2014; Belinaso et al., 2010; Formaggio et al., 1996). Such information can help researches to understand soil characteristics and variability by spectra making its monitoring better (Viscarra Rossel et al., 2016).

The link between pedogenesis and reflectance spectroscopy is an important step to achieve consistency of spectral analysis and understanding of soil behavior. In fact, soil characterization is essential for environmental studies including its management plan, risk analysis, monitoring and assessments. Besides that, important soil properties and environmental quality indicators, such as clay and organic carbon (OC) content, have been properly modeled by reflectance spectroscopy, and their results have been largely improved due to advances in statistical modeling (Guerrero et al., 2016; Shi et al., 2015).

Our aims were (i) to characterize the main soil classes of wetlands regarding their spectral behaviors in visible (VIS – 350–700 nm), near infrared (NIR – 700–1100 nm) and shortwave infrared (SWIR – 1100–2500 nm) and relate them to pedogenesis and environmental conditions, (ii) to determine spectral ranges (bands) with greater expression of the main soil properties, (iii) to identify spectral variations and similarities between hydromorphic soils from wetland and other soils under different moisture condition, and (iv) to propose spectral models to quantify some chemical and physical soil properties used as environmental quality indicators.

2. Material and methods

2.1. Study areas and their respective soil profiles

The Reserva Particular do Patrimônio Natural (RPPN) SESC Pantanal is located between the rivers Cuiabá and São Lourenço, in Barão de Melgaço – Mato Grosso State, Brazil and covers around 106,644 ha (coordinates 16°32' – 16°49′S and 56°03' – 56°26′W). This climate is classified as Aw (Köppen, 1948) and characterized as tropical humid with average annual precipitation of 1200 mm, eight months of water deficit, annual average temperature of 25 °C (Hasenack et al., 2010), and altitudes between 100 and 150 m (Nascimento et al., 2013). According to IUSS/WRB (2015), the nine soil profiles investigated in this region were classified as: Fluvic Cambisol (CM1 and CM2), Plinthic Gleysol (GL1 and GL2), Cutanic Luvisol (LV), Endogleyic Arenosol (ARg), Stagnic Solonetz (SNj), Endogleyic Planosol (PLg) and Pisolithic Plinthosol (PT).

The other area is placed in the Biribiri State Park, in Serra do Espinhaço Meridional, Diamantina – Minas Gerais State, Brazil, at 1.250 m above sea level, and the sampling place was at top of a planning surface in the head of the stream San Miguel (coordinates 18º08′S and 43º35′W). The regional climate is classified as Cwb (Köppen, 1948) and characterized as tropical of altitude with cold and dry winters, and mild and wet summers. The average annual temperature is 18.7 °C and average annual precipitation is 1500 mm. The soil profile studied was classified as Sapric Histosol (HS) (IUSS/WRB, 2015), which presents thick layers rich in organic material alternating with thin layers formed almost by sand, possibly by alternations of dry and wet periods due to paleoclimatic changes. Because of mining activity, the lowering of the drainage network (more than 3.5 m from the surface level) exposed the peatland in talvegue San Miguel Stream (Silva et al., 2009).

2.2. Wet chemical, particle size distribution, and mineralogy analysis

The soil samples were air-dried, sieved at 2-mm mesh, and sent to laboratory for wet chemical and particle size distribution analyses. Chemical analyses consisted of pH in water, extraction of exchangeable cations (Al^{3+}, Ca^{2+}, and Mg^{2+}) by KCl solution 1 mol L^{-1} where Ca^{2+} and Mg^{2+} were quantified by atomic absorption spectrophotometry and Al^{3+} exchangeable by titration with NaOH solution 0.025 mol L^{-1}, extraction of Na^+ and K^+ by Mehlich-1 which were