CORRELATION BETWEEN THE VARIATIONS OF CLAY CONTENT IN SOILS AND SEDIMENTS AND THE SPECTRAL BEHAVIOR OF SUPERJACENT VEGETATION USING SPECTIR HYPERSPECTRAL IMAGES

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ABSTRACT

This work approaches geobotany in southeastern Brazil within terrains comprising Forested Savannas, Gallery and Riparian Atlantic forests developed over fluvial-lacustrine sediments and rocks. The notion was to test the ability of SpecTIR V-S hyperspectral imagery (357 VNIR-SWIR channels; spatial resolution of 1m) to identify the variation of clay content in soils/sediments based on spectral patters yielded by the overlying vegetation. Samples were collected for granulometric analysis in the center of 30 plots with 20x20m each. Vegetation was grouped by floristic similarity. Tailored spectral indices were applied to the SpecTIR V-S data. Different indices were needed to extract parameters of the physical environment from varying vegetation. Results indicate that the physiognomies investigated are influenced differently by clay content in soils and that the vegetation also responds distinctly due to subtle textural variations in the subjacent terrains.

Index Terms — Hyperspectral, SpecTIR, Geobotany, Vegetation, Clay content.

1. INTRODUCTION

The relationship between specific plant species and the substrata from which they receive their sustenance is considered difficult to trace in tropical and subtropical climates due to the high biodiversity found in such environments. However, there have been some successful applications of geobotany using multispectral remote sensing signatures over metal deposits [1] and in regional geologic mapping [2] in the Brazilian Amazon. Currently, the availability of data that combine high spatial and high spectral resolutions, as those generated by the SpecTIR airborne sensor, allows studies to be developed in detail, comparing field and remote sensing data with more accuracy. Thus, the aim of this research is to test the ability of SpecTIR hyperspectral imagery (357 VNIR-SWIR channels; spatial resolution of 1m) to identify the correlation between the variations of clay content in soils and sediments and the spectral responses yielded by the superjacent natural vegetation.

2. METHODOLOGY

2.1. Study area

2.1.1. Localization

The study area is located in São Paulo State, southeastern Brazil, within geographic coordinates 22º16' and 22º18' S and 47º08'30" and 47º12'30" W. It is comprised in the Ecological Station of Mogi-Guaçu, occupying an area of 1,230.5 ha.

2.1.2. Physical characteristics

The area has a CWA-type climate – humid, mesothermal presenting a short or even absent period of drought and with large excess of rain in the summer. Its topography is characterized by hills and wide alluvial plains, with altitudes between 560 and 700 m. The soils are mostly from hydromorphic floodplain. The study area includes approximately 17 km of the Mogi-Guaçu River [3].

The local geology is represented by alluvial deposits of the Mogi-Guaçu River, Itararé Group and Aquidauana Formation. The alluvial deposits are composed of gravel, sand, silt, clay and, locally, peat. Carboniferous sedimentary rocks of the Paraná Basin outcrop in the study area and are represented by rocks from the Itararé Group and Aquidauana Formation, mostly fluvial-lacustrine and glacial clastic sediments [4].

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2.1.3. Vegetation

The study area is inserted in the Cerrado Biome (Brazilian Savanna) and presents Cerrado "lato sensu" formations, both Savanna and forest [5]. However, the area displays a mosaic of both Cerrado and Atlantic Forest formations [6]. The Seasonal Semideciduous Forests – typical from Atlantic Forest – are present in the study area. Their presence in the Cerrado Biome is due to their association with the watercourses [7].

2.2. Field surveys and laboratory analysis

Ten plots (with 60x20 m) were allocated systematically in different environments for characterization of the Cerrado physiognomies according to the literature [7] and for obtaining the Jaccard Similarity Index (Jacc) [8], where:

$$\text{Jacc}(A, B) = |A \cap B| / |A \cup B|;$$

Jacc $\geq$ 0.25 - indicates floristic similarity between two plots.

These plots were divided in thirty sub-plots of 20x20 m each, in the middle of which soils (superficial material – 10.0 cm in depth) and sediments (depth of 2.0 m) were collected for granulometric analysis (Figure 3). The clay content was the grain size considered as an indicator that exerts the most influence on the physical and chemical parameters of soils [9].

2.3. Hyperspectral data and processing

The image used in this study was acquired by the SpecTIR V-S airborne sensor on June 7th, 2010, with 1m spatial resolution and a spectral resolution of 2.3 to 18.4 nm in the VNIR range and 5.8 to 23.2 nm in SWIR range, with 357 contiguous bands between 350 and 2.456 nm.

From these data different spectral indices were calculated (Table 1) based on the literature [10]: vegetation cover, modified NDVI for hyperspectral data (NDVI 750); photosynthetic radiation use efficiency (NDVI 2); canopy water status (NDWI and WBI); chlorophyll content (Achl and BNb); difference between carotenoid and chlorophyll content (CRI 1 and CRI 2); difference between anthocyanins and chlorophyll content (ARI 1 and ARI 2); dried plant material (CAI).

The average values from each index, generated for the 30 sub-plots (around 400 pixels in the image), are used for study its correlation with the percentage of clay in soils and sediments.

Table 1. Vegetation spectral index used in the study.

Index/Formula	References
NDVI $_{750} = (\rho_{750} - \rho_{705}) / (\rho_{750} + \rho_{705})$	(Gitelson & Merzlyak, 1994b; Sims & Gamon, 2002)
NDVI 2 = $(\rho_{800} - \rho_{680}) / (\rho_{800} + \rho_{680})$	(Gamon et al., 1997; Pontius et al., 2008)
NDWI = $(\rho_{857} - \rho_{1241}) / (\rho_{857} + \rho_{1241})$	(Gao, 1995)
WBI = ρ_{900} / ρ_{970}	(Peñuelas et al., 1995b)
Achl = ρ_{550} / ρ_{500}	(Aoki et al.,1981; Pontius et al., 2008)
BNb = ρ_{800} / ρ_{550}	(Buschman & Nagel, 1993; Pontius et al., 2008)
CRI 1 = $(1/\rho_{510}) - (1/\rho_{550})$	(Gitelson et al., 2002)
CRI 2 = $(1/\rho_{510}) - (1/\rho_{700})$	(Gitelson et al., 2002)
ARI 1 = $(1/\rho_{550}) - (1/\rho_{700})$	(Gitelson et al., 2002)
ARI 2 = $\rho_{800}*((1/\rho_{550}) - (1/\rho_{700}))$	(Gitelson et al., 2002)
CAI = 0.5 $(\rho_{2000} + \rho_{2200}) - \rho_{2100}$	(Daughtry, 2001; Daughtry et al., 2004)

Adapted fromUstin (2008).

2.4. Statistical analysis

The Pearson's correlation coefficient (ρ) is a measure of the strength of linear dependence between two variables, giving a value between +1.0 (positive correlation) and -1.0 (negative correlation), from a correlation matrix. For this work, only the values higher than 0.70 (in a positive or negative correlation) were used, which indicated a strong correlation between the variables.

To the relations with ρ higher than 0.70 (in a positive or negative correlation), the coefficient of Determination (R^2) was applied to verify if the spectral indices variances are explained by the clay content variances. Considering that R^2 ranges from 0 to 1.

3. RESULTS AND DISCUSSION

The vegetation inventory data and the biophysical parameters of vegetation were used to distinguish among the following Cerrado Biome's forested physiognomies:

- Forested Savanna: P1 (Plot 1), P3 and P8;
- Forested Savanna /Gallery Forest non-flooding: P4;
- Gallery Forest flooding: P2;
- Riparian Forest: P5, P6, P7, P9 and P10.

The floristic similarity between the plots is represented in the Table 2 for the Forested Savanna and Gallery Forest, and in the Table 3 for the Riparian Forest, consisting by

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Atlantic forest species. The P3 showed no floristic similarity with another plot, and it is most similar to Savanna in restrict sense. Although it presents more species of this physiognomy than the others plots, the biophysical characteristics and the general floristic composition still define it as Forested Savanna.

According to these data, the plots were separated in the following groups. The Forested Savannas and Gallery Forests are represented by the letter A, where Savanna species also occur, and the Riparian Forests are represented by letter B, where only Atlantic forest species occur:

- A1 - P1vsP4vsP8 and A2 - P1vsP4
- A3 - P1vsP2vsP8 and A4 - P2vsP8
- B1 - P5vsP6vsP7 and B2 - P5vsP6 and B3 - P6vsP7
- B4 - P9vsP10

In group A (Forested Savannas and Gallery Forests), the sediment classes varied from sandy to clayey, and in group B (Riparian Forests) the sediments classes varied from clay sandy to highly clayey. The soils classes for both groups varied from sandy to highly clayey.

The correlation results between the clay content of sediments and soils and the spectral indices to the 30 sub-plots, presented in Table 2, indicated that all Forested Savannas and Gallery Forests sampled presented negative strong correlation between the clay content in soils and the NDVI, indicating that as higher the clay content in the soils, lower is the vegetation coverage. The lowest values of A3 and A4 may have been influenced by the Forest Gallery flooded, even though the vegetation of this physiognomy has presented high similarity with the Forested Savanna, in this environment there are also species adapted with high clay contents in the soils. To the clay content in the sediments, the strong correlations occurred only for A1 and A2, with NDVI and NDVI 2. These groups are the ones that presented floristic characteristics of the Forested Savanna, which reinforce that this relationship is more evident for this physiognomy. The Riparian Forests, in contrast, do not show a strong correlation with these parameters.

The correlation between the NDWI and WBI, which evidence the leaf water content, and the clay content of sediments and soils was negative in A1, A2 and B2.Thus, this fact may be indicating that, for these species groups, the lower the amount of clay soil, higher the leaf water. Although they have floristic differences (A1 and A2- Forested Savanna species, more commonly, and B2 - Atlantic forest, but not alluvial species), these species groups in general are observed in more dried environment, where the groundwater does not reach the surface.

The high negative correlation between the amount of chlorophyll in the canopy of the species group of P1, P4 and P8 (A1 and A2) and the amount of clay in soils and sediments signifies that the smaller the amount of clay in soils and sediments, greater the amount of chlorophyll in their leaves.

Table 2. Pearson's correlation coefficients (ρ), only strong positive or negative correlations ($\rho \geq 0.70$), and their respective coefficients of Determination (R^2), presented by group (ρ ; R^2).

Parameters	*% Clay - Sediments*	*% Clay - Soils*
NDVI	A1 (-0.86; 0.74) A2 (-0.88; 0.77)	A1 (-0.83; 0.68) A2 (-0.79; 0.63) A3 (-0.76; 0.58) A4 (-0.71; 0.50)
NDVI 2	A1 (-0.83; 0.69) A2 (-0.81; 0.65)	A1 (-0.75; 0.57)
NDWI	A2 (-0.90; 0.81) A3 (0.78; 0.60) A4 (0.98; 0.96) B2 (-0.82; 0.68)	A2 (-0.78; 0.61) A4 (-0.97; 0.94) B2 (-0.78; 0.61)
WBI	A2 (-0.84; 0.70)	A1 (-0.81; 0.66) A2 (-0.83; 0.69)
Achl	A1 (-0.89; 0.79) A2 (-0.81; 0.65) B4 (-0.73; 0.53)	A1 (-0.78; 0.61)
BNb	A1 (-0.74; 0.56)	A1 (-0.71; 0.50)
CRI 1	A1 (-0.89; 0.80)	A1 (-0.72; 0.51) B4 (0.70; 0.48)
CRI 2	A1 (-0.78; 0.60)	-----
ARI 1 and 2	-----	-----
CAI	A1 (-0.96; 0.93) A2 (-0.92; 0.85) A3 (-0.97; 0.94) A4 (-0.98; 0.96) B2 (-0.85; 0.73)	A1 (-0.89; 0.80) A2 (-0.90; 0.81) A3 (0.78; 0.61) A4 (0.90; 0.82) B2 (-0.83; 0.74) B4 (-0.92; 0.84)

The spectral indices Achl, Bnb, CR1 and CR2 also indicate a negative correlation between the amount of carotenoids in the canopy of species P1, P4 and P8 and the amount of clay in soils and sediments.

The group B4 (P9 and P10) showed a positive correlation between the amount of carotenoids in the canopy (CR1) and the clay amount in the soils. Although the B4 species (riparian) are adapted to clay soils (including alluvial species), the environments where they are P9 and P10 also present seasonal flooding. The clay excess may result in an over accumulation of water, consequently influencing the health of the vegetation. The high values of the ratio carotenoids/chlorophylls in the leaves are indicators of the stress caused by water excess in the substrate. The low coefficient of Determination ($R^2 = 0.48$) for this group may have been influenced by the fact there are sub-plots located on dykes, where there isn't seasonal flooding.

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The indices ARI 1 and ARI 2 do not show strong correlations with the two parameters of the physical environment studied. This fact suggests that the variations in concentration of anthocyanin in groups of species and environments studied are not linearly related.

The CAI index showed strong negative correlations with clay content in sediments for all A groups (Forested Savanna and Gallery Forests), and negative correlation with clay in the soil for A1 and A2 and positive for A3 and A4. The relationship of higher clay content in the soil and leaf area for the species present at A3 and A4 may be influenced by the P2, which has 21.12% of clay content to more than the average values of the plots of A3 and A4. This may be affecting the health of the vegetation, expressed by reduction of its leaf area and, consequently, greater exposure of dry material. In contrast, the negative correlation of B2 and B4 (Riparian forest) between clay content in sediments (B2) and soils (B2 and B4) and amount of dry material in the canopy indicates the relationship of vegetation, characteristic of Semideciduous and Alluvial Forest (Atlantic Forest), with more clayey soils; ie, the greater the amount of clay increased leaf area, indicating the greater adaptability and health of this vegetation on this kind of substrate.

4. CONCLUSIONS

The Pearson's correlation coefficients were efficient for Geobotanic analysis for the vegetation types and environments approached in this study. Their respective coefficients of Determination proved the validity of these correlations.

It represents the highest relationship of health and adaptability of the arboreal Savanna species in soils and sediments with less clay content and the Atlantic forest species in clay-richer soils and sediments.

In seasonal flooding areas, the high concentrations of clay in the soils may become negative for the vegetation health, chlorophylls decreases and carotenoids increases in the Riparian Forest and non-foliar materials increases in Flooded Gallery Forest.

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6. REFERENCES

[1] T.I.R. Almeida, C.R. Souza Filho, C. Juliani, , F.C. Branco, "Application of Remote Sensing to Geobotany to Detect Hydrothermal Alteration Facies in Epithermal High Sulfidation Gold Deposits in the Amazon Region", *SEG Special Publication on Remote Sensing and Spectral Geology*, Society of Economic Geologists, Littleton, v. 1, p. 135-142, 2009.

[2] M.M. Perrotta, T.I.R. Almeida, J.B.F. Andrade, C.R. Souza Filho, G.J. Rizzotto, M.G.M. Santos, "Remote sensing geobotany and airborne gamma-ray data applied to geological mapping of the Amazon: a comparative study in the Guaporé Valley (Mato Grosso State, Brazil)", *Revista Brasileira Geociências*, Geological Brazilian Society, Sao Paulo, v.38, n.1, p.153-166, 2008.

[3] Instituto Florestal, "Áreas protegidas do Instituto Florestal: Estação Ecológica de Mogi-Guaçu", *Instituto Florestal*, São Paulo, 2010.

[4] Serviço Geológico do Brasil, "Geologia e recursos minerais do Estado de São Paulo: sistema de informações geográficas (SIG)" *Mapas Geológicos Estaduais (1:750.000)*, CPRM, São Paulo, 2006.

[5] Instituto Virtual da Biodiversidade, "Estação Ecológica de Mogi-Guaçu", *Programa BIOTA/FAPESP*, São Paulo, 2010.

[6] Joly, C.A., Bicudo, C.E.M. *Biodiversidade do Estado de São Paulo, Brasil: síntese do conhecimento ao final do século XX*. In: M. C. W. Brito, C. A. Joly, *Infra-estrutura para conservação da biodiversidade*, FAPESP, São Paulo, 1999.

[7] Ribeiro, J.F., Walter, B.M.T. *As principais fitofisionomias do Bioma Cerrado*. In: Sano, S.M., Almeida, S.P., Ribeiro, J.F., *Cerrado: ecologia e flora*, EMBRAPA-CPAC, Planaltina, 2008.

[8] Mueller–Dombois, D., Ellenberg, H., *Aims and methods of vegetation ecology*, John Wiley & Sons, New York, 1974.

[9] Lepsch, I.F., *19 lições de Pedologia*, Oficina de Textos, Sao Paulo, 2011.

[10] Ustin, S.L. "Analysis of hyperspectral remote sensing to detect and map tree decline at Ft. Benning, Georgia." *Army Cooperative Agreement*, United States Army Corps of Engineers, Fort Benning, 33p., 2008.

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