Relationship between spectral sugarcane data and local variation of soil attributes

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Abstract
Interest in sugarcane production has strongly increased due to its significant role in biofuel and bioenergy production. The synoptic views generated from multi-temporal remote sensing data allow us to monitor the crop vigour during its lifecycle. Despite the influence of other factors, variation in crop spectral response over an area is in part explained by local variation of soil attributes. The objective of this work was to assess the relationship between spectral data and soil attributes to support site-specific management. The study area was located in Santa Maria da Serra (Sao Paulo). For physical and chemical routine characterizations, soil samples were collected at two depths from 130 locations. Cone index and water content measurements were made at almost 900 sampling points using a hydraulic-electronic penetrometer. The *Green Vegetation Index* was calculated from three Landsat 7/ ETM+ images after atmospheric corrections. Multivariate analyses were carried out. Two models were selected with three (clay, water contents and cation exchange capacity) and four (clay, water, organic matter, and magnesium contents) variables. They explained respectively 39% and 58% of total variation. The results support the fundamental assumption of the work that variation in crop spectral response over an area is in part explained by local variation of soil attributes.

Key Words
Soil site specific management, remote sensing, multi-spectral data, GVI vegetation index.

Introduction
Reflectance is the most analyzed physical phenomenon in remote sensing applications, where vegetation indexes has been employed to monitor the vigor of the vegetation cover on global or regional scales (Miura *et al.* 2001). The synoptic views generated from multi-temporal remote sensing data allow to monitor the crop vigor during its lifecycle. In relation to sugarcane spectral response, Machado *et al*. (1985) stated that many bio-physical factors are involved, such as plant structure and geometry, as well as the size, anatomy and age of leaves. For sugarcane plantation spectral response, besides genetic and morphological differences between varieties, phenological stages and climatic conditions are also important. In Brazil, Joaquim (1998), Machado (2003), and Benvenuti (2005) have related sugarcane spectral response with bio-physical crop parameters and yield. Despite the great influence of the mentioned factors, the variation of crop spectral response over an area could be also explained partially by local variation of soil attributes, information that could be applied in agricultural management. Lourenço (2005) studied the relationship between sugarcane plantation, plant and soil attributes. The author stated that 30% of the observed variation of the NDVI vegetation index was due to local variation of soil attributes. The objective of this work was to assess the relationship between spectral data and soil attributes to support the crop site-specific management in a commercial area in Sao Paulo State.

Methods
Study area and sampling scheme
The studied area encompassed 15 plots occupying 150ha cultivated with a medium maturation sugarcane variety. General topography is gentle (0.05m/m), with increasing slopes until 0.13m/m at the lower part of the hillsides. Main soil types occurring in the area include Typic Hapludox (Red Yellow Latosols medium textured) and Typic Quartzipsamments, both with base saturation under 50%. For physical and chemical routine characterizations, soil samples were collected from 130 DGPS georeferenced sampling points at two depths, 0-0.25m and 0.25-0.50m. Cone index and water contents measurements were also made at almost 900 sampling points using a hydraulic-electronic penetrometer. Figure 1 illustrates the studied area and the soil sampling locations. A total of 42 soil attributes were evaluated.

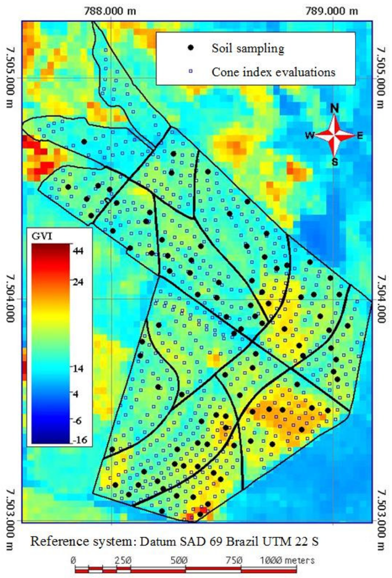

Figure 1. Location of the soil sampling points and cone index evaluations within 15 plots in studied area, with the GVI index map layout underneath.

Remote sensing data

The vegetation index GVI (*Green Vegetation Index*), originally described by Kauth and Thomas (1976) was calculated by equation 1, as described by Crist (1985). Three Landsat 7/ ETM+ images were analyzed, two of them were being acquired during the maximum vegetative crop growth phase, in January and February, and the third in May, at the beginning of the sugarcane maturation phase. In view of their multi-temporal character, the spectral data were previously submitted to atmospheric corrections before vegetation index calculations by applying the software SCORADIS (Zullo Jr 1994). The analyses were performed in a GIS environment.

$$\mathbf{GVI = - 0.1603*b1 - 0.2819*b2 - 0.4934*b3 + 0.7940*b4 - 0.0002*b5 - 0.1446*b7} \quad (1)$$

Where: b1(blue, 0,45-0,52μm), b2 (green, 0,52-0,60μm), b3 (red, 0,60-0,70μm), b4 (NIR, 0,76-0,90μm), b5 (MIR, 1,55-1,75μm), and b7 (MIR, 2,08-2,35μm) of Landsat/ ETM+sensor.

Statistical analysis

The relationship between the spectral response of sugarcane plantation and soil attributes was assessed by multiple linear regression analyses, employing the software Statistica 6.0 and adopting the stepwise method for selecting variables. Despite of having a greater density of soil observations in the study area, only one hundred sampling points, for what there were soil attributes data for both depths, were chosen to perform the multiple regression analyses. To perform these analyses, the values of the distinct soil attributes from one sampling point or geographical location (independent variables) were correlated with the correspondent values of the green vegetation index at the same geographical location (dependent variables).

Results

The results obtained include two multivariate models which are described by the equations 2 and 3 below. The first model (eq.2) for green vegetation index at maximum vegetative crop growth phase could explain approximately 39% of total variation observed on sugarcane spectral response over the studied area. Clay content at 0.25-0.50m could explain 25.4%, water content in the same depth added 9.3%, and CEC at 0-0.25m explains the last 4% of the observed variation of the GVI index. Model is significant ($P<0.00000$) with 95% confidence level, and the Shapiro-Wilk test demonstrated that residues distribution is normal ($W = 0{,}982$, *p*-valor = 0,173). These results are greatly coherent in view of the fact soils in the studied area are medium to sandy textured, with low contents of organic matter. These factors both determine low water retention and low CEC, which affects crop growth and vigor during crop lifecycle and could be characterized by remote sensing data.

GVI_feb25 = 7.96695 + 0.02035*clay p2 + 0.215961*water content p2 + 0.05366*CEC p1 (r^2=0.387) (2)

Where: p1 corresponds to the 0-0.25m depth, p2, 0.25-0.50m depth, and CEC, cation exchange capacity.

The performance of the second model (eq.3) for green vegetation index at the beginning of the sugarcane maturation phase was superior and could explain approximately 58% of total variation observed on sugarcane spectral response over the studied area. In this case, organic matter content at 0.25 to 0.50 m was related with the major variation (42%) observed on sugarcane spectral response, followed by water content (8.1%), clay content (5.5%), and magnesium content (2.7%). Model is also significant ($P<0.00000$) with 95% confidence level, and the Shapiro-Wilk test demonstrated that residues distribution is normal (W = 0.98375, *p*-value 0,234). In May the climate is dryer and at maturation phase the soil conditions become critical to crop development. Under such circumstances, the relative greater importance on model of sub superficial organic matter could be related with its positive effect on soil structure and water retention, which would improve soil water availability and favor water absorption by deeper roots.

GVI_may16 = 7.66488 + 0.13311*O.M. p2 + 0.162793*water content p2 + 0.01678*clay p1 + 0.18583 Mg p1 (r^2=0.583) (3)

Where: p1 corresponds to the 0-0.25m depth, p2, 0.25-0.50m depth, O.M., organic matter content, and Mg, magnesium content.

Finally, considering that clay contents of soils are mostly defined by parent material and soil genesis, data support that site specific management in this area would be concerned with soil organic matter management, to improve levels of soil net negative charge (CEC), nutrients and water contents.

Conclusion

Results are coherent with soil types occurring in the area and support the fundamental assumption of the work that the variation of crop spectral response over an area is in part explained by local variation of soil attributes.

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