MESO-SCALE VARIABILITY OF SOILS AND FOREST CANOPY PROPERTIES IS CONNECTED TO GEOMORPHOLOGIC FEATURES IN EASTERN AMAZONIA

Yosio E. Shimabukuro
Instituto Nacional de Pesquisas Espaciais (INPE)
Av. dos Astronautas, 1758
CEP 12227-010, São José dos Campos, SP, Brazil
E-mail: yosio@ltid.inpe.br

Luiz Eduardo O. C. Aragão
University of Oxford, Centre for the Environment, Dyson Perrins Building
S. Parks Road Oxford OX1 3QY, UK
E-mail: laragao@ouce.ox.ac.uk

Mathew Williams
School of GeoSciences, Darwin Building, University of Edinburgh
Edinburgh EH9 3JU, UK.
E-mail: mat.williams@ed.ac.uk

Abstract

In this study we investigated the relationships between landscape features such as terrain elevation and slope with two variables that drives forest productivity, soil texture and leaf area index (LAI). The study was carried out at the Tapajós region in Pará State, eastern Amazonia. Twenty-four 0.25 ha plots were sampled along a ~150 km north-south transect in October 2002. Soil samples were collected (0-10 cm) in three random points in each plot for texture analysis. LAI was measured at 25 points regularly distributed in each plot. The geomorphologic attributes for each plot were extracted from the Shuttle Radar Topography Mission (SRTM) data linearly resample to 10 m spatial resolution. Terrain slope was linear and negatively related to the soil clay content (r^2=0.73). Soil sand content had an expected opposite pattern (r^2=0.72). The soil content of clay and sand along the elevation gradient can be strongly explained by a cubic polynomial curve (r^2=0.82 and 0.81, respectively). LAI showed to be a logarithmic function of slope (r^2=0.61), excluding plots located in the Valley regions. Moreover, LAI showed a linear and positive relationship with soil clay content (r^2=0.52). Similarly to the relationships found between terrain elevation and soil texture, the 3rd order polynomial could explain 64% of the LAI variability over the Tapajós. Therefore, we concluded that topography is a major driver of the patterns of soil texture at the landscape scale and the combined effect of topography and soil can largely explain the patterns of LAI over the Tapajós. The combination of SRTM data and field-based information has the potential to increase the accuracy of ecosystem scale estimations of forest productivity in the Amazonia.

Keywords: Amazonia, SRTM, LAI, soil texture, LBA

I. INTRODUCTION

To understand many aspects of the Amazonian ecosystem ecology and function, such as the coupling between primary productivity and climate, one of the prime needs is to determine how do the soils and the canopy properties vary across the landscape. Comprehend these meso-scale (~1-1000 km2) patterns is essential to increase the power of spatio-temporal model predictions on how Amazonia, as a biome, responds to the actual and future climate scenarios. The dimension of the Amazon Basin (~5x106 km2) and its ambiguous function as a carbon (C) sink or a source [1]-[2] highlight the necessity for assessing factors that control forest heterogeneity and how it affects the ecosystem productivity. The hypothesis that species distributions are patchy through the landscape emphasizes the connection between environmental characteristics such as soil and topography, and floristic composition of tropical forests. This hypothesis has been extensively tested from small to large scales, in Central America and Western Amazonia [3]. All of these studies have reported species-habitat associations with different degrees. However, in Central and Eastern Amazonia evidences about this pattern are scarce. Based on this previous information, the aim of the current study is to investigate if the mosaic structure of landscape attributes in the eastern Amazonia have any influence on the spatial variability of the components of tropical forest productivity, such as soil texture and leaf area index (LAI). Specifically, this study is focus on three main questions:

Q1. How do the soil and the topography varies across the Tapajós region?

Q2. Can the topography explain the patterns of soil texture across the Tapajós region?

Q3. Does landscape heterogeneity (soil and topography) have any influence on the spatial pattern of LAI across the Tapajós region?

II. MATERIAL AND METHODS

A. Study Area

The study was carried out at the Tapajós region in Pará State, Brazil. This is one of the experimental sites of the Large Scale Biosphere-Atmosphere Experiment in Amazonia (LBA). We selected an area in the eastern Amazonia lying between latitudes 02° 39' S and 04° 10' S and longitudes 55° 13' W and 54° 31' W. The Tapajós National Forest is a protected area that covers about a half of the studied region (~13,000 km^2).

B. Field Survey and Experimental Design

A fieldwork was carried out in October 2002. In total 24-0.25ha plots, along a ~150 km north-south transect were sampled. The sites were selected based on a stratified random sampling [4]. Soil samples were collected (0-10 cm) in three random points in each plot for texture analysis. LAI was measured at 25 points in each plot using a pair of LAI-2000 instruments. The geomorphologic attributes for each plot were extracted from the Shuttle Radar Topography Mission (SRTM) data linearly resample to 10 m spatial resolution. The terrain elevation information was used to derive the terrain slopes in this region (Fig. 1).

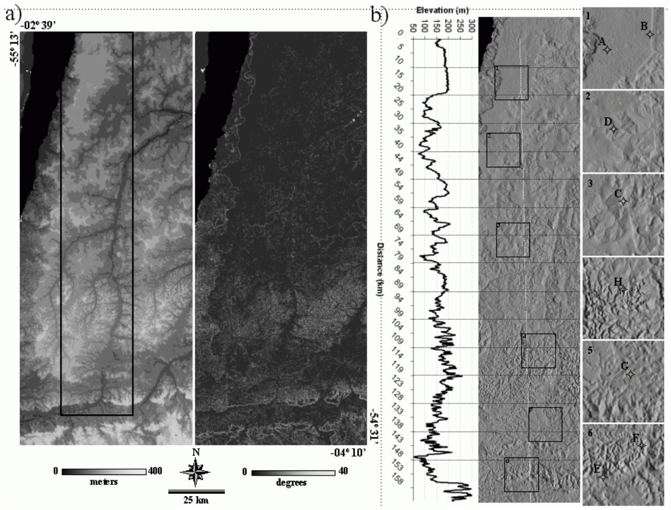

Figure 1. a) Grey-scale image of terrain elevation (left) and terrain slope (right), light colours mean higher elevation or more steep slopes. b) Elevation profile of the transect, location of the studied sites and detailed view of the sites, with the star representing the place where each group of three plots were set up.

C. Statistical Analyses

A cluster analysis was initially carried out to group plots with similar elevation and slope characteristics. This same analysis was again used considering only the soil texture. Finally, a set of regression analyses was applied to evaluate the dependence of soil texture and LAI to the topographic variables.

III. RESULTS AND DISCUSSION

The results indicated at least 5 clusters of plots related to the topography. The regions could be identified as Plateau (elevations >190m, slope < 2°); Valley (elevations ~148m, slope 1° - 3°); Lower-slope (elevations 100-130m) and Upper-slope (elevations 170 - 190m), both with variable slope (2° - 10°), and Riparian (elevations ~80m, slope 1.4° - 5°) (Fig. 2).

Soil texture in the plots showed a high variation regarding to the clay and sand content, with a mean ± standard deviation of 42% ± 30 and 50% ± 32, respectively. On the other hand, silt percentage (8% ± 6) did not vary significantly across the region. This textural pattern is common for Brazilian soils which are concentrate within an area of the textural triangle indicating clay contents > 30% and silt content < 17% [5]. Soil clay content is associated to the plateau region, while soil sand are usually linked to the valley and slope areas.

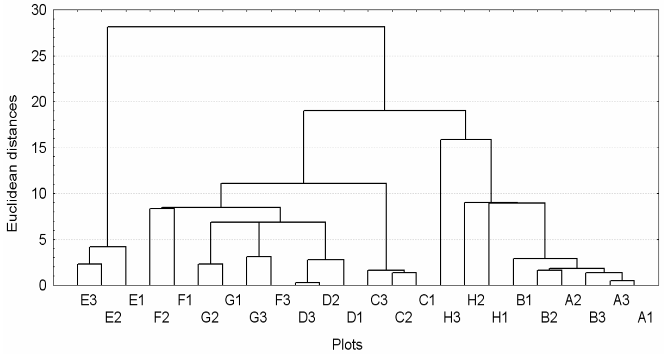

Figure 2. Euclidean distances among plots based on the variation in terrain elevation and slope.

The three plots located at the Riparian area have the higher percentage of silt in the top 10 cm of the soil (between 15 % and 30 %). Low silt content (<10-20%) is typical of Amazonian soils and areas with silt content > 40% are associated to hydromorphic soils [6].

Interestingly, a similar pattern of plot clusters was observed when considering soil texture variation only (Fig. 3). This is an indicative of the covariance between topography and soil texture.

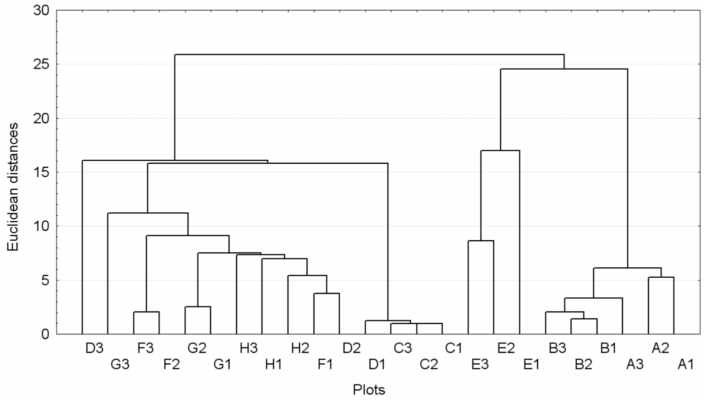

Figure 3. Euclidean distances among plots based on the variation in soil texture (sand, silt and clay fractions).

Results from the regression analyses are presented in table 1. Without considering the Valley samples, which follow an independent pattern (slope < 3° and clay content > 50%), the terrain slope was linear and negatively related to the clay content ($r^2 = 0.73$). Sand content had an expected opposite pattern ($r^2 = 0.72$). The content of clay and sand along the elevation gradient can be described by cubic polynomial equations (Fig. 4). The decrease in clay content from the plateau to the slope and to the valley has been reported for other sites in the Amazonia. A study near Manaus showed that clay content decreased significantly from 65% in the plateau, to 43% in the slope and 5% in the valley. The topographic gradient, along with texture, also caused a significant decrease in soil organic matter and soil moisture from the plateau to the valley [7].

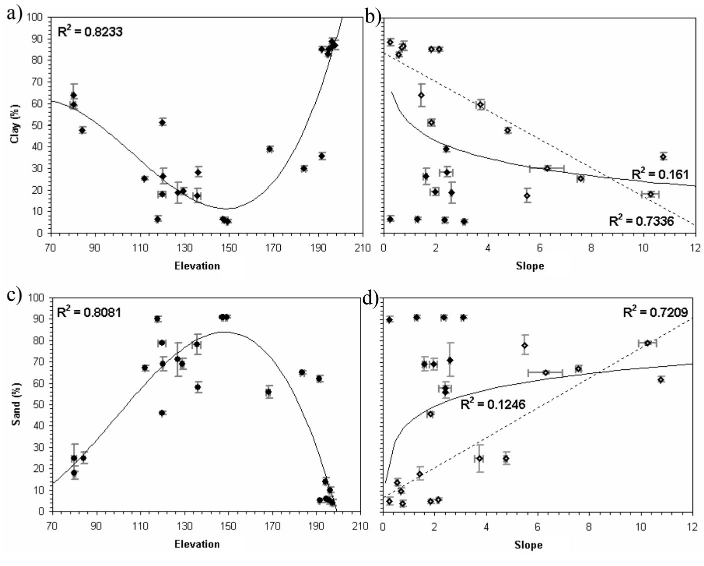

Figure 4. Relationships between (a) clay content and elevation (m), (b) clay content and slope (degrees), (c) sand content and elevation and (d) sand content and slope. . In figure b and d the black dots correspond to samples in the valley areas and the white dots are the samples used for the regression without the valley areas.

Leaf area index showed to be a logarithmic function of terrain slope (r^2=0.61), excluding plots located in the Valley regions. Moreover, LAI showed a linear and positive relationship with soil clay content (r^2=0.52). Similarly to the relationships between terrain elevation and soil texture, the 3rd order polynomial equation was used to fit LAI data (r^2=0.64) (Fig. 5).

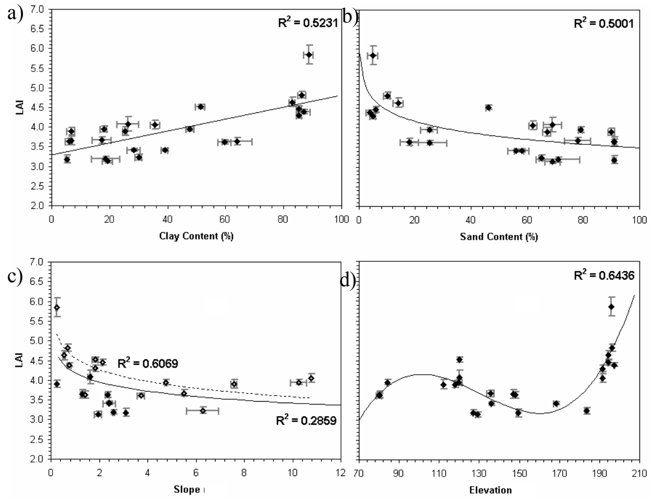

Figure 5. Relationships between leaf area index and (a) clay content, (b)sand content, (c) terrain slope and (d) terrain elevation. In figure c the black dots correspond to samples in the valley areas and the white dots are the samples used for the regression without the valley areas.

These results highlight the link between LAI and soil texture that is driven by topography. The higher LAI values over clay soil can be associated to three different factors that are likely to interact together. 1) High soil clay content is associated to elevated soil organic matter content [7], leading to more fertile soils than those with sand texture. 2) High soil clay content leads also to higher soil water content than in sandy soils[7]. Due to the lower water retention capacity of sandy soils, the vegetation is exposed to water limitation during dry periods. Hence, the decline of LAI in these sites could strategically be used for reducing evapotranspiration. The reduction in the LAI is also expected to constrain other soil-plant-atmosphere processes such as photosynthesis, ecosystem respiration and decomposition. Finally, 3) the interaction of the previous 2 factors is probably responsible for the maintenance of more vigorous vegetation (Higher basal area, canopy height, biomass) in the plateau areas which is expected to have higher LAI due to the tree allometric relationships.

Table 1. Results of the regression analyses showing the variables, the best fitted model, the number of samples (N), the regression coefficient (r^2), and the equations. The slope is represented by SL, elevation by EL, clay by CL and sand by SA.

Dependent Variable	Independent Variable	Best Fit	N	r^2	Equation
Clay	Slope	Logarithmic	24	0.16	$- 11.814\ln(SL) + 51.169$
Clay	Slope	Linear (All except slope < 4° and clay < 50%)	15	0.73	$- 6.779SL + 83.627$
Clay	Elevation	Cubic	24	0.82	$0.0002EL^3 - 0.059EL^2 + 5.4176EL - 91.803$
Sand	Slope	Logarithmic	24	0.12	$11.042\ln(SL) + 41.727$
Sand	Slope	Linear (All except slope < 4° and clay < 50%)	15	0.72	$6.9892SL + 6.7399$
Sand	Elevation	Cubic	24	0.81	$-0.0002EL^3 + 0.0484EL^2 - 3.5684EL + 81.726$
LAI	Slope	Logarithmic	24	0.28	$-0.3303\ln(SL) + 4.1817$
LAI	Slope	Logarithmic (All except slope < 4° and clay < 50%)	15	0.61	$-0.4281\ln(SL) + 4.5643$
LAI	Elevation	Cubic	24	0.64	$(1e-05)EL^3 - 0.0038EL^2 + 0.4768EL - 14.914$
LAI	Clay	Linear	24	0.52	$0.0152CL + 3.2947$
LAI	Sand	Logarithmic	24	0.50	$-0.4159\ln(SA) + 5.4061$

IV. CONCLUSIONS

Therefore, we concluded that topography controls the patterns of soil texture and the combination of these two variables can explain a large amount of LAI heterogeneity over the Tapajós. The development of models based on the relationships presented here could strongly contribute to mapping regional patterns of soil texture and LAI in the Tapajós. However, the relationships presented here are specific for the studied region and for a broad scale application of this models there is a need for more information about topography, soils and canopy properties associations in other regions of the Amazonia. The understanding of the causes of this variability is crucial for increasing the power of the predictions about the function of the Amazonian biome facing to the actual and future climate scenarios.

ACKNOWLEDGMENTS

This research was support by FAPESP grant (Proc. 02/00985-2). We thank LBA-NASA Office staff at Santarém by the logistical support and CNPq and CAPES for the second author studentship.

REFERENCES

[1] O.L. Phillips, Y. Malhi, N. Higuchi, W.F. Laurance, P.V. Nunez, R.M. Vasquez, S.G. Laurance, L.V. Ferreira, M. Stern, S. Brown, J. Grace, “Changes in the carbon balance of tropical forests: evidence from long-term plots”, *Science*, 282, 439-442, 1998.

[2] S.R. Saleska, S.D. Miller, D.M. Matross, M. L. Goulden, S.C. Wofsy, H.R. Rocha, P.B. Camargo, P. Crill, B.C. Daube, H.C. Freitas, L. Hutyra, M. Keller, V. Kirchhoff, M. Menton, J.W. Munger, E.H. Pyle, A.H. Rice, H. Silva, “Carbon in Amazon Forests: Unexpected Seasonal Fluxes and Disturbance-Induced Losses”, *Science*, 302, 1554-1557, 2003.

[3] H.Tuomisto, K. Ruokolainen, M. Yli-Halla, “Dispersal, Environment, and Floristic Variation of Western Amazonian Forests”, *Science*, 299, 241-244, 1995.

[4] L.E.O.C. Aragão, Y.E. Shimabukuro, F.D.B. Espirito-Santo, M. Williams, “Landscape pattern and spatial variability of leaf area index in eastern Amazonia”, *Forest Ecology and Management*, 211, 240-256, 2005.

[5] J. Tomasella, M.G. Hodnett, L. Rossato, “Pedotransfer functions for the estimation of soil water retention in Brazilian soils”, *Soil Science Society of America Journal*, 64 (1), 327-338, 2000.

[6] J. Tomasella, M.G. Hodnett, “Estimating soil water retention characteristics from limited data in Brazilian Amazonia”, *Soil science*, 163 (3), 190-202, 1998.

[7] R.C.C. Luizao, , F.J. Luizao, , R.Q. Paiva, , T.F. Monteiro, L.S. Sousa, B. Kruijt, “Variation of carbon and nitrogen cycling processes along a topographic gradient in a central Amazonian forest”, *Global Change Biology*, 10, 592-600, 2004.