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Discrimination of geomorphic surfaces with multivariate analysis of soil attributes in sandstone - basalt lithosequence[1]

Análise multivariada de atributos do solo na discriminação de superfícies geomórficas em uma litossequência arenito - basalto

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ABSTRACT - The geomorphic surface concept allows interrelationship among various branches of soil sciences, such as geology, geomorphology and pedology. This association enhances the understanding of spatial soil distribution through landscape, pointing out the soil attributes behavior, which are mainly related to stratigraphy and relief forms. Therefore, this study aims to apply multivariate statistics to categorize geomorphic surfaces in sandstone - basalt lithosequence, so as to provide a basis for soil assessment in similar areas. The study area is located in Pereira Barreto County, SP, Brazil. An area of 530 hectare was selected, where three geomorphic surfaces (I, II and III) were located and mapped. In this area, 134 soil samples were collected at depths of 0.0-0.2 m and 0.8-1.0 m below ground surface. Sand, silt and clay contents were determined, pH in $CaCl_2$ solution, OM, P, Ca, Mg, K, Al and H+Al contents were also evaluated. Based on the results, univariate, multivariate analysis of variance, cluster and principal-component analysis were performed in order to compare the three geomorphic surfaces. The univariate statistical analysis of soil attributes was not efficient enough to categorize the three geomorphic surfaces. By using the physical and chemical soil properties, the multivariate statistical techniques enabled the differentiation of the three groups of soil natural bodies which were equivalent to the same three mapped geomorphic surfaces (GS). These results are interestingin order to demonstrate the feasibility of the numerical classification use on geomorphic surfaces to assist the soil mapping.

Key words: Soil Science. Geomorphology. Multivariate analysis.

RESUMO - O conceito de superfície geomórfica permite uma interligação entre os diferentes ramos da ciência do solo, tais como geologia, geomorfologia e pedologia. Esta associação favorece a compreensão da distribuição espacial dos solos na paisagem, e torna possível compreender o comportamento dos atributos do solo, que estão principalmente relacionadas com a estratigrafia e formas do relevo. Assim, este estudo visa à aplicação da estatística multivariada para categorizar superfícies geomórficas em uma litossequência arenito-basalto, de modo a fornecer uma base para a avaliação do solo em áreas afins. A área de estudo está localizada no município de Pereira Barreto, São Paulo, Brasil. A área escolhida possui 530 hectares, onde foram localizadas e mapeadas três superfícies geomórficas (I, II e III). Na área, 134 amostras foram coletadas nas profundidades de 0,0-0,2 m e 0,8-1,0 m, foram determinados os conteúdos de areia, silte e argila, pH em $CaCl_2$, conteúdo de MO, P, Ca, Mg, K, Al e H+Al. Com base nos resultados, foram realizadas a análise univariada e multivariada de variância, clusters e principal componente, a fim de comparar as três superfícies geomórficas. A análise estatística univariada dos atributos do solo não foi eficiente na identificação das três superfícies geomórficas. Utilizando-se os atributos físicos e químicos do solo, as técnicas estatísticas multivariada permitiram à separação dos três grupos de corpos naturais do solo que foram equivalentes as três superfícies geomórficas mapeadas. Estes resultados são interessantes, pois demonstram a viabilidade da utilização de classificação numérica das superfícies geomórficas para ajudar no mapeamento de solo.

Palavras-chave: Ciência do Solo. Geomorfologia. Análises multivariada.

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INTRODUCTION

The digital mapping of soil classes generally starts with soil profile description organizing the soil classes at a taxonomic level in a particular classification system. The current methodology treats soil classes as ‘labels’ and their prediction only considers the minimization of the misclassification error. Soil classes at any taxonomic level have taxonomic relationships between each other, and in some instances the errors in prediction of certain classes are more serious than the others (MINASNY; MCBRATNEY, 2007).

In this sense, some authors (CAMPOS *et al*., 2007; CUNHA *et al*., 2005; SANCHEZ *et al*., 2005; TERAMOTO *et al*., 2001) have been using geomorphic surfaces to assist in more accurate transition lines identification between the involved regions, and help in understanding of greater or lesser variability space areas.

Conceptually, geomorphic surfaces are land portions defined by geographic boundaries and located within time and space (DANIELS *et al*., 1971; RUHE, 1956). The knowledge and practice of these soil study concepts enable the performance of spatial variability studies and pedological assessments. In addition, it consists in an instrument to predict pedological features from still unknown areas (MOTTA *et al*., 2002a).

Hence those studies on soil variability and its geomorphological attributes are aid tools in pedology studies, since they do not consider the pre-established taxonomic limits, but rather follow soil limits as natural bodies. Thus, they improve interpretations in assessments for land suitability studies, capacity use, managing zone establishment and etc (CUNHA *et al*., 2005).

A tool that has been used in such research is the multivariate analysis. The use of multivariate statistical techniques associated with geomorphic surface concepts make it possible to observe the soil attributes variation, thus consisting of an attempt to reduce error and to understand the sequences of pedogenetic processes, and clarifying the participation and importance order of soil variables (YEMEFACK *et al*., 2005). The use of this techniques will categorize clusters in such a way that error rate can be classified as minimal, thus providing important information to give accurate interpretation of land use planning (VASELLI *et al*., 1997), landscape understanding, soil attributes (FU *et al*., 2004; SENA *et al*., 2002; SOUZA *et al*., 2006), behavior as well as its spatial distribution, studies on soil genesis and classification (GOMES *et al*., 2004). Siqueira *et al*. (2010) proposed the use of the soil landscape model and multivariate analysis to identify potentially productive areas in landscape for citrus orchard.

This study aimed to apply multivariate statistical analysis to discriminate between the geomorphic surfaces in a sandstone/ basalt transition located in Pereira Barreto region, São Paulo State, Brazil, in order to support soil assessment over similar areas.

MATERIAL AND METHODS

The study area is located in Pereira Barreto County, northeast São Paulo State, in geographical coordinates of 20°41’15” S latitude and 51°03’45” W longitude. The region has savanna climate (Aw), according to Köppen’s classification, presenting wet summers and dry winters. It lies on a land with relatively low, a plain, and the temperature ranges between 21.2 and 26.8 Celsius degrees (°C) and an annual rainfall of 1.128 millimeters (mm).

The area is currently under transition management from pasture to sugarcane cultivation and includes the geomorphological province of the Western Plateau, with the Latosol predominance distributed downhill on linear and convex profiles.

On the flat hilltop surface, a typical medium texture dystrophic Red Latosol (Haplustox) is found, whose original material proceed mainly from sandstone belonged to *Santo Anastácio* Formation, gradually changes downslope into a clayey texture, Eutroferric Red Latosol (Eutrustox), that is mainly originated from the products of basalt alteration from *Serra Geral* Formation.

A 530 hectares area was mapped using GPS unit device and the geomorphic surfaces were identified and delimited according to criteria proposed by Ruhe (1956) and Daniels *et al*. (1971). Three geomorphic surfaces (I, II and III) were located and mapped (Figure 1). A number of one hundred and thirty-four soil samples were collected from these geomorphic surfaces at 0.0-0.2 m and 0.8-1.0 m depths, in grid shape, to the effect of confirming the occurrence of soil classes.

The soil samples were collected and classified according to criteria established by Embrapa (2006), as typical dystrophic Red Latosol (Haplustox) in geomorphic surface I; typical eutrophic Red Latosol (Eutrustox) in geomorphic surface II; typical eutrophic Red Latosol, typical eutrophic Litholic Neosol (Orthents) and chernozemic eutroferric Red Latosol (Eutrustox) in geomorphic surface III (Table 1 and Figure 1).

Figure 1 - Topographic profile showing the geomorphical surfaces and their respective soil and rock-substratum classes. Soil 1 - Dystrophic Red Latosol (Haplutox - LVd); Soil 2 - Eutrophic Red Latosol (Eutrustox - LVe); Soil 3 - Eutroferric Red Latosol (Haplustox - LVef); Soil 4 - Typical eutrophic Litholic Neosol (Orthents - Rle)

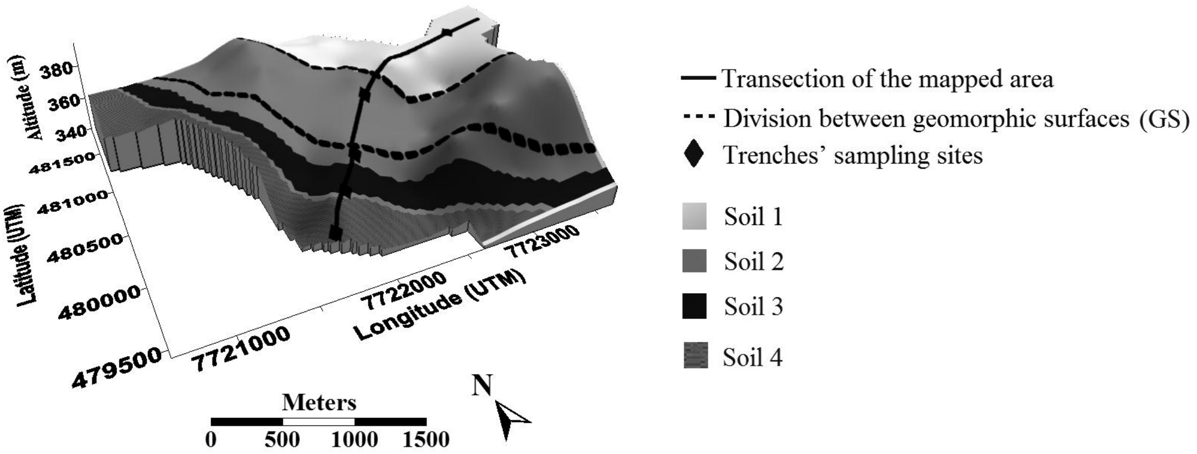


Table 1 - Description of the area soil profiles

Horizon	Depth	Munsell Color scale	Sand	Silt	Clay	pH H_2O	BS	V	OM	Fe_2O_3
	m		g kg^{-1}		cmol$_c$ kg^{-1}	%	g kg^{-1}	g kg^{-1}		
Profile 1 - Dystrophic Red Latosol (Haplutox) - Geomorphic Surface I										
A	0.00-0.32	2.5YR 4/8	777	51	172	4.8	2.4	49	11	33
Bw_2	1.00-1.32	2.5YR 4/8	749	45	206	4.6	0.8	22	4	37
Profile 2 - Eutrophic Red Latosol (Eutrustox) - Geomorphic Surface II										
A	0.00-0.29	2,5YR 4/6	828	34	138	6.1	2.3	56	12	41
Bw_2	0.88-1.29	2,5YR 3/6	688	53	259	5.4	1.7	53	6	57
Profile 3 - Eutrophic Red Latosol (Eutrustox) - Geomorphic Surface III										
A	0.00-0.31	2.5YR 4/8	638	96	266	6.6	4.6	79	14	70
Bw_2	1.02-1.49	2.5YR 4/6	638	71	291	5.9	1.6	52	6	81
Profile 4 - Eutroferric Red Latosol (Haplustox) - Geomorphic Surface III										
A	0.00-0.22	2.5YR 5/6	298	251	451	4.8	6.9	67	31	152
Bw_2	1.07-1.44	2.5YR 4/8	247	234	519	5.7	3.6	69	6	182
Profile 5 - Typical eutrophic Litholic Neosol (Orthents) - Geomorphic Surface III										
A	0.00-0.31	5YR 4/4	325	263	412	6.0	10.4	79	18	172
C	0.31-0.50	5YR 4/4	317	271	412	6.1	8,51	73	22	156

BS - base sum; V - base saturation; OM - organic matter, Fe_20_3 - total ferric iron

Silt, sand and clay contents and also organic matter content were determined by the pipette method according to the Empresa Brasileira de Pesquisa Agropecuária (1997) methodology. Active acidity (pH) was potentiometrically determined in $CaCl_2$ by using a ratio 1:2.5 soil to $CaCl_2$ solution measuring the potential acidity (H+Al), according to Raij *et al*. (2001). Phosphorus (P), calcium (Ca), magnesium (Mg) and postassium (K) were extracted from the soil by an ion-exchanging resin (RAIJ *et al*., 2001).

Using results from samples collected in the different geomorphic surfaces, univariate (ANOVA) and multivariate (MANAVA) analyses of variance were performed conjointly with predefined values for contrast in order to compare them.

The conjoint action of granulometrical (fine and coarse sand, silt and clay) and chemical (pH in $CaCl_2$, P, OM, Ca, Mg, K and H+Al) attributes were also evaluated by multivariate statistics, principal-component analysis and cluster (MORRISON, 1967; SNEATH; SOKAL, 1973) to discrimination the geomorphic surfaces.

The original data were standardized aiming to minimize the effects of the various measuring scales. At this phase, a convertion to normalized scores (distributed, with an average in 0.0 and the standard deviation was 1.0), in order to reach this result it must be subtracted the average and divided by the standard deviation (FERREIRA, 2008).

The principal components analysis, in order to obtain a larger set of linear combination variables, would preserve the most information provided by the original variables (fine sand, coarse sand, silt, clay, pH in $CaCl_2$, P, OM, Ca, Mg, K and H+Al). Due to this, there was a selection of original attributes leading to a smaller set of attributes that had preserved the information from original attributes and reducing the two principal components (PC1 and PC2), through which the identified units were represented in a bi-dimensional graphic. The used criteria in selecting the principal interpreted components was on the percentage of variance explained. According to Carvalho *et al*. (2004) choose the first components that accumulate a variance explained percentage of about 70%. The correlation matrix was composed of 11 variables measured at 67 points. Based on the most important attributes for PC1 at the 0.0 - 0.2 m depth (clay, silt and calcium) and 0.4 - 0.6 m depth (clay fine sand and calcium) the group analysis was used to construct a dendrogram.

The cutoff for the dendrogram which defines the number of groups was obtained by “watching” method, where the researcher specifies the level of grouping for convenience (ALBUQUERQUE, 2005, BARROSO; ARTES, 2003, SNEATH; SOKAL, 1973). It was chosen as the cutoff the mean euclidean distance (4.5). Single linkage cluster was used to obtain other sequential, agglomerative, hierarchical, non-superposed groups expressing the results by means of hierarchical-scheme graphs or dendograms. The similarity coefficient used for cluster analysis (enabling the dendograms design) was the mean Euclidean distance between the studied geomorphic surfaces. The data were processed in Statistica software version 7.0.

RESULTS AND DISCUSSION

The averages of physical and chemical soil attributes located on the three geomorphic surfaces are presented in Table 2. The chemical soil attributes such as pH, calcium, magnesium, and potassium have shown an increasing trend towards the more rejuvenated geomorphic surfaces on transects (geomorphic surfaces III). This reflects the soil source material influence mainly in 0.8-1.0 m depth. Similar results were found by Cunha *et al.* (2005) in sandstone to basalt transition soils.

The soil clay content increases from I to III geomorphic surfaces, which is associated with source material variation and the weathering action emerges as Montanari *et al.* (2010). For the coarse and fine sand means the behavior is, of course, contrary to this trend (Table 2). Anjos *et al.* (1998), while studying the soil genesis and their relationships with the landscape in southeastern Brazil, concluded that geomorphic surfaces define weathering rates and the degree development of *Solum* and the flowing behavior of the water, which coordinate not only the illuviation but also the cations accumulation processes.

When individually analyzed by the univariate analysis of variance (ANOVA) at both depths, the sand and silt attributes have presented the same behavior identified only in two geomorphic surfaces. However, the clay attribute has shown significative differences among those three geomorphic surfaces (Table 3). For the chemical attributes (pH, OM, P, K, Ca, Mg, H+Al), at both depths, there was no clear discrimination between the geomorphic surfaces under study. Therefore, it was not possible to confirm the occurrence of three geomorphic surfaces by using this method (Table 3).

It has been observed that the sand content presented increasing behavior from I to III geomorphic surfaces presenting a sandy texture in Dystrophic Red Latosol (Haplutox) and Eutrophic Red Latosol (Eutrustox) (Table 1). This information has helped in geomorphic surface distinction, since those raised sand contents come from original material, in this case the geomorphic surface I located over the sandstone and the geomorphic surface III over the basalt.

The results from the multivariate analysis of variance (MANAVA) for granulometric attributes (clay, silt, and sand) have presented significant differences among the geomorphic surfaces for all tested contrasts (Table 4) at 0.0-0.2 m and 0.8-1.0 m depths, thus differentiating three environments in agreement with the three previous identified geomorphic surfaces. For chemical attributes, it was observed that, at 0.0-0.2 m depth, there was significant difference for all tested contrasts (Table 4). With regards to 0.8-1.0 m depth, a significant difference was observed for all contrasts, except for GS I vs. GS II contrasts, which did not present significant difference (Table 4).

Table 2 - Average granulometrical and chemical soil attributes in different geomorphic surfaces and soil at 0.0-0.2 m and 0.8-1.0 m depths

Geomorphic Surface	Soil	OM	pH	P	K	Ca	Mg	H+ Al	Clay	Silt	Fine sand	Coarse sand
		g kg^{-2}	CaCl$_2$	------------cmol$_c$ kg^{-1}-------------					-------------------g kg^{-1}-------------------			
Depth (0.0-0.2 m)												
GS I	LVd	15.1	4.8	3.2	0.1	0.9	0.4	2.3	171	100	587	142
GS II	LVe	15.6	5.0	4.1	0.2	1.4	0.7	2.3	184	110	560	146
GS III	LVe	16.7	5.1	4.0	0.2	1.9	0.8	2.2	219	103	529	150
GS III	LVef	19.0	5.1	4.1	0.2	2.6	1.1	2.8	277	83	464	176
GS III	Rle	21.6	5.4	4.3	0.2	3.5	1.7	2.7	389	101	329	181
Depth (0.8-1.0 m)												
GS I	LVd	6.9	5.1	2.3	0.1	1.1	0.4	1.7	217	72	529	182
GS II	LVe	8.7	4.9	2.2	0.1	1.2	0.6	2.1	253	101	497	149
GS III	LVe	8.4	5.2	3.1	0.2	1.8	0.7	1.9	317	111	450	122
GS III	LVef	9.9	5.2	2.8	0.1	2.3	1.0	2.1	374	132	393	101
GS III	Rle	-	-	-	-	-	-	-	-	-	-	-

GS I = Geomorphic Surface I; GS II = Geomorphic Surface II; GS III = Geomorphic Surface III; LVd = Dystrophic Red Latosol (Haplustox); LVe = Eutrophic Red Latosol (Eutrustox); LVef = Eutroferric Red Latosol (Haplustox); Rle = typical eutrophic Litholic Neosol (Orthents)

Table 3 - The univariate analysis of variance (ANOVA) of granulometric and chemical soil attributes on different geomorphic surfaces at 0.0-0.2 m and 0.8-1.0 m depths

	-----Physical Attributes----			------------------------------Chemical Attributes-----------------------						
Geomorphic Surfaces	Sand	Clay	Silt	pH	OM	P	Ca	Mg	K	H+Al
		g kg^{-1}			g kg^{-1}	mg kg^{-1}		cmol$_c$ kg^{-1}		
Depth (0.0-0.2 m)										
I	777 a	154 b	69 b	4.9 b	14.5 b	3.7 a	11.6 b	5.9 b	1.9 a	21.6 b
II	688 a	213 b	99 b	5.0 a	16.2 b	3.8 a	17.3 b	7.6 b	2.3 a	24.5 ab
III	460 b	362 a	178 a	5.3 a	22.1 a	4.4 a	36.3 a	15.9 a	2.6 a	27.5 a
Depth (0.8-1.0 m)										
I	692 a	225 b	83 b	4.9 b	7.9 b	2.2 b	10.5 b	4.2 b	0.6 b	0.7 a
II	582 a	309 b	109 ab	5.0 a	8.5 b	2.7 b	17.1 ab	6.3 ab	0.9 b	0.6 a
III	384 b	448 a	168 a	5.4 a	10.4 a	3.1 a	28.4 a	15.6	1.3 a	0.0 b

GS I = Geomorphic Surface I; GS II = Geomorphic Surface II; GS III = Geomorphic Surface III; Means in the same column followed by the same letter do not differ among them by Tukey's test at 5% significance level

Table 4 - The p-values from the multivariate analysis of variance (MANAVA) tests regarding to soil granulometric (fine sand, coarse sand, silt e clay) and chemical attributes (pH in $CaCl_2$, P, OM, Ca, Mg, K and H+Al) on different geomorphic surfaces at 0.0-0.2 m and 0.8-1.0 m depths

Contrasts	----------------Physical Attributes----------------				-------------Chemical Attributes---------------			
	Wilks	Pillai's Trace Test	Hotelling Lawley's race Test	Roy's Maximum Root	Wilks	Pillai's Trace Test	Hotelling Lawley's race Test	Roy's Maximum Root
Depth (0.0-0.2 m)								
GS I vs. GS II	0.0005	0.0005	0.0005	0.0005	0.0025	0.0025	0.0025	0.0025
GS I vs. GS III	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
GS II vs. GS III	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Depth (0.8-1.0 m)								
GS I vs. GS II	0.0005	0.0005	0.0005	0.0005	0.2149	0.2149	0.2149	0.2149
GS I vs. GS III	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
GS II vs. GS III	<.0001	<.0001	<.0001	<.0001	0.0041	0.0041	0.0041	0.0041

GS I = Geomorphic Surface I; GS II = Geomorphic Surface II; GS III = Geomorphic Surface III; $p < 0.05$ significant at 5%; $p < 0.01$ significant at 1%; $p > 0.05$ non significant

According to Webster and Oliver (1990) in the MANAVA analysis are used statistical tests with multiple variables to investigate the likehood ratio test of the hypothesis (Wilks) or null hypothesis of no treatment effects (Roy, Hotelling-Lawley e o de Pillai). The tests differentiate themselves due to the used criteria to evaluate the treatments' diference: trace (Hotelling-Lawley e Pillai) and largest root (Roy e Wilks), being Wilks' test the most used in multivariate analysis of variance. These tests results have shown that multivariate analysis, independent of the used test, it is more efficient in distinguishing landscape compartments than the univariate statistics (YEMEFACK *et al*., 2005).

In the pedological assessment, univariate statistical criteria are usually used in order to establish taxonomic limits in the discrimination and separation of soil classes. For Hudson (1992) and Young and Hammer (2000), these taxonomically pre-established limits are considered to be artificial. On the other hand, the cluster strategy based on multivariate statistics allows for more complete information concerning soils distinction in the conceptual sense of the natural body (CUNHA *et al*., 2005; YOUNG; HAMMER, 2000).

The results of the grain and chemical attributes analysis, main components at 0.0-0.2 m 0.8-1.0 m depths are presented in Table 5. The first principal component can be interpreted as a physical and chemical quality index of environment. Thus, PC1 and PC2, together, explain 74.77% of the total variance in 0.0-0.2 m depth and 67.67% of the total variance in 0.8-1.0 m depth (FIG. 2). Sanchez-Maranón *et al.* (1996) and Splechtna and Klink (2001) found similar results working with the same soil attributes, mention that PC1 and PC2 explain about 60% of the total soil variation.

In the 0.0-0.2 m depth, attributes that most contributed to the first component (PC1) were: clay, silt and calcium, and in the 0.8-1.0 m depth, the attributes of greatest contribution to PC1 were: sand, calcium and clay (TAB. 4). There was a negative correlation between the attributes of fine and coarse sand with PC1. Manlay *et al.* (2000), studying the relationships among the soil abiotic factors has also observed a negative correlation for the sand fraction. Thus, the attributes of greatest influence on the surface and subsurface horizons were calcium and clay, corroborating to the results found by Motta *et al.* (2002b), whom had studied the occurrence of "macaúba" (a native Brazilian palm) in Minas Gerais State and its attributing relationship with soil and vegetation.

Figure 2 - Projection of soil and greatest importance attributes for PC1 in 0.0-0.2 m depth (a) and 0.8-1.0 m depth (b). GS = Geomorphic surfaces; LVd = Dystrophic Red Latosol (Haplutox); LVe = Eutrophic Red Latosol (Eutrustox) ; LVef = Euetroferric Red Latosol (Haplustox); Rle = typical eutrophic Litholic Neosol (Orthents)

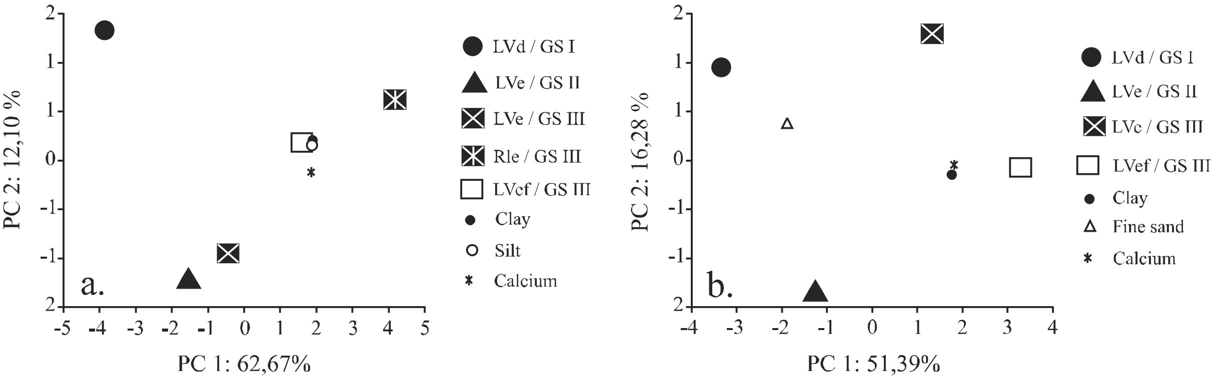


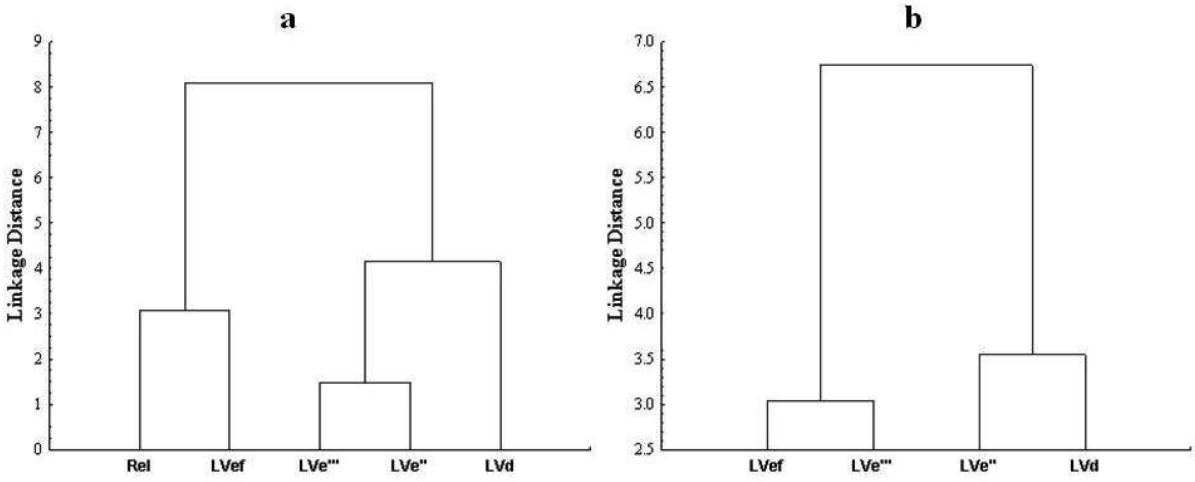
Table 5 - Correlation of soil attributes between the first two principal components and classification of attribute scores according to their contribution

Attributes	PC1	PC2	Ranking[1]	PC1	PC2	Ranking
	Depth (0.0-0.2 m)			Depth (0.8-1.0 m)		
OM	0.797	0.276	7	0.599	0.514	7
pH	0.801	-0.416	6	0.720	-0.605	6
Available P	0.359	-0.519	11	0.483	-0.154	10
K	0.524	-0.563	10	0.577	0.333	9
Ca	0.940	-0.058	2	0.904	-0.157	2
Mg	0.929	-0.081	4	0.792	0.230	5
H + Al	0.566	0.660	9	0.079	0.928	11
Clay	0.948	0.109	1	0.878	-0.201	3
Silt	0.936	0.080	3	0.866	0.193	4
Fine sand	-0.923	-0.053	5	-0.945	0.104	1
Coarse sand	-0.727	-0.171	8	-0.586	-0.005	8
Autovalue	6.90	1.33		5.65	1.79	
Cumulative variance explained (%)	62.67 /	74.77	-	51.39	67.67	-

[1] = Classification of attributes in terms of contribution to the construction of the PC 1 vector

The Figure 3 confirms the relationship among the (classification) of different land classes, when located within the same geomorphic surface. Analyzing the correlation values of clay, silt and calcium attributes (TAB. 5) with the PC1 axis (FIG. 2a), it can be observed that the soils located to the right of these attributes are soils developed from basalt. This same pattern occurred in 0.8-1.0 m depth. Ogg *et al.* (2000) has mentioned that the groups follow the occurrence logic in the landscape. In this study, the soil occurrence logic follows the pattern of geomorphic surfaces.

Figure 3 - Dendrograms of the soil classes built based on attributes of greater relevance to PC1 in 0.0-0.2 m depth (a) and 0.8-1.0 m depth (b). Geomorphic surfaces I (LVd = Dystrophic Red Latosol - Haplustox); Geomorphic surfaces II (LVe” = Eutrophic Red Latosol - Eutrustox); Geomorphic surfaces III (LVe’” = Eutrophic Red Latosol; LVef = Eutrophic Red Latosol - Haplustox; Rle = typical eutrophic Litholic Neosol - Orthents)



The results of cluster analysis are demonstrated in Figure 5. Groups created based on the three most important attributes for PC1 (Table 2) validated the limit classification of soil natural bodies in the landscape (HUDSON, 1992), because the boundaries of these bodies concur with the geomorphic surfaces boundaries mapped in the field. Webster and Oliver (1990) confirm the effectiveness of cluster analysis when examining and separating classes of geomorphic surfaces and soil incorporated within these areas.

According to Fu *et al.* (2004), the idea that the multivariate statistic allows the viewing of variability within a minimal group and maximum variability among groups is applied in this study. In studying the relationship between topography and plant diversity, by means of multivariate statistics, it was observed that the landscape allowed the distinction of groups with different variability.

Analyzing the clusters, it was observed that within a Euclidean distance of 4.5 there was an even number of groups in the 0.0-0.2 m depth (Figure 3a) and in 0.8-1.0 m depth (Figure 3b). This indicates a consistency in both depths, reinforcing the concept of Latosol (Oxisol) concerning the homogeneous depth distribution of clay (EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA, 2006).

According to Adams *et al*. (1992), cluster analysis in soil studies favors the organization of similarity degree; therefore, its use is also indicated for taxonomic purposes. According to Young and Hammer (2000), a more detailed soil study using cluster analysis may show important pedological relations that are not apparently observed when pedons are classified separately in the landscape.

Consequently, soils of the same class when located in different geomorphic surfaces should present different characteristics. Similar results were observed by Young and Hammer (2000) performing a study on the soil positions within the landscape, using cluster analysis. These results are interesting in order to demonstrate the feasibility of using numerical classification of geomorphic surfaces to assist the soil mapping or other technical surveys based on soil taxonomy. Hence, this knowledge may help future work in the identification of boundaries among soil classes collected at different scales (BORUJENI *et al*., 2009) or reduce the forecasting taxonomic errors (MINASNY; MCBRATNEY, 2007).

CONCLUSIONS

1. The individual mean test comparison of the soil attributes were not efficient to discriminate the three mapped geomorphic surfaces;
2. The use of multivariate statistical techniques (cluster and principal component analysis) enabled the separation of three groups of soil natural bodies that were equivalent to the mapped geomorphic surfaces;
3. The identification of geomorphic surfaces should be used to assist in soil surveys in order to better map the precise boundaries between different soil types or areas with different patterns of soil attributes.

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