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Quality indices in degraded pasture in hilly relief

Indicadores de qualidade de pastagens degradadas sob condições de relevo acidentado

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Abstract

Due to the influence of relief on soil variability, homogenous pedogenetic conditions have been recommended for developing soil quality indices based on their chemical, physical and biological attributes. This limits the development and application of an index to the same pedoenvironment in hilly relief. The present work aimed to evaluate the soil coverage and soil chemical and physical attributes as indicators of quality related to visual aspects of pasture degradation and contextualizing the influence of the relief. For this purpose, degradation levels were separated from visual aspects, and soil coverage as well as soil chemical and physical attributes were evaluated. Such levels were less subjectively defined, with the discriminant functions generated using information from soil coverage. Factor Analysis showed that altitude and slope explain a lower proportion of the total variation of the data. On the other hand, slope variations control the majority of soil attribute variations, especially the physical attributes that do not present a clear and direct relationship with degradation levels, which makes it difficult to use these attributes as indicators of quality. This relationship with the soil attributes is differentiated mainly as a function of the sun-facing slope: on the East/South facing slope, a greater relationship was observed for the physical attributes and plant cover, which was not observed on the West/North facing slopes. The influence of hilly relief on controlling solar radiation and soil moisture modifies the soil-vegetation relationship dynamic. As such, on hilly relief the measure of plant cover and use of discriminant functions becomes a more efficient way to discriminate among degradation levels, with environmental factors (temperature, solar radiation and soil moisture) also influencing pasture quality.
Key words: Soil coverage, chemical and physical attributes of soil, multivariate analysis, soil degradation

Resumo

Devido à influência do relevo na variabilidade do solo, condições pedogenéticas homogêneas têm sido recomendadas para desenvolvimento de índices de qualidade do solo baseados em seus atributos químicos, físicos e biológicos. Tal fato limita o desenvolvimento e aplicação de um índice para um mesmo pedoambiente de relevo mais acidentado. O presente trabalho teve como objetivo avaliar a cobertura do solo e atributos químicos e físicos do solo como indicadores de qualidade relacionando-os com aspectos visuais de degradação das pastagens e contextualizando a influência do relevo. Para tanto, separaram-se níveis de degradação a partir de aspectos visuais, avaliou-se a cobertura do solo,

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atributos químicos e físicos do solo. Tais níveis foram definidos de forma menos subjetiva a partir das funções discriminantes geradas utilizando-se informações da cobertura do solo. Pela Análise de Fatores observa-se que altitude e faces de exposição ao sol estão relacionadas à explicação de uma menor proporção da variação total dos dados. Em contrapartida, a declividade controla a maior parte da variação dos atributos do solo, principalmente os físicos que não apresentaram uma relação direta e clara com a cobertura do solo e com níveis de degradação dificultando o uso desses atributos como indicadores de qualidade. Essa relação com os atributos dos solos se diferencia principalmente em função da face de exposição: na face Leste/Sul observa maior relação dos atributos físicos com a cobertura vegetal, diferentemente na face Oeste/Norte. De fato, a influência do relevo no controle da intensidade de insolação e da umidade do solo modifica a dinâmica da relação solo-vegetação. Assim, a mensuração da cobertura vegetal e uso de funções discriminantes torna-se, em relevo mais acidentado, uma forma mais eficiente na discriminação entre níveis de degradação, ponderando adicionalmente a influência de fatores do ambiente (temperatura, intensidade de insolação, umidade do solo) na qualidade das pastagens.

Palavras-chave: Cobertura do solo, atributos químicos e físicos do solo, análise multivariada, degradação do solo

Introduction

Soil quality indicators should be sensitive in identifying different degradation levels and these indicators must reflect a specific soil function, with these indicators being particular for each region (DORAN; PARKIN, 1994; KARLEN et al., 1997). In pastures, biomass production from livestock becomes the principal soil function and the principal objective of developing soil quality indices. Swanepoel et al. (2014) found the most sensitive indicators for monitoring pasture production in South Africa are available P, gravel content and available water capacity. In the Alps, pasture production is regulated by the presence of urease, microbial nitrogen and soil organic carbon (LI et al., 2013). In Ireland the decrease in pasture productivity with increased intensity of land use was directly related to the decrease of total organic carbon (TOC) and total nitrogen (TN), as well as an increase in the C:N relationship and soil density (ASKARI; HOLDEN, 2014). Among different types of pasture management in the Cerrado, soil density, total porosity and mechanical resistance to penetration were most affected by intensity of land use, while chemical attributes were little affected (PIGNATARO NETTO et al., 2009). Microbial carbon was the attribute most sensitive to changes related to different types of pasture management in the Pantanal (CARDOSO et al., 2009). Among biological indicators of soil fertility, the microbial biomass attribute was the best indicator of pasture quality in western of São Paulo state (VICENTE; ARAUJO, 2013).

Additionally to soil attributes, visual aspects, such as those used by Spain and Gualdrón (1988), are widely used in studies of degraded pastures (SOUZA et al., 2010; SILVA NETO et al., 2012) despite some subjectivity. On the other hand, the quantitative measurement of soil covering the field as the presence of bare soil or invasive plants make evaluations of pasture quality less subjective. Additionally, soil coverage presents a direct relationship with the soil quality indicators as demonstrated by Costa et al. (2000). The influence of hilly relief on the soil attributes and plant cover limits the development of soil quality indicators used to monitor incorrect soil management, since the relief may enhance soil degradation. Moreover, hillier conditions may influence temperature variation, the presence of water in the soil and solar radiation, consequently affecting the soil-vegetation relationship. This makes it difficult to evaluate the relationship between soil quality indicators and pasture biomass production for constructing a soil quality index applicable to regions of hilly relief.

Soil quality indicators have strong relationships with soil formation factors, e.g. relief, climate and geology. According to Norfleet et al. (2003), studies of soil quality indicators should consider the influence of pedological processes. Studies show that the influence of soil attribute variability on the landscape makes it difficult to evaluate the relationship between soil quality indicators and disturbances due to management (EMMERLING; UDELHOVEN, 2002; LENTZSCH et al., 2005; ZORNOZA et al., 2007). Reducing this variability using homogenous pedogenetic conditions has been recommended for developing pedogenetic quality indices (TRASAR-CEPEDA et al., 1998). These conditions however limit the use of the quality indices across a wide range of soil environments, making them disadvantageous and limiting their use in regions of hilly relief in southern Espírito Santo State. This region has higher soil variability, from the hydrographic basins to toposequence scales.

Within this context, the following objectives are outlined: a) to relate soil coverage evaluated by the line transect method with pasture degradation levels based on visual aspects; b) to select soil attributes that best distinguish the different pasture degradation levels to contextualize the influence of the slope, altitude and different sun-facing slopes; c) to relate soil coverage and degradation levels with soil attributes to evaluate their performance as quality indicators.

Materials and Methods

Region of study and sample collection

The study area represents the sub-basin of the Alegre river (Basin of the Rio Itapemirim) Alegre municipality, Espírito Santo State, Brazil, located in the Mares de Morro region. The climate is Cwa by the Koppen classification, characterized by dry winter and rainy summer. Samples were collected for 20 days during fall/winter. Using the digital elevation model and soil information from previous studies, pedogenetically representative areas were selected within the studied sub-basin, delineated between altitudes of 118 and 400 m; 400 and 700 m and 700 and 1242 m, collected on two opposite-facing slopes (East/South and West/North) and on slopes varying from 22 to 62 %. Latosol samples were collected under convex slope.

Degradation levels and soil coverage

In the study area, pastures with extensive livestock systems were selected and different degradation levels were evaluated according to Spain and Gualdrón (1988). Eighteen sampling points were selected with varying degrees of degradation: light (3 areas – pastures with vigor and quality – abundant green mass), moderate (6 areas – pastures with less vigor and lower quality – little abundance of green mass), strong (6 areas – marked by the presence of invasives) and very strong (3 areas – marked by the presence of bare soils, the presence of ants/termites and signs of erosion). Soil samples were collected in the 0.0-0.10 and 0.10-0.20 m layers.

Soil coverage evaluation was carried out in the field by the line transect method proposed by Olszevskiet al. (1998) and cited by Costa et al. (2000) to estimate pasture degradation within the selected areas. The line transect method uses the association of linear methods and the point-frame method of sampling range vegetation to determine botanic composition and soil cover. An area of approximately 50 x 50 m was delineated with 10 repetitions for each area and the relative frequencies of bare soil, Brachiaria (current botanic classification *Urochloa*), weedy plants and mulching were recorded and expressed as percentages.

Soil attributes

For all chemical and physical attributes of the soil texture (coarse sand, find sand, silt and clay) and clay dispersed in water (CDW), five samples were collected by obtaining a composite sample. Undeformed samples were used for the soil physical indicators of soil density, particle density, total porosity, soil water content at field capacity at a tension of 10 kPa and at the permanent wilting point at a tension of 1500 kPa. Soil blocks were collected for aggregate analysis by wet sieving using Yoder equipment.

The following chemical analyses were done on the soils: exchangeable Al^{3+}, $Ca^{2+}$and Mg^{2+} and available K and P, according to EMBRAPA (1997). Total organic carbon (TOC) was quantified by wet oxidation of the organic material with $K_2Cr_2O_7$ 0.167 mol L^{-1} in a sulfuric medium (YEOMANS; BREMNER, 1988). Total nitrogen (TN) was quantified by means of sulfuric digestion followed by Kjeldahl distillation, according to EMBRAPA (1997). The remaining phosphorous (P-REM) was determined according to Alvarez et al. (2000).

For granulometric analysis (fractions of coarse sand, fine sand, silt and clay) slow agitation (50 rpm) was used with a chemical dispersant (NaOH, 0.1 mol L^{-1}). Clay dispersed in water (CDW) was obtained without dispersant, and the degree of flocculation (DF) was calculated from this (EMBRAPA, 1997). For the undeformed samples in the 0.0-0.10 m layer soil density (SD) by the volumetric ring method, total porosity and volumetric moisture of the soil at field capacity at a tension of 10 kPa (FC) and at the permanent wilting point at a tension of 1500 kPa (PWP) using the porous plate extractor were determined (EMBRAPA, 1997). For aggregate analysis via wet separation, mean weight diameter of soil aggregates (MDW) was calculated according to Kemper and Rosenau (1986).

Statistical analyses

Descriptive analyses of the soil coverage and chemical and physical attributes were done using the mean, the coefficient of variation and the 10^{th} and 90^{th} percentiles. The homogeneity of variance and normal distribution by the Bartlet and Kolmogorov-Smirnov tests are evaluated and variables are transformed (logarithmic and quadratic roots transformations) when these assumptions are violated. Such transformations were necessary for the means test by analysis of variance (ANOVA) and the Tukey test. Pearson correlations were used for the variables adjusted to normal distribution and Spearman correlation (non-parametric test) when such adjustments did not occur.

For use of Discriminant Analysis (DA), the visually separated degradation levels were established as dependent variables (categories) and the soil coverage frequencies (bare soil, pasture, mulching and invasive plants) expressed as percentages were used as independent variables. For both, the data were evaluated as the linearity, multivariate normal distribution and homogeneity of the covariance matrices with the SAS® program (SAS, 2000). DA is comparable to multivariate analysis of variance with the advantage of better quantification of the relationship of the dependent and independent attributes and enabling the use of the DA scores for other interpretations (HAIR et al., 2009).

Canonical Discriminant Analysis (CDA) was carried out. This is a data dimensionality reduction technique that aims to obtain a lower number of new variables (canonical variables), which can help with maximum discrimination of the different groups (KHATTREE; NAIK, 2000). In this way, the contributions of the explanatory variables may be better interpreted in the group discrimination process. Additionally, the scores attributed to canonical discriminant functions were used to compare means by ANOVA to compare opposite-facing slopes and Pearson correlations related to slope. In this way, the influence of relief on the discrimination process may be evaluated.

Fisher's linear discriminant functions were generated using the original variables, which made it easier to classify new individuals within the established groups as dependent variables (categories). The discriminant functions are linear combinations of the original variables where the coefficients of the function corresponding to each variable (bare soil, pasture, mulching and invasive plants) are calculated to minimize within-group variation (categorical variables) and maximize between-group variation in the DA (HAIR et al., 2009). The efficiency of the discriminant function in the prediction was evaluated by the percentage of classification errors of the discriminant functions using the cross validation method. A table was generated with the percentage of correct and incorrect classifications, from which the predictive capacity of the functions was measured. DA was done by the PROC DISCRIM procedure in the SAS® program (SAS, 2000) licensed by the Universidade Federal de Viçosa.

Factor Analysis was carried out using the principal component method to select groups of variables that best explain the total variance of the data (HAIR et al., 2009). Factors were rotated by the Varimax method. Variables with redundant information or that resulted from linear combinations of other variables (e.g. effective cationic exchange capacity and sum of bases) were removed. Logarithmic transformations and quadratic roots were used for variables without normal distribution. Calcium and Mg content were evaluated together with multivariate statistics due to their high collinearity. The scores attributed to each sample within each factor of Factor Analysis were used to compare opposite-facing slopes by ANOVA and evaluate the relationship with slope and altitude by Pearson correlation. Tukey tests were done to compare scores among degradation levels separated by visual aspects. In this way the variation retained in the factors was evaluated to see if it was related to the relief or degradation levels. Factor Analysis was done by the PROC FACTOR procedure in the SAS® program (SAS, 2000), licensed by the Universidade Federal de Viçosa.

Results

Descriptive Analyses

Descriptive analyses of soil coverage and soil attributes are presented in tables 1 and 2. With respect to soil coverage (Table 1), brachiaria was predominant, followed by bare soil, indicating that all studied pasture areas presented some level of degradation and optimal pasture conditions were not found.

Table 1. Descriptive analyses of the frequency of soil coverage variables.

Variable	Mean	CV[1] %	Percentile th	
			10	90
Bare soil (%)	25.19	52	7.1	41.0
Mulching (%)	16.70	77	2.5	38.2
Brachiaria (%)	44.23	44	19.8	70.5
Invasives (%)	6.92	119	0.0	20.5

[1] Coefficient of variation.

Table 2. Descriptive analyses of soil attributes in the 0 – 0.1 and 0.1 – 0.2 m layers.

Attributes(1)		Mean	CV %	Percentile 10 th	Percentile 90 th	Mean	CV %	Percentile 10 th	Percentile 90 th
		0 – 0.1 m				0.1 – 0.2 m			
P	mg dm^{-3}	1.29	35	0.90	2.10	0.94	21	0.70	1.30
K	mg dm^{-3}	46	76	16	102	27	94	9	80
Ca	cmol$_c$ dm^{-3}	0.89	101	0.00	2.22	0.66	105	0.00	1.73
Mg	cmol$_c$ dm^{-3}	0.61	90	0.06	1.39	0.43	101	0.03	1.05
Al	cmol$_c$ dm^{-3}	0.60	104	0.00	1.21	0.73	81	0.00	1.40
PREM	mg L^{-1}	24	45	12	41	14	41	10	37
TOC	g kg^{-1}	17.5	29	11.3	28.4	0.11	25.1	8.2	24.1
TN	g kg^{-1}	0.13	18	0.10	0.18	0.11	51	0.07	0.15
SD	mg m^{-3}	1.41	10	1.23	1.60	1.31	14	1.04	1.51
TP	m^3 m^{-3}	0.42	13	0.33	0.47	0.48	14	0.39	0.59
CS	dag kg^{-1}	33	24	24	47	31	27	20	41
FS	dag kg^{-1}	12	25	9	17	11	20	9	15
SI	dag kg^{-1}	11	24	7	15	12	34	8	17
CLA	dag kg^{-1}	43	20	32	54	44	19	33	57
CDW	dag kg^{-1}	11.3	26	8.0	17.0	10.5	45	3.0	16.0
DF	%	73	10	64	84	75	16	62	92
FC	m^3 m^{-3}	0.35	13	0.27	0.39	0.33	13	0.28	0.40
PWP	m^3 m^{-3}	0.27	13	0.23	0.33	0.23	18	0.18	0.30
MWD	mm	2.63	7	2.31	2.82	2.63	7	2.30	2.87

(1) P – phosphorous extracted by Mehlich-1; K – potassium extracted by Mehlich-1; Ca, Mg and Al – Ca, Mg and Al contents extracted by KCl 1 mol L^{-1}; TOC – total organic carbon; TN – total organic nitrogen by the Kjeldahl method; PREM – remaining phosphorous; SD – soil density; TP- total porosity; CS – coarse sand content; FS- fine sand content; SI- silt content; CLA – clay content; CDW- content of clay dispersed in water; DF – degree of flocculation; FC – field capacity moisture content; PWP – moisture at the permanent wilting point; MWD – mean weight diameter of soil aggregates.

Available P and K content were classified at a low soil fertility level (PREZOTTI et al., 2007), considering the mean (Table 2). Few samples (90th percentile) were framed at the medium fertility level for K. Mean Ca contents were classified as low level and their 90th percentile was classified as medium level. Magnesium contents were classified as medium level (mean) and high fertility (90th percentile) (PREZOTTI et al., 2007). Transformed data of Ca, Mg and Al contents were used for statistical analyses because of the high coefficients of variation. Mean TOC and TN content were low in the soils studied, with few samples reaching values higher than 20 g/kg (Table 2). In general, the chemical attributes of the soil were less than ideal for adequate pasture growth.

The mean soil density (1.4 kg dm^{-3}) was at the maximum limit considered critical for plant growth in clayey to very clayey soils (RESENDE, 1995) (Table 2). The majority of the soils were highly weathered, reflecting high clay contents with an elevated degree of flocculation. In these conditions, elevated water retention at permanent wilting point (PWP) and mean weight diameter of soil aggregates (MWD) were observed.

Degradation level discrimination and soil coverage

The performance of the classification using Fisher's linear discriminant function (Table 3) indicated that intermediate degradation levels were misclassified. For example, 45% of the samples identified in the field at the moderate degradation level were classified by the discriminant function as strong degradation level and 35% of the samples identified in the field at the strong level degradation were classified as moderate by the discriminant function. There is greater ambiguity between the moderate and strong degradation levels as a consequence of the difficulty in visually differentiating the fields. As such, three degradation levels were established, with the moderate and strong levels combined in a single level (moderate to strong) to achieve greater precision in the following discriminant analyses (Table 4).

Table 3. Correct and incorrect classifications of the four levels of predicted degradation by the discriminant functions from the plant cover frequencies.

Level	Classification by discriminant function				% classifications correct
	Light	Moderate	Strong	Very strong	
Light	100	0	0	0	100
Moderate	5	35	45	5	35
Strong	5	35	50	10	50
Very strong	0	20	10	70	70

Table 4. Results of the explained variation, eigenvalues and canonical correlation of the canonical discriminant functions generated and discriminant loadings of the variables used. Pearson and ANOVA correlation of the scores of the discriminant functions using three degradation levels.

Model parameters		
	CDF_1	**CDF_1**
Explained variation	0.90	0.10
Eigenvalues	1.41	0.03
Canonical Correlation	0.78	0.37
	Discriminant Loadings	
Variables	**CDF_1**	**CDF_2**
Bare soil	**0.74**	0.08
Mulching	**0.64**	0.27
Brachiaria	**-0.66**	-0.46
Invasives(2)	-0.09	**0.97**
Pearson Correlation — Discriminant Scores	**CDF_1**	**CDF_2**
Slope	0.23	0.36
Altitude	0.10	-0.21
ANOVA – Discriminant Scores – Opposite-facing slopes	**CDF_1**	**CDF_2**
East/South facing slope	-0.54	-0.092
West/North facing slope	0.54	0.092
F	0.991	0.165
P-value	0.372	0.704

(1) bold – moderate and strong discriminant loading (>0.50) (HAIR et al., 2009) (2) Transformed data (% invasives + 0.5)$^{0,.5}$.

For Canonical Discriminant Analysis (CDA) (Table 4), the first canonical discriminant function (CDF_1) explained 90% of the variation of the two generated functions. The second function (CDF_2) contributed little (10%) to degradation level discrimination. In CDF_1, an elevated contribution of bare soil followed by brachiaria and mulching was observed according to the discriminant loading values (Table 4). In CDF_2 a low proportion of explained variation was correlated with the presence of invasive plants showing that visual separation of the degradation levels was less efficient using this variable (Table 4). Pearson correlations of the scores with slope and altitude, as well as ANOVA not being significant between different sun-facing slopes, shows that the relief has little relation to the groups separated by CDA. The evaluations were made more precise using three degradation levels since the percentage of classification using Fisher's linear discriminant function (Table 5) reached a value above 67 % when the moderate and strong degradation levels were joined in a single level (moderate to strong).

Table 5. Correct and incorrect classifications of the three levels of predicted degradation by the discriminant functions from the frequencies of plant cover.

Level	Classification by discriminant function			% classifications correct corretas
	Light	Moderate	Strong	
Light	100	0	0	100
Medium to strong	7.5	67.5	25.0	67.5
Very strong	0	10.0	80	80.0

To classify the degradation level of new samples in the study area based on the concepts of Spain and Gualdrón (1988) the classification coefficients of the discriminant function in Table 6 may be used. From these functions that are associated to the different degradation levels (light, moderate to strong and very strong), the pasture level found was evaluated by calculating the scores. The means among the three levels of degradation established by the soil coverage indicate that from the lowest to highest degradation levels, the frequency of bare soil and mulching increased and the frequency of brachiaria decreased (Table 7). The presence of invasives was greatest at the intermediate degradation level ($p<0.05$) (moderate to strong) in accordance with the concepts of Spain and Guáldron (1988) in which a strong degradation level was characterized by the significant invasive presence in the pasture.

Table 6. Coefficients of Fisher's linear discriminant function for classification at light, moderate to strong and very strong degradation levels(1) from the frequency (in percentage) of plant cover.

Cover attribute	Light	Moderate to strong	Very strong
Bare soil	0.497	0.732	0.855
Mulching	0.387	0.598	0.704
Brachiaria	0.415	0.407	0.444
Invasives (2)	0.596	1.032	0.606
Constant	-17.618	-24.690	-31.375

(1) Example: Sample 1 (4.7% bare soil, 5.4 % mulching, 79.8 % brachiaria, 6.14 % invasives). Calculated from the scores of sample 1 – Light = 23.41; Moderate to strong = 20.04; Very strong = 16.84. Classification result – light degradation level. Sample 2 (45.4 % bare soil, 41 % mulching, 24.9 % brachiaria, 5.89 % invasives). Calculated from the scores of sample 2 – Light = 32.6; Moderate to strong = 45.8; Very strong = 48.9. Classification result – very strong degradation level (2) Transformed data (% invasives + 0.5)$^{0.5}$.

Table 7. Means test [1] on soil coverage variables among different degradation levels on the area studied.

Variable	Degradation levels [2]		
	Light	Moderate to strong	Very strong
Bare soil (%)	9.60 c	26.1 b	36.4 a
Mulching (%)	3.17 a	19.2 b	24.2 b
Brachiaria (%)	68.0 a	39.9 b	35.3 b
Invasives[2] (%)	0.89 a	2.44 c	1.73 b

[1] Comparison of means for unequal samples by the Tukey Post-Hoc test significant at 5% probability. [2] Means test done with transformed data $(\% \text{ invasives} + 0.5)^{0.5}$.

Influence of relief on soil attributes and degradation level definitions

To better evaluate the attributes of greatest variation and that best distinguish the different degradation levels, Factor Analysis was done (Tables 8 and 9). In this way the most promising variables or group of variables for separating different degradation levels may be selected by their higher variance in the studied area. Diverse works have used multivariate statistics with the aim of selection of more efficient soil attributes as soil quality indicators to separate different degradation levels or for management of the studied areas (SHUKLA et al., 2006; LIAO; CHANG, 2005; NOSRATI, 2013).

The first four factors explained 87.4 % of the total variability of the data in the 0- 0.1 m layer and 90.4% of the total variability of the data in the 0.1 – 0.2 m layer (Tables 8 and 9) and presented autovalues higher than 1 (Table 8). Additionally, high communality values were obtained for the four first factors, with these parameters being sufficient for summarizing the information of the set of variables with the most information and the lowest number of factors (HAIR et al., 2009). The attributes with strong discriminant loadings among the Factors that present significant differences among degradation levels were selected for evaluating soil quality indicators.

In the 0.0 – 0.1 m layer, Factor 1 (F1) had a strong factorial loading attributed to the physical attributes CS, CLA, FC, PWP, TP and SD, as well as the TOC and TN contents (Table 8). This factor may represent the variations in texture and organic material of the soil. The positive correlations of CLA, C and TN and negative correlation of CS suggested the influence of the clay fraction as being most active in protecting organic material (VICENTE; ARAUJO, 2013, JAYAGANESH; SENTHURPANDIAN, 2010). The positive correlation of the variables CLA, FC and PWP and negative correlation of the variables CS and SD with F1 indicates that the texture controls attributes related to the soil water properties, so that higher coarse sand content (CS) decreases moisture at field capacity (FC) and the permanent wilting point (PWP). The slope showed highly significant Pearson correlation with F1 scores. The correlation of altitude and F1 scores was not significant and the ANOVA test comparing the opposite-facing slopes showed a greater influence of slope on the CLA, CS, FC, PWP, TP, SD, TOC and TN variables: steeper slopes increased coarse texture sand content and total porosity and decreased organic material content (Table 8).

The attributes Al, FS, CDW and GF were strongly correlated with Factor 2 (F2) which presents negative correlation with altitude ($p<0.021$) and highly significant difference between the F1 scores attributed to opposite-facing slopes (ANOVA, $F=25.3$; $p<0.0001$) (Table 8). This indicates that these attributes, despite being related by altitude, are strongly controlled by the solar radiation: at lower altitudes the values of clay dispersed in water will be higher, with lower Al and GF content, principally on the East/South-facing slope.

Table 8. Factorial loadings [(1)] of the soil attributes, eigenvalues and variance explained by the factors after the orthogonal Varimax rotation method, ANOVA statistics and Pearson correlations on the scores in the 0 – 0.1 m layer.

Attributes[(2)]	Factor 1	Factor 2	Factor 3	Factor 4	*Communality*
P	-0.16	-0.04	**0.82**	-0.18	0.54
K[(3)]	-0.21	*0.57*	*-0.66*	0.29	0.79
CaMg[(3)]	*-0.68*	*0.65*	-0.04	0.13	0.82
Al[(3)]	*0.50*	**-0.75**	0.02	-0.20	0.73
TOC	**0.84**	-0.37	0.28	0.06	0.85
NT	**0.83**	0.01	0.32	0.12	0.65
PREM	-0.46	*0.63*	*-0.59*	0.03	0.92
SD	**-0.84**	0.29	-0.23	0.19	0.77
TP	**0.81**	-0.31	-0.15	-0.32	0.77
CS	**-0.83**	0.19	0.37	-0.21	0.82
FS	-0.38	**-0.84**	-0.22	-0.31	0.99
SI	0.00	0.17	-0.23	**0.92**	0.86
CLA	**0.92**	-0.07	-0.16	0.09	0.78
CDW	0.32	**0.86**	-0.27	0.08	0.85
DF	0.37	**-0.87**	0.09	-0.11	0.84
FC	**0.83**	-0.04	-0.41	0.19	0.80
PWP[(3)]	**0.89**	-0.03	0.28	0.06	0.77
MWD	0.21	*-0.51*	*0.66*	0.29	0.68
Eigenvalues	*8.73*	*3.91*	*1.98*	*1.10*	
Explained variance (%)	*48.5*	*21.7*	*11.0*	*6.1*	
Accumulated variance (%)	*48.5*	*70.2*	*81.3*	*87.4*	
Comparison of scores between opposite-facing slopes [(4)]					
East/South-facing slope	0.207	0.761**a**	0.419	-0.107	
West/North facing slope	-0.207	-0.761**b**	-0.419	0.107	
Pearson Correlation[(5)]	F1	F2	F3	F4	
Slope	**-0.88**	0.35	*0.61*	-0.17	
Altitude	0.18	*-0.54*	**0.73**	-0.25	
Mean comparison of scores among degradation levels [(6)]					
Light	1.64 **a**	0.17	0.81	0.33	
Moderate to strong	-0.56 **b**	0.21	-0.14	-0.19	
Very strong	0.60 **a**	-1.03	-0.23	0.43	

[(1)] bold – strong factorial loading (>0.75), underlined italic – moderate factorial loading (0.5 to 0.74) (HAIR et al., 2009);[(2)] Identification of variables – same as Table 1; [(3)] Transformed data; [(4)] Comparison exposed sides by ANOVA significant at 5% probability; [(5)] Pearson correlation- bold- significant at 0.1% probability, underlined – significant at 1% probability [(6)] Comparison of means for unequal samples by the Tukey Post-Hoc test significant at 5% probability.

Comparing the mean scores of F1 at the three levels of degradation showed that higher values are related with light and very strong degradation levels, with no relationship between higher degradation levels and higher scores values (Table 6). Correlations between the factors and the soil coverage were not significant, with the highest correlation obtained by Factor 1 and bare soil ($r_{Factor\ 1\ x\ BarSoil}$= 0.42, p=0.0568).

In the 0.1 – 0.2 m layer, the Factor 1 (F1) again had a strong factorial loading attributed to the physical attributes CLA, CS, TP, SD and FC (Table 9). From the means test and the Pearson correlations with the slope and altitude, the same tendency may be observed for the 0 – 0.1 m layer: the majority of the variation (56%) of the group of attributes related to Factor 1 (CLA, CS, TP, SD and FC) is controlled by the steepness of the slope. The difference between the mean scores of the exposed sides was not significant at 5% (ANOVA, p=0.0702) (Table 7). The means test among the scores of the different degradation levels was significant, but it did not demonstrate a relationship between the increases in degradation levels and increased score values. Factor 2 had a strong factorial loading from the attributes K and CaMg and a moderate factorial loading with Al, COT, MWD, CDW and GF. Factor 2 presents strong correlation with altitude ($p<0.001$). Factor 3, which was strongly related to the higher P and Al contents and explained 7.6 % of the variation of the data, presented significant differences among mean scores of the different degradation levels, with higher scores attributed to the lowest degradation levels (Table 7). Factors in the 0.1 – 0.2 m layer and soil coverage presented non-significant correlations, with the highest significant correlation obtained for Factor 1 and bare soil ($r_{Factor\ 1\ x\ BarSoil}= 0.56$, p=0.014).

Table 9. Factorial loadings [(1)] of the attributes of the soil, eigenvalues and variance explained by the factors after the orthogonal Varimax rotation method, ANOVA statistics and Pearson correlations in the 0.1 – 0.2 m layer.

Attributes[(2)]	**Factor 1**	**Factor 2**	**Factor 3**	**Factor 4**	***Communality***
P	0.20	-0.09	**0.89**	-0.23	0.80
K[(2)]	-0.14	**0.92**	-0.02	0.09	0.76
CaMg[(3)]	*-0.59*	**0.75**	-0.26	0.10	0.95
Al[(3)]	0.43	*-0.59*	*0.67*	-0.10	0.81
COT	*0.65*	*0.59*	-0.26	0.05	0.94
NT	*0.73*	*-0.50*	0.48	0.04	0.81
PREM	-0.44	-0.25	0.45	0.04	0.40
SD	**-0.88**	0.40	-0.07	0.00	0.88
TP	**0.89**	-0.34	0.10	-0.08	0.85
CS	**-0.93**	0.11	-0.06	-0.26	0.90
FS	-0.17	-0.27	-0.02	**-0.78**	0.50
SI	0.05	0.17	-0.31	**0.86**	0.75
CLA	**0.94**	-0.12	0.19	0.06	0.88
CDW	0.03	*0.57*	0.00	0.48	0.31
GF	0.35	*-0.53*	0.15	-0.46	0.41
FC	*0.63*	-0.10	0.38	*0.52*	0.89
PWP[(3)]	**0.81**	-0.06	0.46	0.25	0.47
MWD	0.29	*-0.67*	0.49	0.34	0.58
Eigenvalues	*10.08*	*3.77*	*1.37*	*1.03*	
Explained variance (%)	*56.0*	*20.9*	*7.6*	*5.7*	
Accumulated variance (%)	*56.0*	*77.0*	*84.6*	*90.4*	
Comparison of scores between opposite-facing slopes [(4)]					
East/West Face	-0.025	0.426	0.271	0.325	
North/South Face	0.025	-0.426	-0.271	-0.325	
Pearson Correlations [(5)]	F1	**F2**	F3	F4	
Slope	**-0.77**	0.07	0.08	0.07	
Altitude	0.08	**-0.77**	0.35	-0.08	
Mean comparison of scores among degradation levels [(6)]					
Light	0.982 **a**	0.002	1.491 **a**	-0.045	
Moderate to strong	-0.539 **b**	0.271	-0.101 **b**	-0.094	
Very strong	1.176 **a**	-1.087	-1.085 **b**	0.423	

[(1)] bold – strong factorial loading (>0.75), underlined italic – moderate factorial loading (0.5 to 0.74) (HAIR et al., 2009);[(2)] Identification of variables – same as Table 1; [(3)] Transformed data; [(4)] Comparison sides of exposition by ANOVA significant at 5% probability; [(5)] Pearson correlation – bold- significant at 0.1% probability, underlined – significant at 1% probability; [(4)] Comparison of the medians/mean/means for unequal samples by the Tukey Post-Hoc test significant at 5% probability.

Levels of degradation, soil coverage and attributes

Chemical Attributes

The relationship between soil coverage and attributes (Tables 10 and 11) was evaluated in different sun-facing slopes and selecting the most promising attributes as indicators of quality, i.e., those with the highest factorial loadings among the factors that present significant differences among degradation levels (Tables 8 and 9).

Table 10. Spearman Correlation [(1)] between chemical atributes and soil coverage, separating the groups of the East/South-facing slope (n = 9) from the West/North facing slope (n=9) and selecting the attributes of greater participation in the Factor Analysis.

	BarSoil	**Mulch**	**Braq**	**Inv**	**BarSoil**	**Mulch**	**Braq**	**Inv**
	East/South-facing slope				**West/North facing slope**			
	Attributes of greater relationship with Factor 1 – 0- 0.1 m							
CaMg	-0.16	<u>-0.79</u>	<u>0.80</u>	<u>-0.77</u>	**<u>-0.95</u>**	0.47	-0.45	0.47
Al	0.00	0.67	-0.65	0.62	0.48	**<u>-0.96</u>**	-0.48	**<u>-0.96</u>**
TOC	-0.16	0.63	-0.63	0.62	0.95	-0.47	0.48	-0.48
TN	0.05	<u>0.72</u>	<u>-0.73</u>	<u>0.76</u>	0.40	-0.08	0.32	-0.08
	Attributes of greater relationship with Factor 1 – 0.1 – 0.2 m							
CaMg	0.26	-0.58	0.58	-0.58	-0.42	-0.41	0.41	-0.43
TOC	0.27	**0.86**	**-0.86**	**0.86**	-0.64	0.17	-0.16	0.15
TN	0.26	**0.85**	**-0.85**	**0.85**	-0.62	0.16	-0.18	0.16
	Attributes of greater relationship with Factor 3 – 0.1 – 0.2 m							
P	0.05	<u>0.51</u>	<u>0.74</u>	<u>0.74</u>	**-0.82**	-0.63	0.61	-0.58
Al	-0.06	<u>0.72</u>	<u>-0.75</u>	<u>0.70</u>	**0.96**	-0.46	-0.17	-0.48

[(1)] bold underlined – significant at 0.1% probability; bold – significant at 1% probability; underlined – significant at 5% probability.

On the West/North facing slope, based on the highest correlations in the 0 – 0.1 m layer (Table 10), reduced Ca and Mg content increased the presence of bare soil while increased Al content reduced mulching and invasives. In the 0.1 – 0.2 m layer, with greater solar radiation, higher Al content and lower P content increased the frequency of bare soil and higher P content increased the presence of brachiaria and invasives. Considering the two different sun-facing slopes together (n=18) the high Spearman correlations among chemical attributes and plant cover decreased in the 0 – 0.1 m layer ($r_{CaMg\ x\ BarSoil}$= –0.62,p<0.01; $r_{Al\ x\ Mulch}$= 0.20, p>0.05;$r_{Al\ x\ Inv}$=0.14, p>0.05) and the 0.1 – 0.2 m layer ($r_{Al\ x\ BarSoil}$= 0.45; p>0.05; $r_{P\ x\ BarSoil}$= 0.09; p>0.05; $r_{P\ x\ Braq}$= –0.11; p>0.05; $r_{P\ x\ Inv}$= –0.36; p>0.05) indicating the necessary homogenous terrain conditions for best performance of the chemical attributes as pasture quality indicators.

From of the results in Table 11, it was shown that the Ca, Mg and Al contents of the light and very strong levels did not differ significantly in the 0 – 0.1 m layer. In the 0.1 – 0.2 m layer the Al content was not significantly different among degradation levels. It was possible to distinguish the light degradation level with P Content in the 0.1 – 0.2 m soil layer, but the non-significant differences in the other two levels made it difficult to use them for differentiating the other degradation levels. In the same way, the tendency is higher values of TN and TOC at light degradation levels, but these attributes were not statistically different between the moderate to strong level and the very strong level of degradation. In conditions of heterogeneous relief, however, there was no well-defined relationship between soil chemical attributes and plant cover.

Table 11. Mean test (1)for the chemical attributes (2) of the soils, among different levels of degradation.

Attributes(1)		Degradation level (3)					
		Light		Moderate to strong		Very strong	
		Attributes of greater relationship with Factor 1 – 0 – 0.1 m					
CaMg	$cmol_c\ dm^{-3}$	0.38	b	2.1	a	0.26	b
Al	$cmol_c\ dm^{-3}$	1.04	a	0.37	b	1.10	a
TOC	$g\ kg^{-1}$	26.95	a	14.63	c	19.66	b
TN	$g\ kg^{-1}$	0.18	a	0.12	b	0.14	b
		Attributes of greater relationship with Factor 1 – 0.1 – 0.2 m					
CaMg	$cmol_c\ dm^{-3}$	0.12	b	1.54	a	0.03	b
TOC	$g\ kg^{-1}$	24.1	a	11.3	b	16.74	b
TN	$g\ kg^{-1}$	0.16	a	0.09	b	0.13	ab
		Attributes of greater relationship with Factor 3 – 0.1 – 0.2 m					
P	$mg\ dm^{-3}$	1.20	a	0.91	b	0.80	b
Al	$cmol_c\ dm^{-3}$	1.07	a	0.51	a	0.98	a

(1) Comparison of means for unequal samples by the Tukey Post-Hoc test significant at 5% probability; (1) Identification of variables – same as Table 1; (3)Referring to the three levels separated in the most accurate manner for Discriminant Analysis (Table 5).

Physical attributes

Solar radiation has a reduced effect on soil moisture of the East/South-facing slopes, where physical attributes may more effectively regulate water availability, nutrient absorption and soil coverage. Very strong correlations occurred between physical attributes (CS, CLA, PWP and FC) and plant cover on the East/South-facing slope (Table 12) of higher soil moisture, indicating that higher course sand fraction and lower clay content can facilitate water absorption by plants. Furthermore, the higher coarse sand presence may favor the exchange of gases in the soil, and consequently plant growth. On the other hand, brachiaria present positive correlation with clay on the West/North facing slope: the participation of the clay in water retention makes absorption more difficult by plants, but becomes important for the presence of the brachiaria in low soil moisture areas. For example, considering the 0 – 0.1 m layer and the two different sun-facing slopes (n=18) the high Spearman correlations among physical attributes and plant cover decreased for coarse sand ($r_{CS\ x\ Mulch}$=-0.52, p>0.05 $r_{CS\ x\ Braq}$= 0.10, p>0.05 $r_{CS\ x\ Inv}$= 0.51 p>0.05) clay ($r_{CLA\ x\ Mulch}$= 0.36, p>0.05; $r_{CLA\ x\ Braq}$= –0.14, p>0.05; $r_{CLA\ x\ Inv}$= 0.56, p>0.05) and moisture at field capacity ($r_{FC\ x\ Mulch}$= 0.62, p=0.006; $r_{FC\ x\ Braq}$= –0.07, p>0.05; $r_{CLA\ x\ Inv}$= 0.50, p>0.05). As a result, these attributes became less efficient as physical indicators of soil quality for pasture productivity.

In Table 13, considering the two layers, it was observed that higher SD and CS content and lower values of PWP and CLA occurred at the mean degradation level, with such attributes being statistically equal between the light and very strong levels. The present work showed a weak relationship between degradation levels and soil physical attributes, making it difficult to develop a soil quality index based on these attributes. Slope, altitude and opposite-facing slopes influenced the temperature, solar radiation and water availability in the soil, which are important factors that regulate pasture development beyond the attributes related to the soil (CRUZ, 2010).

Table 12. Spearman Correlation [(1)] among soil coverage attributes, separating the groups of the East/South-facing slope (n = 9) from the West/North facing slope (n=9) and selecting the attributes of greater participation in the Factor Analysis.

	BarSoil	Mulch	Braq	Inv	BarSoil	Mulch	Braq	Inv
	East/South-facing slope				West/North facing slope			
	Attributes of greater relationship with Factor 1 – 0- 0.1 m							
SD	-0.05	-0.72	0.70	-0.77	-0.95	0.46	-0.47	0.47
TP	0.42	**0.84**	**-0.84**	**0.84**	0.49	-0.63	0.16	-0.63
CS	-0.48	**-0.95**	**0.95**	**-0.95**	0.26	-0.32	**-0.87**	-0.32
CLA	0.44	**0.94**	**-0.95**	**0.94**	-0.34	0.00	0.74	0.00
FC	0.46	**0.95**	**-0.93**	**0.95**	0.32	0.58	**0.84**	0.58
PWP	0.47	**0.95**	**-0.94**	**0.95**	0.32	0.47	0.79	0.47
	Attributes of greater relationship with Factor 1 – 0.1 – 0.2 m							
SD	-0.32	**-0.87**	**0.87**	**-0.87**	0.47	-0.44	0.47	-0.45
TP	0.26	**0.84**	**-0.84**	**0.84**	-0.53	0.37	-0.37	0.37
CS	-0.48	**-0.96**	**0.96**	**-0.96**	-0.21	-0.82	-0.82	-0.82
CLA	0.48	**0.95**	**-0.95**	**0.95**	-0.28	0.61	-0.61	0.61
FC	0.05	0.74	-0.75	0.74	0.48	0.87	-0.87	0.87
PWP	0.43	**0.92**	**-0.94**	**0.93**	-0.49	0.49	-0.49	0.49

[(1)] bold underlined – significant at 0.1% probability; bold – significant at 1% probability; underlined – significant at 5% probability.

Table 13. Mean test [(1)] for soil attributes [(2)] among different degradation levels.

Attributes[(1)]		Degradation levels [(3)]					
		Light		Moderate to strong		Very strong	
		Attributes of greater relationship with Factor 1 – 0- 0.1 m					
SD	mg m^{-3}	1.23	b	1.49	a	1.27	b
TP	m^3 m^{-3}	0.48	a	0.39	a	0.46	a
CS	dag kg^{-1}	25	b	37	a	25	b
CLA	dag kg^{-1}	53	a	38	b	52	a
FC	m^3 m^{-3}	0.41	a	0.33	b	0.37	ab
PWP	m^3 m^{-3}	0.30	a	0.22	b	0.24	b
		Attributes of greater relationship with Factor 1 –0.1 – 0.2 m					
SD	mg m^{-3}	1.12	b	1.42	a	1.06	b
TP	m^3 m^{-3}	0.55	a	0.45	b	0.57	a
CS	dag kg^{-1}	21.67	b	36.50	a	21.67	b
CLA	dag kg^{-1}	55.67	a	39.92	b	54.33	a
FC	m^3 m^{-3}	0.40	a	0.31	c	0.36	B
PWP	m^3 m^{-3}	0.18	a	0.24	b	0.25	B

[(1)] Comparison of means for unequal samples by the Tukey Post-Hoc test significant at 5% probability; [(1)]Identification of variables – same as Table 1; [(3)] Relative to the three levels separated with most accuracy by Discriminant Analysis (Table 5).

Discussion

The relief attributes controls the pedogenetic processes, resulting in wide variability of the studied attributes due to slope, altitude and different sun-facing slopes. In a general way, it was observed that the slope presents a stronger relationship with the Factor 1 (Tables 8 and 9) that explains the majority of the variance of the physical attributes. The different sun-facing slopes and altitude were associated with a lower variation of the data, about 20% of the total in Factor Analysis. The slope increased the flow of runoff and regions with steeper slopes are residually enriched in coarse sand. The surface runoff of the organic material and the finest fraction, such as clay, in regions with higher slopes has been highlighted in the literature (WALTON et al., 2000; BURAK et al., 2012).

The effect of leaching and removal of bases with altitude is showed in Factor 2 (Tables 8 and 9) in the 0 – 0.1 m and 0.1 – 0.2 m layers, i.e., at higher altitudes there is a greater presence of exchangeable aluminum ($r_{0\text{-}10cm\ Al\ x\ ALT}$= 0.57, p<0.0149; $r_{10\text{-}20cm\ Al\ x\ ALT}$=0.63, p<0.0043) and lower presence of bases ($r_{0\text{-}10cm\ CaMg\ x\ ALT}$ = –0.57, p<0.0149; $r_{10\text{-}20cmAl\ x\ ALT}$= –0.75 p<0.0023). The attributes correlated with Factor 2 are also influenced by the different sun-facing slopes. Due to the greater range of the soil moistures and wet-dry cycles on the West/North facing slope, higher stability aggregates may be found in the 0 – 0.1 m layer (Table 8, factorial loading MWD x Factor 1 = 0.51). Moreover, higher Al content and degree of flocculation (DF) are associated with higher aggregate stability. According to Portugal et al. (2010), the relationship between the greater wetting and drying cycle and the increased presence of stable aggregates may be related to the possibility of the destruction and removal by erosion of the most unstable and dispersive aggregates. On the East/South facing slope the increased presence of clay dispersed in water may be observed principally at lower altitudes, as these conditions of lower intensity wetting and drying cycles during soil development and formation, as well as consequent lower selection of stable aggregates, may result in higher clay content dispersed in water in the current conditions. With altitude, higher exchangeable aluminum content facilitates soil aggregation in the 0 – 0.1 m layer ($r_{MWD\ x\ Al}$ = 0.46, p<0.053; $r_{MWD\ x\ Altitude}$ = 0.73, p<0.001). In West/North facing slope, higher mean weight diameter of soil aggregates can be associated whit residual e more stables aggregates. Additionally, pastures are not managed with physical preparation, contributing to higher clay flocculation and physical soil stability (FERREIRA et al., 2010).

The soil coverage, on the other hand, presents a relationship with soil attributes that varies as a function of the relief and the flow of energy and water. Zornoza et al. (2007) caution that soil quality indicators evaluated in particular conditions of a landscape segment may not be extrapolated to other segments in regions of hilly relief. The relationships between the soil physical attributes and soil coverage become more evident on the East/South facing slopes (Table 12). As such, the greater presence of sand, lower porosity and higher soil density increase the presence of brachiaria due to increased soil-root contact, in accordance with the observations of Cavallini et al. (2010). Under these conditions, the constant conservation of soil moisture as a result of reduced solar radiation favors the absorption of water and nutrients controlling the presence of the brachiaria. According to Cruz (2010), among the determinant factors for forage production (temperature, luminosity, water and nutrients) water availability is the most important. Another fact, noted by Corsi and Nascimento Junior (1989), would be the environmental conditions of high evapotranspiration that may be harmful for grazing. Exposed sides are important microclimatic factors controlling the vegetation dynamic (ÅSTRÖM et al., 2007; CARLETTI et al., 2009).

In the present study there was no strong relationship between soil attributes and visual degradation levels, within which other environmental factors (solar radiation and the humidity) regulate the soil coverage in association with soil attributes. The direct measurement of the soil coverage (bare soil, invasives, brachiaria and mulching) were more efficient in discriminating among degradation levels and weighing the influence of limiting climatic factors on pasture quality. Being influenced by relief variability, soil attributes had less control over plant cover and degradation levels in the study area. The higher variation attributes in Factor Analysis in the study area, which are potentially more useful for discriminating among groups of similar soils (NOSRATI, 2013), did not have a direct relationship with the degradation levels (Tables 8 and 9). It depends primarily on the solar radiation on sun-facing slopes whether these attributes will have a higher or lower relationship with the soil coverage (Tables 10 and 12) that will directly influence the visual evaluation of the degradation level; e.g., conditions of greater humidity (East/South-facing slope) and higher sand content increase the presence of brachiaria, causing a contrary trend in lower humidity conditions (West/North facing slope), where the higher sand content favors the presence of brachiaria.

Conclusions

In the study area the attributes with the highest variance by Factor Analysis did not present a direct and evident relationship with degradation levels and soil coverage due to the influence of relief on controlling solar radiation and soil moisture modifying the soil-vegetation relationship dynamic. This makes it difficult to use these attributes as indicators of soil quality that best distinguish the degradation levels of pastures in regions of hilly relief.

Depending on the sun-facing slope, soil coverage presents a stronger relationship with the soil attributes: a stronger relationship of physical attributes and plant cover was observed on the East/South-facing slope, which was not observed on the West/North face.

The soil coverage measurement using discriminant functions was a more efficient way to discriminate among the three degradation levels than using the soil quality indicators, additionally weighing the influence of other environmental factors (temperature, solar radiation intensity, soil moisture) on pasture quality in regions of hilly relief.

The slope controls the majority of the group attributes of the highest variance soils in the studied area, principally the physical attributes. Altitude and different sun-facing slopes explain a small proportion of the explained variation of the data in Factor Analysis principally associated to the chemical attributes.

References

ALVAREZ, V. V. H.; NOVAIS, R. F.; DIAS, L. E. Determinação e uso do fósforo remanescente. *Boletim Informativo da Sociedade Brasileira de Ciência do Solo*, Viçosa, MG, v. 52, n. 1, p. 27-32, 2000.

ASKARI, M. S.; HOLDEN, N. M. Indices for quantitative evaluation of soil quality under grassland management. *Geoderma*, Amsterdam, v. 230-231, p. 131-142, 2014.

ÅSTRÖM, M.; DYNESIUS, K.; HYLANDER, A.; NILSSON, C. Slope/downhill/gradient aspect modifies community responses to clear-cutting in boreal forests. *Ecology*, Ithaca, v. 88, n. 3, p. 749-758, 2007.

BURAK, D. L.; PASSOS, R. R.; ANDRADE, F. V. Variabilidade espacial de atributos químicos do solo sob cafeeiro Conilon: relação com textura, matéria orgânica e relief/raised. *Bragantia*, Campinas, v. 71, n. 4, p. 538-547, 2012.

CARDOSO, E. L.; SILVA, M. L. N.; MOREIRA, F. M.; CURI, N. Atributos biológicos indicadores da qualidade do solo em pastagem cultivada e nativa no Pantanal. *Pesquisa Aglinecuária Brasileira*, Brasília, v. 44, n. 6, p. 631-637, 2009.

CARLETTI, P.; VENDRAMIN, E.; PIZZEGHELLO, D.; CONCHERI, G.; ZANELLA, A.; NARDI, S.; SQUARTINI, A. Soil humic compounds and microbial communities in six spruce forests as function of parent material, slope/downhill/gradient aspect and stand age. *Plant Soil*, Austrália, v. 315, n. 2, p. 47-65, 2009.

CAVALLINI, M. C.; ANDREOTTI, M.; OLIVEIRA, L. L.; PARIZ, C. M.; CARVALHO, M. P. Relações entre produtividade de *Brachiaria brizantha* e atributos físicos de um latossolo do cerrado. *Revista Brasileira de Ciência do Solo*, Viçosa, MG, v. 34, n. 4, p. 1007-1016, 2010.

CORSI, M.; NASCIMENTO JÚNIOR, D. Princípios de fisiologia e morfologia de plantas forrageiras aplicados no manejo das pastagens. In: PEIXOTO, A. M.; MOURA, J. C.; DE FARIA, V. P. (Ed.). *Manejo de pastagens*. Piracicaba: FEALQ, 1989. p. 113-152.

COSTA, O. V.; COSTA, L. M.; FONTES, L. E. F.; ARAUJO, Q. R.; KER, J. C.; NACIF, P. G. S. Cobertura do solo e degradação de pastagens em área de domínio de Chernossolos no South da Bahia. *Revista Brasileira de Ciência do Solo*, Viçosa, MG, v. 24, n. 4, p. 843-856, 2000.

CRUZ, P. G. *Produção de forage em Brachiaria brizantha*: adaptação, geração e avaliação de modelos empíricos e mecanicistas para estimativa do acúmulo de forage. 2010. Tese (Doutorado em Zootecnia) – Escola Superior de Agricultura Luiz de Queiroz, Piracicaba.

DORAN, J. W.; PARKIN, T. B. Defining and assessing soil quality. In: DORAN, J. W.; COLEMAN, D. C.; BEZDICEK, D. F.; STEWART, B. A. (Ed.). *Defining soil quality for a sustainable environment*. Madison: Soil Science Society of America, 1994. p. 3-21.

EMMERLING, C.; UDELHOVEN, T. Discriminating factors of the spatial variability of soil quality parameters at landscape-scale. *Journal of Plant Nutrition and Soil Science*, Oldenburg, v. 165, n. 6, p. 706-712, 2002.

EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA – EMBRAPA. Centro Nacional de Pesquisa de Solos. Manual de métodos de análise de solo. 2. ed. Rio de Janeiro: EMBRAPA, 1997. 212 p.

FERREIRA, R. R. M.; TAVARES FILHO, J.; FERREIRA, V. M.; RALISCH, R. Estabilidade física de solo sob diferentes manejos de pastagem extensiva em cambissolo. *Semina: Ciências Agrárias*, Londrina, v. 31, n. 3, p. 531-538, 2010.

HAIR, F. J.; BLACK, W. C.; BABIN, B.; ANDERSON, R. E.; TATHAN, R. L. *Análise multivariate de dados*. 6. ed. Porto Alegre: Bookman, 2009. 593 p.

JAYAGANESH, S.; SENTHURPANDIAN, V. K. Extraction and characterization of humic and fulvic acids from latosols under tea cultivation in South India. *Asian Journal of Earth Science*, New York, v. 3, n. 3, p. 130-135, 2010.

KARLEN, D. L.; MAUSBACH, J. W.; DORAN, R. G.; CLINE, R. F.; SCHUMAN, G. E. Soil quality: a concept, definition, and framework for evaluation. *Soil Science Society of America Journal*, Madison, v. 61, n. 1, p. 4-10, 1997.

KEMPER, W. D.; ROSENAU, R. C. Aggregate stability and size distribution. In: KLUTE, A. (Ed.). *Methods of soil analysis*. 2th ed. Madison: American Society of Agronomy, 1986. p. 425-443.

KHATTREE, R.; NAIK, D. N. *Multivariate data reduction and discrimination with SAS software*. New York: BBU and John Wiley Sons, 2000. 574 p.

LENTZSCH, P.; WIELAND, R.; WIRTH, S. Application of multiple regression and neural network approaches for landscape-scale assessment of soil microbial biomass. *Soil Biology & Biochemistry*, Philadelphia, v. 37, n. 6, p. 1577-1580, 2005.

LI, Y.; DONG, S.; WEN, L.; WANG, X. W. Y. Assessing the soil quality of alpine grasslands in the Qinghai-Tibetan Plateau using a modified soil quality index. *Environmental Monitoring and Assessment*, Columbia, v. 185, n. 10, p. 8011-8022, 2013.

LIAO, S. W.; CHANG, W. L. Interpretation and discrimination of marshy wetlands by soil factors in the kuan-tu natural park, Taiwan. *Environmental Monitoring and Assessment*, v. 107, n. 2, p. 181-202, 2005.

NORFLEET, M. L.; DITZLER, C. A.; PUCKETT, W. E.; GROSSMAN, R. B.; SHAW, J. N. Soil quality and its relationship to pedology. *Soil Science*, Brunswick, v. 168, n. 3, p. 149-155, 2003.

NOSRATI, K. Assessing soil quality indicator under different land use and soil erosion using multivariate statistical techniques. *Environmental Monitoring and Assessment*, Columbia, v. 185, n. 4, p. 2895-2907, 2013.

OLSZEVSKI, N.; BRAGA, A. P.; COSTA, L. M.; SILVA, H. R. F. Proposição de metodologia para avaliação da degradação de pastagens em propriedades rurais. In: REUNIÃO BRASILEIRA DE MANEJO E CONSERVAÇÃO DO SOLO E DA ÁGUA – AGRICULTURA E SUSTENTABILIDADE NO SEMI – ÁRIDO, 12., 1998, Fortaleza. *Anais*... Fortaleza: Sociedade Brasileira de Ciência do Solo, 1998. p. 256-257.

PIGNATARO NETTO, I. T.; KATO, E.; GOEDERT, W. J. Atributos físicos e químicos de um Latossolo vermelho-amarelo sob pastagens com diferentes históricos de uso. *Revista Brasileira de Ciência do Solo*, Viçosa, MG, v. 33, n. 5, p. 1441-1448, 2009.

PORTUGAL, A. F.; JUNCKSH, I.; SCHAEFER, C. E. R. Estabilidade de agregados em argissolo sob diferentes usos, comparado com mata. *Revista Ceres*, Viçosa, v. 57, n. 3, p. 545-553, 2010.

PREZOTTI, L. C.; GOMES, J. A.; DADALTO, G. G.; OLIVEIRA, J. A. de. *Manual de recomendação de calagem e adubação para o Estado do Espírito Santo*. 5ª aproximação. Vitória: SEEA/INCAPER/CEDAGRO, 2007. 305 p.

RESENDE, P. C. S. *Resistência mecânica e sua variação com a umidade e com a densidade do solo em Latossolo Vermelho-Escuro do Cerrado*. 1995. Dissertação (Mestrado em Solos e Nutrição de Plantas) – Universidade Estadual de São Paulo, Botucatu.

SHUKLA, M. K.; LAL, R.; EBINGER M. Determining soil quality indicators by factor analysis. *Soil & Tillage Research*, Amsterdam, v. 87, n. 2, p. 194-204, 2006.

SILVA NETO, S. B.; SANTOS, A. C.; LEITE, R. L. L.; DIM, V. P.; NEVES NETO, D. N.; SILVA, J. E. C. Variação espacial do teor de matéria orgânica do solo e produção de gramínea em pastagens de capim-marandu. *Bioscience Journal,* Uberlândia, v. 28, n. 1, p. 41-53, 2012.

SOUZA, C. M. P.; MOREAU, M. S.; MOREAU, A. M. S. S.; FONTES, E. O. Níveis de degradação de pastagens da Bacia do Rio Colônia-BA com uso de imagens LANDSAT 5TM. *Revista Brasileira de Geografia Física*, Recife, v. 3, n. 3, p. 228-243, 2010.

SPAIN, J. M.; GUALDRÓN, R. Degradacion y rehabilitacion de pasturas. In: REUNIÓN DEL COMITÉ ASESOR DE LA RED INTERNACIONAL DE EVALIACION DE PASTOS TROPICALES, 6., 1988, Veracruz, México. *Estabelecimento y renovación de pasturas: memorias*. Cali: CIAT, 1988. p. 269-283.

STATISTICAL ANALYSIS SYSTEM – SAS. SAS/STAT 8. 02 User´s guide. Cary, NC, USA: SAS Institute Inc., 2000.

SWANEPOEL, P. A.; PREEZ, C. C.; BOTHA, P. R.; SNYMAN, H. A.; HABIG, J. Soil quality characteristics of kikuyu-ryegrass pastures in South Africa. *Geoderma*, Amsterdan, v. 232-234, p. 589-599, 2014.

TRASAR-CEPEDA, C.; LEIRO´S, C.; GIL-SOTRES, F.; SEOANE, S. Towards a biochemical quality index for soils: an expression relating several biological and biochemical plinerties. *Biology and Fertility of Soils,* Florence, v. 26, n. 2, p. 100-106, 1998.

VICENTE, G. C. M. P.; ARAUJO, F. F. Uso de indicadores microbiológicos e de fertilidade do solo em áreas de pastagens. *Semina: Ciências Agrárias*, Londrina, v. 34, n. 1, p. 137-146, 2013.

WALTON, R. S.; VOLKER, R. E.; BRISTOW, K. L.; SMETTEM, K. R. J. Experimental examination of solute transport by surface runoff from low-angle slope/downhill/gradients. *Journal of Hydrology*, Amsterdam, v. 233, n. 6, p. 19-36, 2000.

YEOMANS, J. C.; BREMNER, J. M. A rapid and precise method for routine determimation of organic carbon in soil. *Communication in Soil Science of Plant Analysis*, Georgia, v. 19, n. 13, p. 1467-1476, 1988.

ZORNOZA, R.; MATAIX-SOLERA, J.; GUERRERO, C.; ARCENEGUI, V.; MAYORAL, A. M.; MORALES, J.; MATAIX-BENEYTO, J. Soil plinerties under natural forest in the Alicante Province of Spain. *Geoderma*, Amsterdam, v. 142, n. 2, p. 334-341, 2007.