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Soil quality indicators to evaluate environmental services at different landscape positions and land uses in the Atlantic Forest biome

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ABSTRACT

The objective of this study was to compare the potential of different land uses and landscape positions to provide environmental services by comparing the soil quality indicators. The study was conducted in the municipality of *Alegre,* Brazil on a Red- Yellow Oxisol. Three land uses (pasture, coffee, and secondary forest) were evaluated in the upper and lower slope positions at two depths (0.0–0.10 and 0.10–0.20 m) with three replications. The chemical indicators analyzed were pH, Al^{3+}, H + Al, Ca^{2+}, Mg^{2+}, K^{+}, P, sum of base (SB), base saturation (BS), aluminum saturation (AS), and total organic carbon (OC). The physical indicators analyzed examined were aggregate stability in water and calculating the geometric mean diameter (GMD), bulk density (BD), particle density (PD), macroporosity (Ma), microporosity (Mi), total porosity (TP), field capacity (FP), wilting point (WP), and available water (AW). The succession of forest area followed by the establishment of coffee or pasture has led to a decrease in soil quality, reducing the ability of these areas to provide environmental services. The positions of the landscape did not show any influence on soil quality for all the studied areas. This finding indicates that the relief is not a specific factor controlling the soil quality, but the observed variations resulted from the difference in land use practice.

1. Introduction

Population growth has led to an increase in food production, mainly livestock products such as milk and meat. However, this development has a direct impact on land use and land cover, affecting soil quality and the ability of ecosystems to provide environmental services, which are essential for the maintenance of life (Turreta et al., 2010; van Beek et al., 2014; Hamdy and Aly, 2014; Rojas et al., 2016).

In agriculture, environmental services are related to regulating processes or supporting life on earth. The most common environmental services are the production of fiber, food, and wood, as well as soil formation, nutrient cycling, water control and climate regulation (Millennium Ecosystem Assessment, 2005; Bünemann et al., 2018). However, the removal of natural vegetation for the expansion of agricultural areas and the adoption of conventional soil management practices have declined the soil quality (Rocha et al. al., 2014) and consequently the soil capacity to provides environmental services in the last few decades.

An example is the Brazilian Atlantic Forest, which is one of the most biodiversity hotspots in the world. It comprises an area of about 148,194.638 ha, but now only contains 9% of native forest (Ribeiro et al., 2009). In the state of Espírito Santo, where all its territory is within the Atlantic forest, natural vegetation was slashed off to establish pasture (1, 320,029.27 ha) and agricultural area such as coffee plantation (530, 245.09 ha). Currently, 18% of pasture area and 22% of the coffee area are in some stage of degradation or already degraded. In this state, the percentage of native vegetation remaining is higher than the national average of 11% forest. However, this figure may be as low as 1% in the northern region of the state (Cedagro, 2012).

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Improper soil management practices in *Espírito Santo* have reduced the productive capacity of the soils and agriculture areas to provide environmental services (Bertossi et al., 2016; Martins et al., 2010; Rocha Junior et al., 2017a, 2017b). With low pasture support capacity of the state that is only 0.7 AU (Animal Unit = 450 kg of Live Weight) per ha year, and low cattle (947 kg/ha) and Conilon coffee production (22.49 bags/ha) (Incaper, 2011; Conab, 2017), the decrease in the productive capacity of these soils is evident.

The monitoring of soil quality through chemical and physical attributes is a crucial tool to evaluate the quality of agricultural systems, as well as to measure their capacity to provide environmental services (Adhikari and Hartemink, 2016; Andrea et al., 2017; Rinot et al., 2019). A large part of the Atlantic Forest is still present in the region called *Mares de Moro*, with a landscape varying from mild to undulating. Since the slope controls most of the soil attribute variation and does not have a clear relationship with soil cover (Passos et al., 2016), it is of great importance to study these associations. It is also essential to know how the land use and landscape position influence the quality of the soils, and the capacity to provide environmental services.

Measuring the ability of these systems to maintain soil quality, and thus providing environmental services in comparison to the natural system like the forest is essential. In agricultural areas, the soil management overwhelms the native vegetation and affects the soil attributes. The evaluation of soil quality can provide a guideline for appropriate soil management in these areas. Therefore, the objective of this study was to evaluate and compare the soil physical and chemical attributes to provide environmental services for different land uses and landscape positions.

2. Material and methods

2.1. Location and soil

The study was conducted in the experimental area of the Federal Institute of Education of *Espírito Santo* (IFES), *Alegre*-ES. The municipality is located at 20°45′31″ S and 41°27′49″ W, with an undulating relief (Fig. 1). The predominant climate in the region is the Cwa type (subtropical, hot and humid in the summer and dry in the winter), according to Köppen classification, with an annual average rainfall of 1200 mm and a mean annual temperature of 23 °C. The soil was classified as Red-Yellow Oxisol (USDA, 2013) with a texture varying from medium to clayey (Table 1).

2.2. Land use

Table 1
Soil physical characterization under three land uses (coffee, forestry and pasture), two slope positions (upper and lower) and two depths (0.0–0.10 and 0.10–0.20 m).

Land use	Slope position	Sand	Silt	Clay
0.0–0.10 m		g kg^{-1}		
Coffee	Upper	557.80	131.08	311.16
Forestry		412.84	103.03	484.51
Pasture		551.51	163.70	284.46
Coffe	Lower	521.84	80.27	398.44
Forestry		580.96	63.20	355.84
Pasture		629.52	79.49	291.11
0.10–0.20 m				
Coffee	Upper	557.80	131.08	311.16
Forestry		412.84	103.03	484.51
Pasture		551.51	163.70	284.46
Coffee	Lower	580.96	63.20	355.84
Forestry		580.96	63.20	355.84
Pasture		629.52	79.49	291.11

Pipette method (Ruiz, 2005).

Three land uses evaluated in this study were pasture, coffee, and secondary forest. The area managed with the coffee crop was composed of Conilon coffee (*Coffea canephora Pierre* ex Froehner) without intercropping with an age of 13 years, and spacing of 2.0 × 2.5 m. Nutrient management in the area consisted of the annual application of formulated N–P–K fertilizers, with no history of liming. Pre-emergent herbicides application or manual weeding was done to control the weeds. Before coffee plantation, the area was planted with *Paspalum maritimum*. The pasture area was planted with *Brachiaria* sp., established in 2004 with *Paspalum maritimum* under continuous cattle grazing in the extensive regime and without soil fertility management. The forest evaluated was secondary vegetation, in natural regeneration for approximately 30 years, with the predominant species of Angico Vermelho *Anadenanthera macrocarpa*.

2.3. Soil indicators, functions, and services

Twenty physical and chemical soil indicators were selected to evaluate the environmental services in different land uses and landscape positions. The soil function and contribution were separated into four primary environmental services. These selections were considered and assessed with a different level of approximation, based on existing soil data and related research (Andrea et al., 2017; Adhikari and Hartemink, 2016; Calzolari et al., 2016; Prado et al., 2016; Gissi et al., 2017) (Table 2).

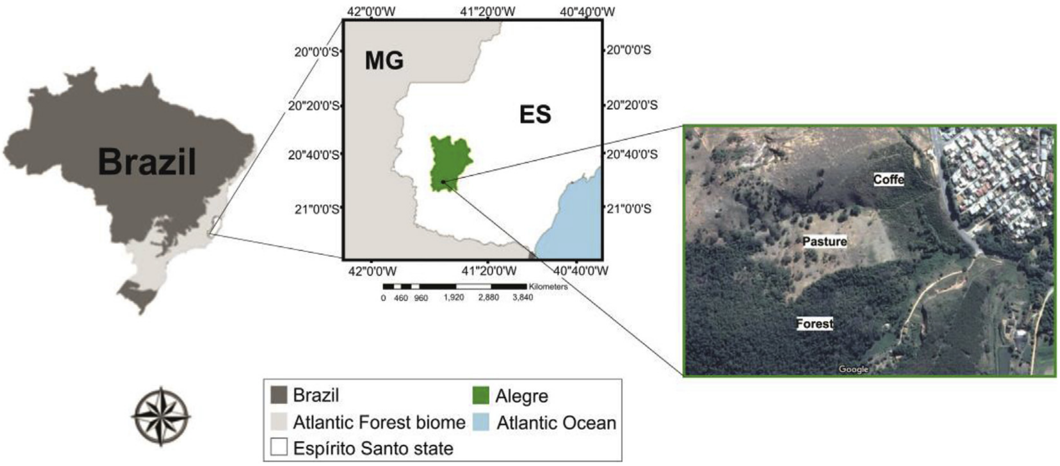

Fig. 1. Map of the research area.

Table 2
Environmental services (ESs), underpinning soil functions and indicators.

ESs categories	Soil function	Soil contribution to ESs	Soil indicator
Regulation	Carbon and organic matter pool	Soil formation and renewal, nutrient cycling, maintenance of biodiversity, GHG and climate regulation	OC
Regulation	Nutrient cycling, retention and release	Support to primary production, nutrient cycling and release, prevention of pathogens and diseases	Ca, Mg, K, P, SB
Regulation	Acidification control	Conditions to roots growth, conditions to nutrients uptake and cycling, plant growth and better environment to microorganisms activity	pH, Al, H + Al, BS, SB, AS
Provision	Water storage capacity and regulation	Storing water to plants and crops, filtering and transport of nutrients, flood mitigation and groundwater recharge	TP, Ma, Mi, WP, FC AW
Supporting	Soil compaction and erosion process	Habitat for soil organisms, conditions to plant growth, aeration for microorganisms and roots, conditions to water infiltration, nutrients transport and erosion control	GMD, BD, TP, Ma, Mi

Adapted from Adhikari and Hartemink (2016), Andrea et al. (2017), Calzolari et al. (2016), Prado et al. (2016) and Gissi et al. (2017).

2.4. Soil samples

Soil samples were collected at the 0.0–0.10 and 0.10–0.20 m depths, with three replications, in two (upper and lower) positions in the landscape (Fig. 2). Samples with deformed structure were collected to analyze chemical (pH, Al^{3+}, H + Al, Ca^{2+}, Mg^{2+}, K^+, P, sum of base - SB, base saturation - BS, aluminum saturation - AS) and physical (particle density - PD, soil moisture - SM, field capacity - FC, and wilting point - WP) indicators. For the analysis of the stability of aggregates, soil samples were collected in blocks with undisturbed structure with 0.10 × 0.10 × 0.10 m. They were air dried and passed through a 4 mm sieve and retained in a 2 mm sieve. To determine the macroporosity (Ma), microporosity (Mi), total porosity (TP), and soil bulk density (Bd), undisturbed samples with a volumetric ring of 0.05 × 0.05 × 0.05 m were collected.

2.5. Statistical analyses

The means of the chemical and physical soil indicators were calculated and subsequently subjected to the Shapiro–Wilk test, to test the normality of the data. After testing the data for the normality, the analysis of variance (ANOVA) was conducted to test if there was a difference in soil indicators for various land covers and landscape positions using SISVAR program (Ferreira, 2008). Data were analyzed using F-test (ANOVA) ($p < 0.05$). A relative deviation from the average was estimated for the soil attributes in two landscape positions.

To explore general trends between the variables and the soil uses in the different positions and depths, the principal components analysis was

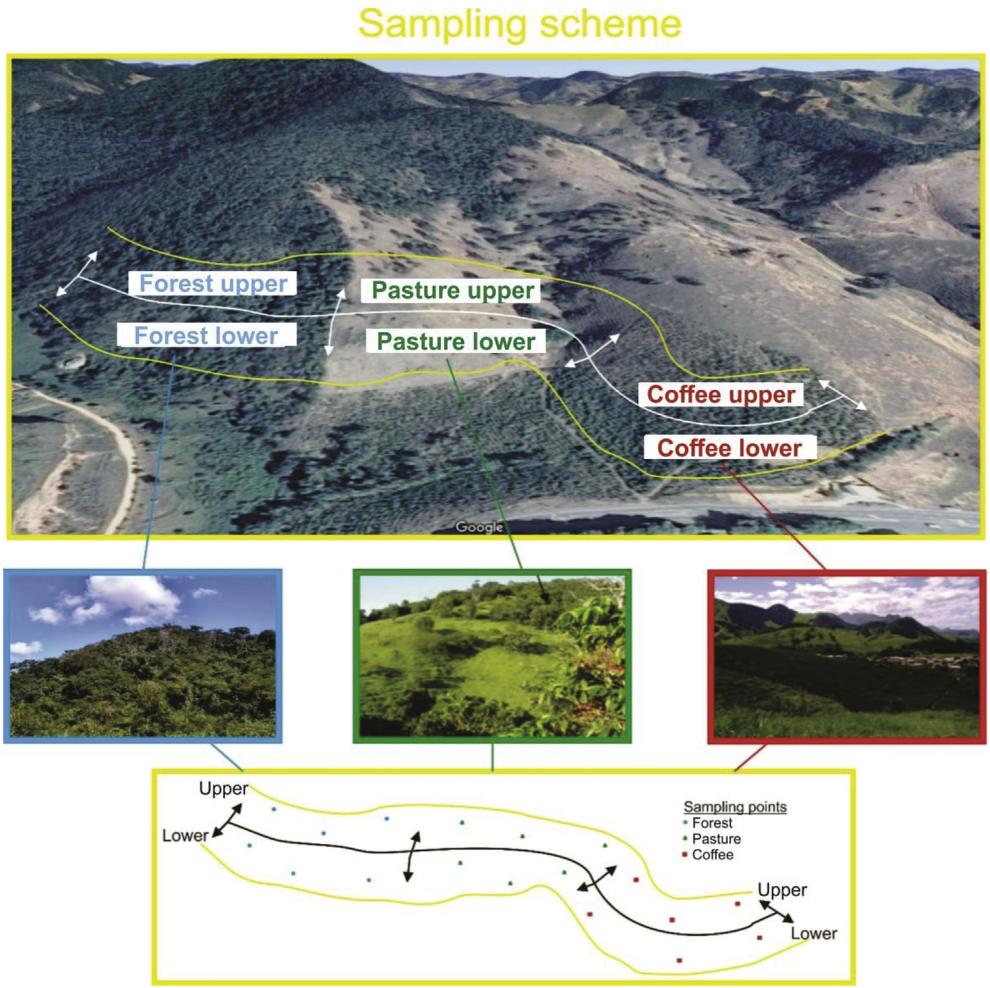

Fig. 2. Sampling scheme of soil.

carried out. The clustering analysis was also performed to compare the set of variables involved using the Euclidean distance.

3. Results

3.1. Soil chemical and physical indicators

The soil chemical attributes are shown in Table 3. Most of the chemical attributes were significantly different for three land uses and two landscape positions studied, except for Mg at two depths, K at a depth 0.0–0.10 m, and pH at a depth of 0.10–0.20 m ($p < 0.05$). For two landscape positions (upper and lower) and depths (0.0–0.10 and 0.10–0.20 m), the differences were smaller for the chemical attributes in the forest area compared to other two land uses (Table 3).

For the 0.0–0.10 m depth, in general, fertility was lower in the pasture area compared to the other areas for the lower landscape position (Table 2). The pasture showed values of pH (4.93), Ca (0.48 $\text{cmol}_c\ \text{dm}^{-3}$), Mg (0.48 $\text{cmol}_c\ \text{dm}^{-3}$), K (16.67 mg dm^{-3}), P (0.22 mg dm^{-3}), BS (19.96%) and OC (0.81 dag kg^{-1}) well below the general average. On the other hand, the highest values of Al (0.25 $\text{cmol}_c\ \text{dm}^{-3}$), H + Al (4.02 $\text{cmol}_c\ \text{dm}^{-3}$) and AS (5.02%) ($p < 0.05$) were observed for the pasture area. At the same depth and position of the landscape, the coffee area presented higher values of Ca (3.03 $\text{cmol}_c\ \text{dm}^{-3}$), K (93.33 mg dm^{-3}) and BS (55.28%), and these values were higher than the general average. The forest area resulted in higher values of pH (5.85), Mg (0.95 $\text{cmol}_c\ \text{dm}^{-3}$), P (1.17 mg dm^{-3}) and OC (1.15 dag kg^{-1}) ($p < 0.05$).

It was also observed that the lower position of the landscape provided better soil fertility in the pasture area, except for few chemical attributes (pH 6.13, Ca 2.24 $\text{cmol}_c\ \text{dm}^{-3}$, Mg 1.03 $\text{cmol}_c\ \text{dm}^{-3}$, K 89.33 mg dm^{-3}, OC 0.98 dag kg^{-1}). The pH, Mg, and K values for the pasture were higher than those for the coffee area and the forest area ($p < 0.05$).

For 0.10–0.20 m depth, the pasture area tended to have lower soil fertility values (except for K and P). The coffee area showed higher pH (5.57), Ca (3.05 $\text{cmol}_c\ \text{dm}^{-3}$), Mg (1.23 $\text{cmol}_c\ \text{dm}^{-3}$), K (32 mg dm^{-3}) and BS (57%) in comparison to the forest area in the upper position. In the lower landscape position, the soil attributes for the pasture area were similar in the comparison to forest and coffee area, except for Ca, OC, P, and K, which were higher for the forest area (Table 3).

The relative derivation calculation showed that K, Al, H + Al, BS, AS and OC were significantly different between the landscape positions at 0.0–0.10 m depth. While for the depth 0.10–0.20 m, the pH, Mg, P, Al, H + Al, and OC were different in depth 0.10–0.20 m ($p < 0.05$) (Fig. 3).

In terms of the soil physical attributes, the soil density did not show any difference at the two depths studied for all the land uses since the soil density was statistically same at 0.10–0.20 m depth ($p > 0.05$). However, all of the other soil physical attributes were different ($p < 0.05$) (Table 4).

For the other depths and position of the landscape, the pasture area resulted in higher values of the soil physical properties. The values were always above the general average ($p < 0.05$), except for geometric mean diameter - GMD (2.01 mm) at 0.0–0.10 m depth in the upper position of the forest area. Similar results were obtained for microporosity - Mi and the FC in the pasture area (Table 4).

However, the coffee area resulted in higher values of macroporosity (Ma) and total porosity (TP) and lower values of bulk density (BD), while the pasture area generally led to the higher BD values (except for 0.10–0.20 m depth in the lower position) (Table 4).

For the physical attributes, more considerable differences between the two positions of the landscape were observed in the superficial layer 0.0–0.10 m, where all the other attributes were different ($p < 0.05$) except for PD and Mi. For the depth 0.10–0.20 m, attribute differences were observed only for Mi and FC (Fig. 3).

For the 0.0–0.10 m depth, higher values of BD, WP, HR, and AW were obtained for the upper position, while the lower position showed higher values of GMD, TP, and Ma. At 0.10–0.20 m depth, the upper position had higher values of Mi, FC, and AW (Fig. 3).

Table 3

Mean values of soil chemical attributes in upper and lower slope positions, in two depths (0.0–0.10 and 0.10–0.20 m) under coffee, pasture and forestry.

Land use	Slope position	pH	Ca	Mg	K	P	Al	H + Al	SB	BS	AS	OC
0.0–0.10 m		H_2O	$\text{cmol}_c\ \text{dm}^{-3}$		mg dm^{-3}		$\text{cmol}_c\ \text{dm}^{-3}$			%		dag kg^{-1}
Forestry	Upper	5.85	2.48	0.95	69.00	1.17	0.08	3.96	3.60	44.89	1.28	1.15
Coffee		5.64	3.03	0.89	93.33	0.38	0.08	3.36	4.16	55.28	1.13	0.94
Pasture		4.93	0.48	0.48	16.67	0.36	0.25	4.02	1.00	19.96	5.02	0.81
Forestry	Lower	5.75	2.75	0.76	18.00	0.55	0.08	3.96	3.56	46.71	1.08	1.18
Coffee		5.96	1.98	0.73	20.33	0.86	0.12	2.64	2.76	50.81	2.54	0.86
Pasture		6.13	2.24	1.03	89.33	0.22	0.07	2.64	3.50	55.06	1.16	0.98
Mean		5.71	2.16	0.81	51.11	0.59	0.11	3.43	3.10	45.45	2.04	0.99
C.V.		14.10	2.04	3.38	1.45	1.82	2.07	5.23	2.48	3.66	1.52	8.24
F		**	**	ns	ns	**	**	**	**	**	**	**
0.10–0.20m												
Forestry	Upper	5.34	2.96	1.09	13.33	0.42	0.10	4.07	4.09	47.84	1.41	1.00
Coffee		5.57	3.05	1.23	32.00	0.20	0.10	3.14	4.36	57.93	1.34	0.87
Pasture		4.97	0.55	0.60	81.00	0.25	0.30	3.91	1.36	25.85	5.71	0.67
Forestry	Lower	5.40	2.25	0.66	36.00	0.58	0.08	3.91	3.00	36.21	1.50	1.12
Coffee		5.48	1.76	0.68	20.33	0.18	0.08	2.97	2.50	45.33	1.56	0.91
Pasture		5.89	1.92	0.86	85.33	0.28	0.15	3.52	3.00	44.10	2.31	0.74
Mean		5.44	2.08	0.86	44.67	0.32	0.14	3.58	3.05	42.88	2.31	0.89
C.V.		16.93	1.84	2.85	1.26	2.35	2.10	7.30	2.19	3.52	1.93	5.43
F		ns	**	ns	**	**	**	**	**	**	**	**

pH in H_2O, ratio 1: 2.5; calcium and magnesium (Ca^{2+} and Mg^{2+}) - extracted with KCl 1 mol L^{-1} and determined by atomic absorption spectrometry (Thermo Scientific ICE-3000); potassium and sodium (K^+) - extracted with Mehlich-1 and determined by flame photometry (Digimed DM-62); phosphorus extract extracted with Mehlich-1 and determined by absorbance reading (725 nm) in a spectrophotometer (P); exchangeable acidity (Al^{3+}) - extracted with KCl 1 mol L^{-1} and titrated with 0.025 mol L^{-1}NaOH, using phenolphthalein as an indicator; acidity (H + Al) - extracted with 0.5 mol L^{-1} calcium acetate at pH 7.0 and titrated with 0.060 mol L^{-1}NaOH; sum of bases Ca, Mg and K (SB); percentage of base saturation (BS); percentage of aluminum saturation (AS) (EMBRAPA, 2011); and total organic carbon (OC) - by wet oxidation by dichromate (Cr_2O_7) and subsequent determination of the non-reduced dichromate by titration of oxidation with Fe^{2+} with the help of external heating (Yeomans and Bremner, 1988); C.V.: coefficient of variation; *F*: F test (ANOVA); **: Significant by the F test (ANOVA) at 5% probability; ns: no significant.

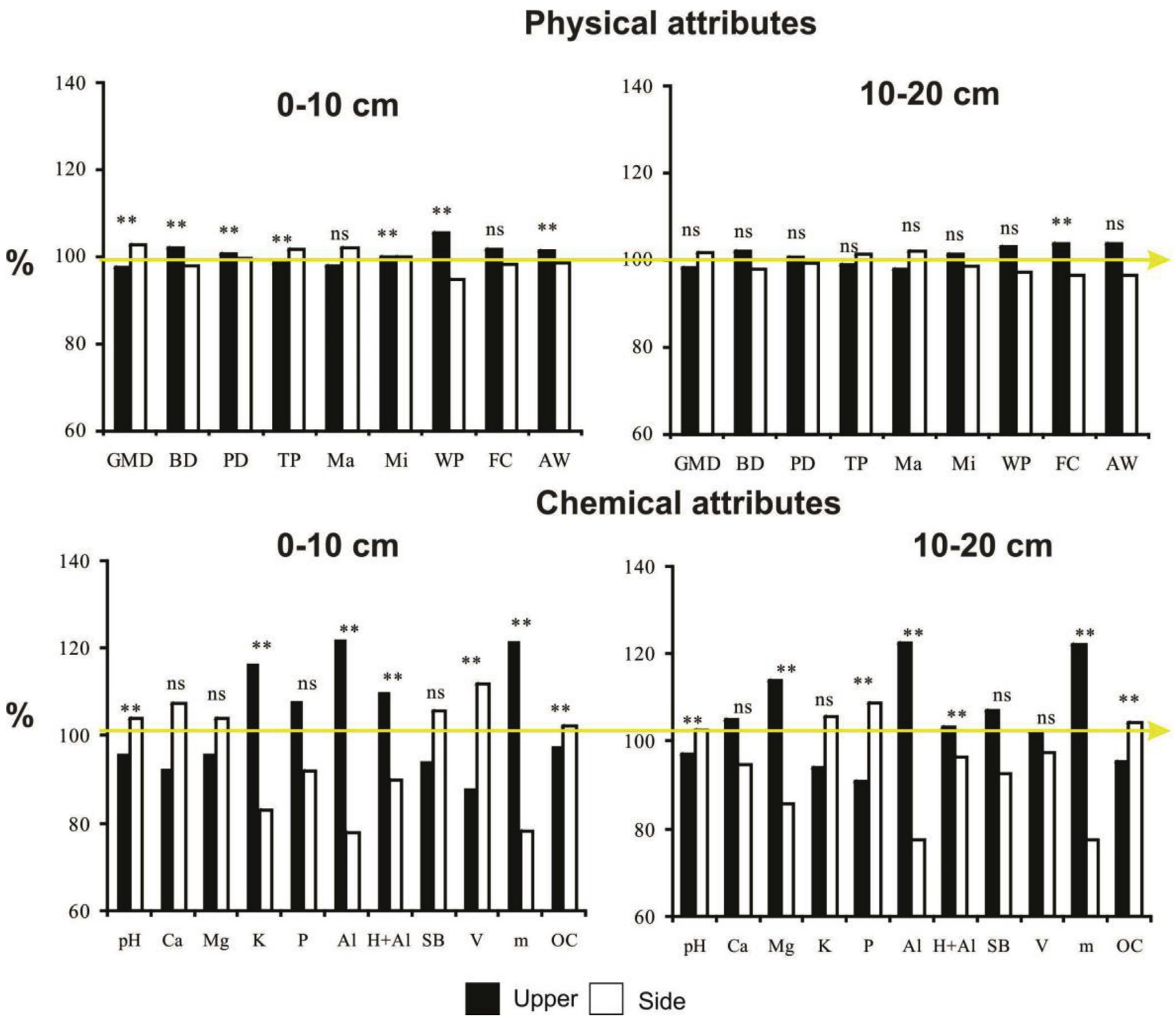

Fig. 3. Relative derivation of soil physical and chemical analyzes for two landscape positions.

3.2. *Multivariate analysis*

The principal component analysis demonstrated that the physical and chemical attributes studied explained the variations found between the treatments (Table 5). For exploratory analysis, the possible grouping between the treatments by physical and chemical characteristics, the scree-plot graph was generated. It was observed that the first two components were sufficient to explain most of the total variation of the data since they retained more than 77% of the discriminant function generated at the two depths (Fig. 4). The highest percentage of accumulated variation was explained by the first component, being 50.07% at 0.0–0.10 m depth and 44.95% at 0.10–0.20 m depth (Table 5). The highest value of eigenvalue was found for the same component. Except for P and H + Al at 0.0–0.10 m depth, Mi, pH, H + Al, BS, and SB in all other attributes studied correlated with the main components, resulting in the values above 0.70 (Table 5). These results demonstrated that all the attributes chosen explained most of the variation among the studied areas (Regazzi, 2001).

By visualizing the dendrogram, it was observed that the most significant dissimilarity among the studied areas for the two depths was observed in the forest area in the upper position. At a 70% cut in relation to the dissimilarity, it was observed that the pasture in the lower position along with the coffee in the upper position and the forest area in the upper position were grouped together for 0.0–0.10 m depth. The second grouping for this depth was formed by pasture in the upper position, and forest and coffee in the lower position (Fig. 5).

At depth 0.10–0.20 m, the forest area in the lower position formed an individualized group, with the two pasture areas near this group. A separate third group was formed, which composed of the two positions of the landscape in the coffee area and the upper position in the forest area (Fig. 5).

4. Discussion

4.1. *Chemical indicators*

The smaller differences observed for the soil chemical quality indicator between the two landscape positions in the forest area show that the system maintains soil quality levels for both landscape positions. It also indicates the capacity of the system to maintain the environmental services, such as climate regulation, cycling, and release of nutrients, prevention of pathogens and diseases, conditions to roots growth, conditions to nutrients uptake, and a better environment to microorganisms activity (Table 2). This observation may be attributed to the absence of anthropic practices such as soil tillage, soil exposure, and practices that accelerate soil erosion and consequently soil losses (Panagos et al., 2015), which can lead to differences in soil nutrient content from the top to the bottom part of the landscape.

The lowest soil fertility among the studied areas was observed for the pasture area in the upper landscape position. This result indicates that

Table 4
Mean values of soil physical attributes in upper and lower slope positions, in two depths (0.0–0.10 and 0.10–0.20 m) under coffee, pasture and forestry.

Land use	Slope position	GMD	BD	PD	TP	Ma	Mi	WP	FC	AW
0.0–0.10m		mm	g cm^{-3}		m^3 m^{-3}					
Coffee	Upper	1.40	1.27	2.69	0.52	0.40	0.12	0.01	0.14	0.13
Forestry		2.01	1.31	2.72	0.52	0.40	0.12	0.02	0.15	0.13
Pasture		1.99	1.40	2.80	0.50	0.37	0.13	0.02	0.16	0.14
Coffee	Lower	1.46	1.24	2.75	0.55	0.43	0.12	0.01	0.14	0.13
Forestry		1.94	1.26	2.72	0.53	0.41	0.12	0.01	0.14	0.13
Pasture		2.28	1.31	2.66	0.51	0.38	0.13	0.01	0.15	0.14
Mean		1.84	1.30	2.72	0.52	0.40	0.12	0.02	0.15	0.13
C.V.		6.29	19.41	30.20	17.31	12.71	64.88	12.72	16.86	17.08
F		**	**	ns	**	**	**	**	**	**
0.10–0.20 m										
Coffee	Upper	1.09	1.34	2.72	0.51	0.38	0.12	0.02	0.15	0.14
Forestry		1.77	1.37	2.67	0.48	0.35	0.13	0.02	0.16	0.15
Pasture		2.14	1.39	2.66	0.48	0.35	0.13	0.02	0.16	0.14
Coffee	Lower	1.53	1.29	2.77	0.53	0.41	0.12	0.01	0.14	0.13
Forestry		1.78	1.34	2.54	0.47	0.34	0.12	0.02	0.15	0.13
Pasture		1.86	1.31	2.63	0.50	0.38	0.12	0.02	0.15	0.13
Mean		1.70	1.34	2.66	0.50	0.37	0.13	0.02	0.15	0.14
C.V.		4.82	19.35	20.75	12.75	9.34	52.80	19.97	15.99	15.63
F		**	ns	ns	**	**	**	**	**	**

Stability of aggregates was done according to EMBRAPA (2011). Geometric mean diameter (GMD) was calculated, according to Kemper and Rosenau (1986); soil bulk density (BD) was determined by the volumetric ring method, using Uhland sampler (Blake and Hartge, 1986); particle density (PD) was determined by the volumetric flask; total porosity (Tp), obtained by the relationship between the soil density and the particles density (1-Bd/Pd); microporosity (Mi), tension table (60 cm water column); and macroporosity (Ma), determined by the difference between total porosity and microporosity (Ma = Tp-Mi); soil water retention in the field capacity (FC) (10 KPa), and at the permanent wilt point (WP) (1500 KPa), were determined by the porous plate extractor. Available water (AW) was calculated, after the determining FC and WP (EMBRAPA, 2011). C.V.: coefficient of variation; *F*: F test (ANOVA); **: Significant by the F test (ANOVA) at 5% probability; ns: no significant.

Table 5
Principal component analysis for the first two principal components (PC) considering different soil physical and chemical attributes associated to the upper and slope position in different land use managements.

Principal components	0.0–0.10 m		0.10–0.20 m	
	PC_1	PC_2	PC_1	PC_2
Eigenvalue	12.02	6.69	10.79	6.96
Total variance (%)	50.07	27.87	44.95	28.98
Factor coordinates of the variables				
GMD	**−0.74**	0.47	**−0.70**	−0.45
BD	**−0.96**	−0.23	**−0.84**	0.26
PD	−0.27	**−0.89**	**0.84**	0.14
TP	**0.96**	−0.14	**0.98**	−0.17
Ma	**0.97**	−0.14	**0.97**	−0.24
Mi	**−0.84**	0.15	−0.68	0.64
WP	**−0.81**	−0.47	**−0.93**	0.20
FC	**−0.99**	−0.09	**−0.80**	0.51
AW	**−0.98**	−0.01	**−0.79**	0.53
pH	0.57	**0.71**	0.09	0.25
Ca	**0.72**	0.60	0.27	**0.90**
Mg	0.35	**0.89**	−0.25	**0.90**
K	−0.11	**0.90**	−0.42	**−0.83**
P	0.65	−0.24	**0.96**	−0.21
Al	−0.67	**−0.74**	−0.58	**−0.71**
H + Al	0.09	−0.65	0.52	−0.54
SB	0.61	**−0.73**	0.19	0.63
BS	**0.81**	−0.49	0.44	0.51
AS	−0.38	**0.79**	0.02	−0.52
OC	**0.76**	0.12	**0.88**	0.43

Geometric mean diameter (GMD); soil bulk density (BD); particle density (PD); particles density (Pd); total porosity (Tp); macroporosity (Ma); microporosity (Mi); permanent wilt point (WP); field capacity (FC); available water (AW); sum of bases (SB); percentage of base saturation (BS); percentage of aluminum saturation (AS); OC: Organic carbon.

pasture management is inadequate for this region since the soil has been losing the ability to provide environmental services such as support the primary production of grass, cycling and release nutrient to the grass, prevention of pathogens and diseases, soil renewal, maintenance of biodiversity and climate regulation (Table 2). The loss of pasture quality in this region has been pointed out in other studies (Bertossi et al., 2016; Rocha Junior et al., 2017b). The improvement in soil fertility in the lower position of landscape in this treatment indicates that anthropic activities such as super grazing, burning and absence of fertilization may be accelerating erosion processes and depositing sediment from the higher parts of the landscape to the lower regions, and therefore improving soil fertility in the lower position. According to Rocha Junior et al., 2017a, 2017b, soil losses in grazing areas under conventional management can reach ~10 t ha/year, and Ca, Mg, P, K and OC depositions in these areas can reach respectively ~95, ~55, ~89, ~425 and ~141,610 g ha/year. In this sense, the indirect gain in soil fertility in the lower position of the pasture is due to the soil quality loss in the higher position of the landscape.

In the soil with the coffee plantation, better soil fertility was observed in the higher landscape position. It is possible that the differences found between the landscape positions in the coffee area are related to fertilization. Higher levels of nutrients were expected in the lowest part of the coffee plantation, since the highest clay content was found in this area, which has a higher nutrient retention capacity (Table 1), in addition, a tendency to deposit nutrient in the lower parts of the landscape (Nie et al., 2013). However, a proper explanation for the lower nutrient values in the lower position of the coffee area is inadequate soil fertilization allowing higher levels in the upper part of the landscape.

4.2. *Physical indicators*

For particle density (PD), it was expected that there would be no significant differences since the studied area presented the same class of soil, Red-Yellow Oxisol and was formed under the same material as granite-gneiss. As observed by Bertossi et al. (2016), the values of PD of the study area ranged from 2.54 to 2.80 g dm^{-3}, indicating the predominance of quartz in the sand fraction and the presence of kaolinite in

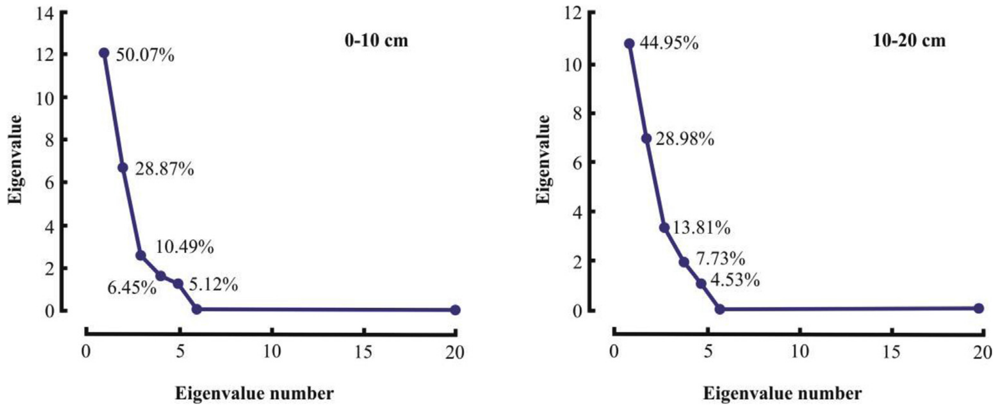

Fig. 4. Graph of the eigenvalues according to the order of the main components for two depths.

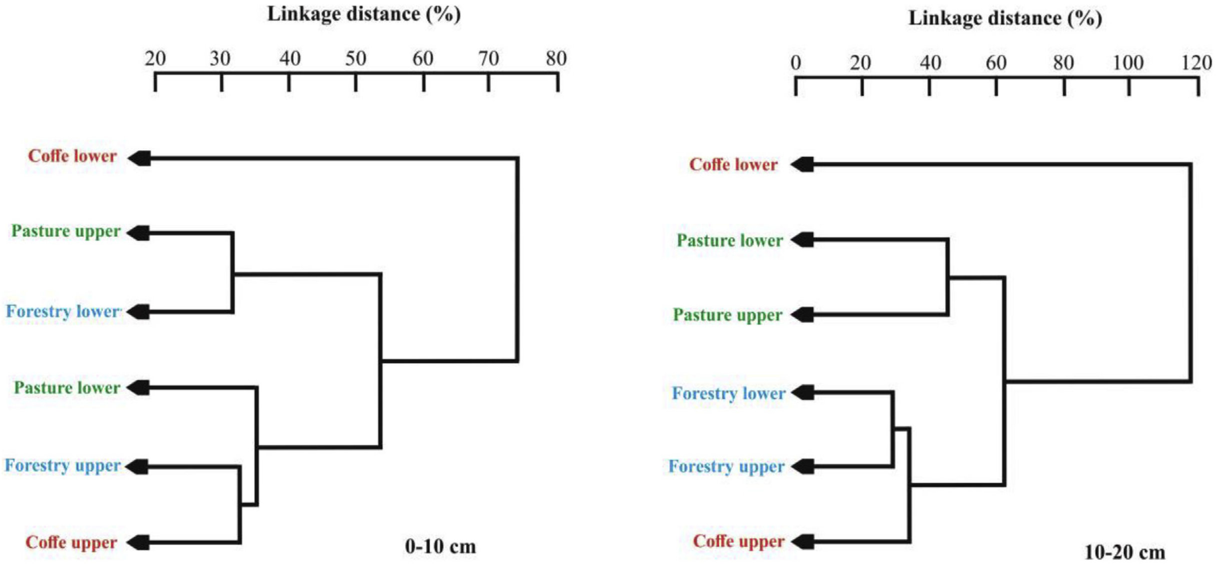

Fig. 5. Dendrogram obtained by the square method of the mean Euclidean distance between the six treatments (combinations between land uses and position in the landscape).

the clay fraction (Macedo and Crestana, 1999). Since there was no difference in measured PD for three different land uses, it indicated that PD was not a good indicator of soil quality in this case. This result also asserted that the soils were similar pedogenetically and the variation in other soil physical attributes found were due to the adoption of different soil management practices.

Highest values of aggregation obtained for pasture area are typical for this practice. Even at a particular stage of degradation, pasture may provide higher values than those found in the forest area and, especially in an area with coffee (Rocha Junior et al., 2017a). The highest aggregation in the pasture area is related to the constant root growth as well as to its renewal in the superficial layer, which conditions the formation of stable aggregates (Salton et al., 2008). This higher aggregation of soil in the pasture area indicates improvement in the soil property to provide better environmental services with the adoption of this management system since more aggregate soils are subject to suffer less from erosive processes (Rocha Junior et al., 2017b). However, higher BD values may indicate higher soil compaction in this area.

Excessive trampling, lack of pasture management control and erosion are the leading causes of soil compaction in the Atlantic region (Favero et al., 2008; Bertossi et al., 2016; Rocha Junior et al., 2017a, 2017b). This leads to less sustainable soils in this area, and, consequently, less capacity of this area to provide environmental services (e.g., create a habitat for soil organisms, conditions to plant growth, aeration for microorganisms and roots, better conditions to water infiltration and erosion control), especially to those related to the infiltration of water in the soil (Table 2).

The higher FC and WP values can be related to the higher values of Mi, and the better aggregation of the soil, which allows better retention of water in the soil. However, due to the greater compaction indicated by the BD, it leads us to interpret this data with caution, suggesting that this higher retention of water may not be beneficial and can condition soil drenching, and consequently increase compaction by animal trampling.

The results of Ma and TP, as well as low BD values, may indicate an improvement in the physical quality of the soil area with coffee cultivation and the ability of this management system to provide improved environmental services (Table 2), especially in the lower position of the landscape. This result can be related to the plants between the planting lines, which are being managed with chemical and manual ways. The litter left under the soil by the natural plants may promote the regeneration of the soil structure between the coffee planting lines, and consequently improving the physical quality of these soils. In this case, natural plants may promote ideal conditions for fauna attraction, rapid growth and significant litter deposition in these soils (Chada et al., 2004). The presence of vegetation cover may improve the physical properties of the soil, the renewal of the root system or the deposition of straw in the soil. In the literature, it is documented that soil physical properties might improve after eight years of the appearance of spontaneous plants under regeneration (Rocha Junior et al., 2017a, 2017b).

4.3. Derivation relative

The greater difference between the two positions of the landscape in the 0.0–0.10 m depth observed by the relative derivation may be related to the greater presence of the root system at this depth, which has a significant influence on the chemical and physical properties of the soil. Specifically, in pasture and coffee land uses, where soil management practices such as fertilization, machine traffic, and animal trampling are frequent, and they may also have influenced the attributes in the two landscape positions.

For the 0.0–0.10 m depth, the no significant difference in the physical attributes PD and Mi between the two landscape positions indicate that these properties are not controlled by the relief. The same is observed for the chemical attributes Ca, Mg, P and SB, which did not exhibit any statistical differences. It seems that the PD and Mi are controlled by soil mineralogy as they were similar between the two positions of the landscape. The presence of kaolinite may have influenced the structural development of the studied Oxisol, which impacted Mi (Ferreira et al., 1999) and PD. On the other hand, the differences between the two positions in the 0.10–0.20 m depth for Mi, FC, and AW may be related to the difference in soil texture between the two landscape positions. The higher clay content (Table 1) in the upper position of the landscape may be the reason for higher Mi, and consequently increasing water retention and FC.

The lower position of the landscape had lower BD but higher GMD, TP, and Ma. Since this increase is beneficial to soil quality and the capacity of different land uses to provide environmental services, it is observed that it is necessary to adopt different soil management practices between the two landscape positions to improve the ability of the upper position to provide environmental services regardless of soil management. In addition, since the improvement of soil properties in the lower position is related to the decrease in soil quality in the upper position, the valuation of environmental services must be performed differently between the two landscape positions.

Since P-available is little mobile in the soil profile because these soils are highly weathered (Novais and Smyth, 1999), P leaching from one position of the landscape to another is almost non-existent. Therefore, it was expected that there would be no differences in the P content at the 0.0–0.10 m depth between the two landscape positions. The differences observed for P-available between the two landscape locations in the 0.10–0.20 m depth may be related to the higher sand content in the lower position of the landscape, which may have reduced the adsorption of the P in the surface layer.

For the 0.0–0.10 m depth, there was a tendency of higher pH, Ca, Mg, BS, SB, and OC, but lower Al, H + Al and AS at the lower position when compared to the upper position of the landscape. This tendency occurred since the basic cations and OC tend to be eroded from the highest positions of the landscape to the lower parts, leaving the acidic cations as Al. Since the 0.10–0.20 m soil depth was less influenced by erosive processes, and consequently, there was no specific trend.

The higher content of K in the upper landscape position may be due to the erosive process that removes the superficial layer of the soil. This phenomenon consequently makes the surface layer similar to the source material that is rich in this nutrient, thus promoting the higher contents of this nutrient.

4.4. Multivariate analysis

The strong correlation (>0.70) of soil physical and chemical attributes with the first two principal components, with the exception of P and H + Al at both depths, and Mi, SB, BS at 0.10–0.20 m depth indicate that the soil attributes studied can be used to measure the capacity of different soil uses to provide environmental services.

Based on the grouping generated from the dendrogram, it could be concluded that the treatments with closer proximity had similar behaviors. The dendrogram result indicated that there were three groups with the capacity to provide environmental services.

Based on the multivariate analysis, the lower capacity to provide environmental services was related to the upper position of the landscape, especially under the pasture. The higher ability to deliver environmental services was related to the forest area, followed by the Coffee area in the lower position of the landscape, indicating a better chemical and physical attributes in the lower position of the landscape.

The better soil quality was observed in the forest area in the lower position of the landscape in the two depths, which presented greater dissimilarity from the other areas. The second group in the 0.0–0.10 m depth was that related to pasture in the lower position of the landscape, and the forest and coffee area in the side position. The group to provide the lowest capacity of environmental services contained the pasture and the coffee in the upper position.

At the 0.10–0.20 m depth, the two coffee areas (upper and lower), as well as forest area in the higher position, formed the second group and the pasture areas (upper and lower) formed the third group.

5. Conclusion

This paper investigated the potential of different land uses and landscape positions to provide environmental services by comparing the soil indicators related to the physical and chemical properties of the soil. This study identified that forest area was the one that presented higher soil quality and capacity to provide environmental services among the three land uses studied. One of the more significant findings to emerge from this study is that the landscape positions did not show any general tendency for all the studied areas indicating that the relief is not a specific factor controlling the soil quality. These findings suggest that, in general, the variations in soil quality are found due to the land use system. The general usability of these results is subject to certain limitations. For instance, the study was conducted with one soil class and relief. However, the soil class studied is the most common in Brazil, and the relief studied its very common in the region of "*mares de morro*". A natural progression of this work is to analyze other soils classes and relief degrees so that the potential to provide environmental service in different land use and landscape position can be investigated.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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