STRUCTURAL QUALITY OF SOILS CULTIVATED WITH COFFEE AND PASTURE IN AN ENVIRONMENTAL PROTECTION AREA⁽¹⁾

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ABSTRACT

Studies of soils in Environmental Protection Areas (EPAs) are of great importance, because they are an essential component of ecosystems, directly interfering in environmental sustainability. The objective of this study was to evaluate the structural quality of soil cultivated with coffee and used as pasture in the Capituva's River microbasin, which is located in the Environmental Protection Area in Coqueiral, south of the state of Minas Gerais. Uniaxial compression test (preconsolidation test) and soil resistance to penetration were used. Undisturbed samples were taken from the surface layer (0–5 cm) of the soils in the area: a typic dystrophic Red Latosol (LVd - Oxisol), a typic eutrophic Red Argisol (PVe - Ultisol), and a typic dystrophic Haplic Cambisol (CXbd - Inceptisol). A significant linear positive correlation was observed between the results of the preconsolidation test and soil resistance to penetration. Load bearing capacity of soil could be estimated accordingly by means of penetration resistance for LVd, PVe, and CXbd. Cambisol - CXbd showed lower loading support capacity and resistance to penetration than LVd and PVe, due to the better crop management in this soil that resulted in higher physical quality which accounts for higher production and environmental sustainability.

Index terms: compression, environmental sustainability, soil water availability, load support capacity, soil penetration resistance.

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RESUMO: *QUALIDADE ESTRUTURAL DE SOLOS CULTIVADOS COM CAFÉ E PASTAGEM EM ÁREA DE PROTEÇÃO AMBIENTAL*

O estudo do solo em áreas de proteção ambiental (APAs) é de grande importância, pelo fato deste ser componente essencial dos ecossistemas, interferindo diretamente na sustentabilidade do ambiente. Objetivou-se, com este trabalho, avaliar a qualidade estrutural de solos cultivados com café e pastagem na microbacia do Ribeirão Capituvas, inserido na APA Coqueiral, tendo por base uma caracterização pedológica e utilizando-se os ensaios de compressão uniaxial e resistência do solo à penetração. Coletaram-se amostras indeformadas na camada superficial (0–5 cm) do Latossolo Vermelho distrófico típico (LVd), do Argissolo Vermelho eutrófico típico (PVe) e do Cambissolo Háplico distrófico típico (CXbd). Verificou-se correlação positiva, linear e significativa entre a pressão de preconsolidação e a resistência do solo à penetração, podendo a capacidade de suporte de carga ser adequadamente estimada, por meio da resistência à penetração, para LVd, PVe e CXbd. Para os usos estudados, o CXbd apresentou a menor capacidade de suporte de carga e a menor resistência à penetração, comparado ao LVd e ao PVe, devido ao bom manejo do solo resultando em alta qualidade física e no cumprimento da função produtiva e da sustentabilidade ambiental desse solo.

Termos de indexação: compactação, sustentabilidade ambiental, disponibilidade hídrica do solo, capacidade de suporte de carga, resistência do solo à penetração.

INTRODUCTION

Environmental Protection Areas are recognized for linking the conservation of natural resources with sustainable crop production. Improving human activities in these conservation units based on crop production potential and soil limitation studies, showed significant results on maintaining diversity of species and natural processes in these environments.

As an essential component of ecosystems, soils directly influence sustainability of these areas. Thus, understanding the processes in the soil-plant aimed at the management of soil quality must be preceded by a search for soil quality (Vezzani & Mielniczuk, 2009). Every producer is very important in the maintenance of sustainability, since their decisions about soil management affects the entire hydrographic basin in which their land is located.

Innumerous authors point out the importance of studying soil physical qualities (Oliveira et al., 2003; Tormena et al, 2007; Severiano et al., 2008; Ajayi et al., 2009). Attributes that define the physical quality express environmental stability, mainly when it is evaluated using physical characteristics and properties that directly correlate with soil role within hydric aspects.

In this context, evaluations of the load bearing capacity of soil (Dias Junior et al., 2002) in order to predict compression, based on uniaxial compression tests (Dias Junior & Pierce, 1995; Peng et al., 2004; Gontijo et al., 2007) and soil penetration resistance studies (Tormena et al., 1998; Oliveira et al., 2007; Severiano et al., 2008, Ajayi et al., 2009) have been widely used since they consider several soil attributes in a single evaluation.

Some soil physical attributes can support inferences on soil quality, since differences in these attributes can help to define specific soil management practices in order to improve the edaphic environment for plant growth.

The objective of this research was to evaluate the structural quality comparing uniaxial compression and soil penetration resistance tests in soils cultivated with coffee and used as pasture in the Capituva's River microbasin, which is part of the Coqueiral Environmental Protection Area.

MATERIALS AND METHODS

The research was carried out in the Capituva's River microbasin located in the Coqueiral Environmental Protection Area, in the south of the state of Minas Gerais, Brazil. According to Koppen, the local climate is classified as Cwa: rainy and mild summer with a moderate temperature (21 °C annual average). The average annual rainfall is 1,500 mm and air relative humidity is 70 % (Emater, 2002).

This microbasin was selected because it is representative of the Coqueiral Environmental Protection Area, which represents quite well the southern region of the state of Minas Gerais, as related to land use, terrain, and soil classes. Soils were classified using the Brazilian Soil Classification System (Embrapa, 2006) up to the fourth categorical level, using the Soil Description and Field Sampling Manual (Santos et al., 2005) to describe the morphology of the three complete soil profiles and nineteen complementary soil profiles.

The soils are mostly shallow, formed from weathering of granitic rocks from the pre-Cambrian period (Brasil, 1962). The landscape has been dissected by water erosion and is mainly undulated, whose surfaces vary from convex to concave, at the top of hills and the bottom of valleys, respectively.

This microbasin has an area of 33.8 ha, with typic dystrophic Haplic Cambisol (CXbd - Inceptisol), 51 % of the area, typic eutrophic Red Argisol (PVe - Ultisol), 33 % of the area, and a typic dystrophic Red Latosol (LVd - Oxisol), 8 % of the area. In addition to these soils, a Litholic Neosol, associated with rocky outcroppings, and mixed footslope and toeslope soils are also found along the drainage network, which takes up 8 % of the area. The chemical properties of these soils are shown on table 1 and the physical and mineralogical characterization on table 2.

Coffee and pasture (*Brachiaria decumbens*), respectively, make up 8 and 84 % of the area. The soils were tilled for coffee and pasture implementation and have been cultivated for about eight years; they were previously used as natural grazing. Although the LVd area has some old terraces, the farmers have used this area for pasture only with no other soil conservation practices. In the PVe area, the farmer hasn't adopted adequate soil conservation and management practices; for this reason the coffee crop is in bad shape and the pastures are degraded. On the other hand, in the CXbd area, there are terraces and adequate practices for coffee cropping; the farmer takes good care of native areas, keeping the soil surface covered between rows of the crop and an appropriate management in the pasture area. All farmers use manual harvesting for coffee crops.

Table 1. pH in water, soil organic matter (SOM) and sorptive complex components of the soils in the Capituva's River microbasin, Coqueiral Environmental Protection Area

Layer (1)	pH	SOM	P	K	Ca^{2+}	Mg^{2+}	Al^{3+}	V (2)	m (3)
cm		dag kg $^{-1}$	mg dm^{-3}		cmol$_c$ dm^{-3}			%	
				Typic dystrophic Red Latosol – LVd					
0–5	4.5	3.1	1.4	41	0.2	0.1	2.0	3.1	83
80–100	4.5	1.8	0.6	8	0.5	0.2	1.5	6.8	68
				Typic eutrophic Red Argisol – PVe					
0–5	5.7	2.2	1.2	89	2.3	0.9	0.2	46.2	6
50–70	5.8	0.6	1.2	33	1.8	0.8	0.2	50.8	7
				Typic dystrophic Haplic Cambisol – CXbd					
0–5	6.0	2.1	2.8	246	2.1	1.1	0.2	54.5	5
25–45	5.4	0.8	0.9	131	0.2	0.1	1.2	15.1	65

(1) Depth corresponding to the surface layer and B (diagnostic) soil horizon. (2) Base saturation (V). (3) Saturation by Al (m). Analyses carried out using the Embrapa (1997) methodology.

Table 2. Physical and mineralogical characterization of soils in the Capituva's River microbasin, Coqueiral EPA

Horizon	Dp (1)	Grain size			Sulfuric attack			Ki	Kr
		Clay	Silt	Sand	SiO_2	Al_2O_3	Fe_2O_3		
	Mg m^{-3}	g kg^{-1}							
			Typic dystrophic Red Latosol – LVd						
A	2.50	552	115	333	-	-	-	-	-
Bw	2.67	589	91	320	188	208	89	1.53	1.20
			Typic eutrophic Red Argisol – PVe						
A	2.53	264	184	552	-	-	-	-	-
Bt	2.70	560	127	313	231	208	101	1.89	1.44
			Typic dystrophic Haplic Cambisol – CXbd						
A	2.60	270	200	530	-	-	-	-	-
Bi	2.60	213	271	516	166	147	25	1.92	1.73

(1) Particle density by the volumetric balloon method. Ki: molecular ratio SiO_2/Al_2O_3; Kr: molecular ratio $SiO_2/(Al_2O_3 + Fe_2O_3)$. Analyses carried out using the Embrapa (1997) methodology.

Undisturbed soils were sampled in triplicate in volumetric rings (8.25 cm high by 6.95 cm diameter) for saturated-soil hydraulic conductivity (K_{sat}) (Lima et al., 1990), soil density (Ds) (Blake & Hartge, 1986) and penetration resistance at 10 kPa tension ($RP_{10\ kPa}$), as in Tormena et al. (1998) adapted for penetration speed; obtaining a total of 54 samples (3 soils x 2 uses x 3 points x 3 repetitions).

For the uniaxial compression and soil penetration resistance tests, undisturbed samples were collected using an Uhland sampler in the superficial layer of each soil in 6.40 cm diameter and 2.50 cm high volumetric rings, with six replicates at each sampling site, obtaining a total of 108 samples (3 soils x 2 uses x 3 points x 6 repetitions).

Undisturbed samples were saturated from the bottom of each column with water using a suction column (Reinert & Reichert, 2006). Then, these samples were air dried until water content was between -10 and -1,500 kPa; half of them (54) were submitted to uniaxial compression tests (Dias Junior, 1994) and the other half to penetration resistance tests (RP) (Tormena et al., 1998) adapted for penetration speed.

The uniaxial compression test was at the following pressures: 25, 50, 100, 200, 400, 800, and 1,600 kPa; each level of pressure was applied until 90 % of maximum deformation was reached (Taylor, 1948), before the next level. Then, the samples were dried at 105 °C for 48 h in order to determine soil density (DS). Preconsolidation pressure (σ_p) was estimated as in Dias Junior & Pierce (1995). Load bearing capacity models (CSC) were obtained by adjusting σ_p as a function of volumetric water content of the soil sample (Gontijo et al., 2007), using equation 1 (Dias Junior, 1994). Comparisons of regression equations were done as in Snedecor & Cochran (1989).

$$\sigma_p = 10^{(a + b\theta)} \qquad (1)$$

where σ_p: preconsolidation pressure (kPa); a and b: fitting parameters; and θ: volumetric water content ($m^3\ m^{-3}$).

RP was determined using a Marconi MA 933 Model electronic penetration-meter, at constant speed (10 cm min^{-1}), after equilibrating the sample for the desired water content; four tests were done in each sample. Then, the samples were oven dried at 105 °C for 48 h to determine Ds. The RP values (kgf cm^{-2}) were multiplied by a factor of 0.098 to transform them into MPa and adjusted to nonlinear models as a function of volumetric water content (θ), using equation 2 (Dias Junior, 1994). Comparisons of the regression equations were carried out as in Snedecor & Cochran (1989).

$$RP = 10^{(a + b\theta)} \qquad (2)$$

where RP = penetration resistance (MPa); a and b = fitting parameters; and θ = volumetric water content ($m^3\ m^{-3}$).

Data exploration analysis was done to the Ds, K_{sat} and $RP_{10\ kPa}$ results in order to obtain distribution and dispersion measures. Analysis of normality of error was done using the Shapiro-Wilk test. Analysis of variance and means comparison by the Scott-Knott test to 5 % were done using the Sisvar statistical program (Ferreira, 2005).

RESULTS AND DISCUSSION

For the three soil classes, the higher the Ds values, the higher the RP_{10kPa} and lower the K_{sat} values (Table 3). The soil under the pasture had higher Ds which is accounted for by the constant pressure that is applied by grazing cattle; as a consequence, high RP and low K_{sat} values are found in this pasture area.

A positive and significant correlation between Ds and K_{sat} (0.71) was found, despite the high variation coefficient in K_{sat} data (CV = 86 %). These results are justified by the fact that K_{sat} is a function of pore distribution by size, directly varying with the amount of macropores (Ferreira & Dias Junior, 2001). Macropores are thus related to Ds, in a way that their decrease means increased density.

According to the Soil Survey Staff (1993), K_{sat} can be classified into fast, > 254; moderate to fast, 254–127; moderate, 127–63.5; slow to moderate, 63.5–20; slow, 20–5; and very slow, < 5 mm h^{-1}. In general, the cultivated soils in this microbasin area had moderate to slow K_{sat}. The best scenario for water infiltration in soil is found in the CXdb soil, which shows a moderate K_{sat}.

Table 3. Soil density (Ds), hydraulic conductivity of saturated soil (K_{sat}), and penetration resistance at 10 kPa tension (RP_{10kPa}) of the soil surface layer cultivated with coffee and pasture in the Capituva's River microbasin, Coqueiral EPA

Land use	Ds	K_{sat}	$RP_{10\ kPa}$
	Mg m^{-3}	mm h^{-1}	MPa
	Typic dystrophic Red Latosol – LVd		
Coffee	1.37a	117.97a	2.06a
Pasture	1.50b	23.06b	3.03b
	Typic eutrophic Red Argisol – PVe		
Coffee	1.44a	31.33a	1.84a
Pasture	1.44a	15.86a	2.54b
	Typic dystrophic Haplic Cambisol – CXbd		
Coffee	1.32a	120.18a	2.27a
Pasture	1.46b	27.52b	2.70a

Means followed by the same letter, comparing land uses within each soil in columns do not differ from each other at 5 %, by the Scott-Knott test.

As can be observed, σ_p (left) and RP (right), as a function of water content for LVd, PVe, and CXbd, do not point out differences on structural quality diagnosis, independent of usage as coffee plantation or pasture (Figure 1). Using the statistical procedures suggested by Snedecor & Cochran (1989), significant difference was only found in RP of LVd. For CXbd and PVe, there were no differences between compression behavior and RP, when these soils were used either for coffee plantations or pasture.

For both coffee and pasture uses, the CSC curves get close to each other, as the water content of samples increases (Figure 1-left); at this point, water content is the main property that accounts for soil compression (Kondo & Dias Junior, 1999). When the soil is dry, the structure is mainly responsible for soil CSC (Dias Junior, 1994). At low water content, there is a tendency for these curves to be separated from each other, due to different σ_p values that are always higher for soil used for coffee cultivation. This behavior is attributed to the better soil structure and resilience of soils cultivated with coffee, mainly due to greater additions of organic residues and lack of deep soil tilling (Soane, 1990).

Since no significant differences were found between CSC models in coffee and pasture areas, a single model with 18 samples was plotted. This model represents the compression behavior of the soil for both uses. Analyzing the compressive behavior of the three soils when the models were linearized ($\log\sigma_p = a + b\theta$), a higher CSC was observed in PVe, followed by LVd, and CXbd. The three soils behave differently in terms of CSC; the curves are homogenous for regressions, not significant for the linear coefficient and significant for the angular coefficient ($F = 13.97$, $p < 0.001$ between CXbd and LVd; $F = 6.34$, $p < 0.05$ between LVd and PVe; and $F = 45.66$, $p < 0.001$ between CXbd and PVe) (Figure 2).

The greatest CSC observed for PVe is due to the combination of greater Ds values (Table 3) resulting from medium texture of the upper layer (Dias Junior et al., 2002) along with the more intensive use of this soil without conservation practices, as suggested by the degradation of the pasture and the coffee field. This soil had a moderate to strong structure, medium to large blocks, that, according to Peng et al. (2004), accounts for a greater load bearing capacity. Cohesion and friction forces between particles are more intense

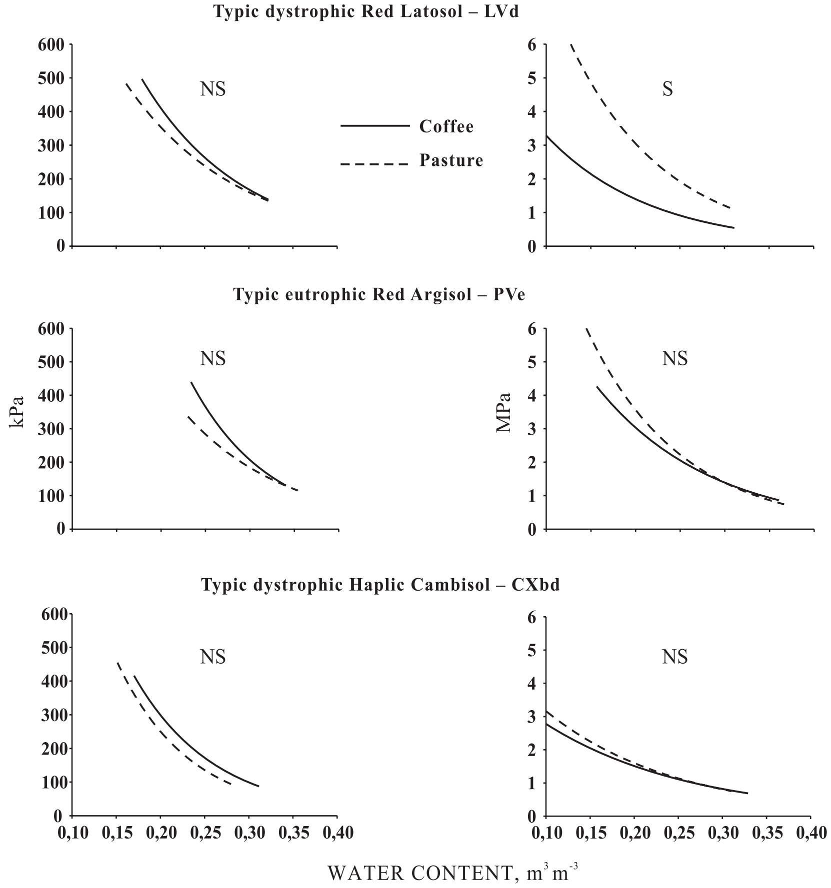

Figure 1. Preconsolidation pressure (left) and penetration resistance (right) in function of water content for the surface layer of soil cultivated with coffee and pasture in the Capituvas River microbasin, Coqueiral EPA. S: Models presented are significantly different; NS: models are not significantly different by the test suggested by Snedecor & Cochran (1989).

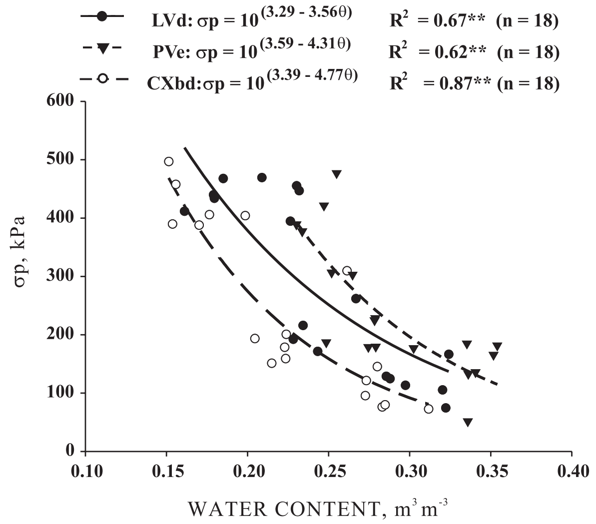

Figure 2. Load bearing capacity models in a Typic dystrophic Red Latosol (LVd), a Typic eutrophic Red Argisol (PVe), and a Typic dystrophic Haplic Cambisol (CXbd) cultivated with coffee and pasture at a depth of 0–5 cm in the Capituva's River microbasin, Coqueiral EPA.

in soils that have already undergone greater changes of its structure (Michel, 1976) which overcomes the effect that water would have on soil compression behavior (Kondo & Dias Junior, 1999) in the water tension range used in this study. The pre-compression effect was also verified by Silva et al. (2002); the authors found a significant increase in preconsolidation pressure from 68 to 164 kPa for Ds values of 1.3 and 1.6 Mg m^{-3}, respectively, in Red-Yellow Argisol.

The CXbd had the lowest CSC (Figure 2). Since it is a less weathered soil (Ki = 1.92) (Table 2), consequently with weak and more cohesive structure, a greater CSC was expected, compared to the other studied soils. However, this soil has a history of less degrading tension, confirmed by the better shape of pasture and the coffee plantation. It is suggested that this result is related to the owner's concern and use of adequate soil management for this area.

On the other hand, lower CSC was expected for the LVd, due to its higher weathering (Ki = 1.52) (Table 2) that is associated with better structure, formed by small and stable aggregates, high porous space (Peng et al., 2004; Santos et al., 2005), as well as clay content. However, the LVd had an intermediate load bearing capacity, which was attributed to the degrading management that caused laminar erosion in the area. Severiano (2010) stated that Latosols with clayey- and very-clayey textures are more susceptible to compression, which can take place even when the soil is dry.

Changes in the structure of all three soils take place due to plowing and management adopted for coffee cultivation and pastures. The PVe had the highest RP values, followed by LVd and CXbd (Figure 3). RP, as a function of moisture content, was studied by several authors, such as Imhoff et al. (2000), Dias Junior et al. (2004), Oliveira et al. (2007), and Severiano et al. (2008), showing the importance of RP in determining the soil physical quality.

Significant differences were found between RP models linearized ($\log\sigma_p = a + b\theta$) as a function of soil moisture content. The CXbd, differed from LVd (F = 10.05; $p < 0.001$) and the LVd differed from PVe (F = 40.28; $p < 0.001$) for the angular coefficient; The CXbd differed from PVe for homogeneity (F = 1.88; $p < 0.001$) and angular coefficient (F = 134.16; $p < 0.001$). Lower RP values with increasing moisture content are due to decreasing cohesion and internal friction angle (Camp & Gill, 1969).

The amplitude of RP values is smaller for CXbd; values greater than 2.5 MPa only were possible for moisture content smaller than 0.13 m^3 m^{-3}. Such RP values are restrictive for most crops (Camargo & Alleoni, 1997). This indicates a better state of soil structural preservation (Oliveira et al., 2007), keeping in mind that these conditions are only reached when the moisture content of this soil is very low.

Higher RP values in PVe, followed by LVd and CXbd, are in agreement with CSC results, suggesting that what changes σ_p also changes RP. Some authors, such as Culley & Larson (1987) and Lima et al. (2006), also verified significant, positive linear correlations between RP and σ_p, showing that high σ_p values are associated to RP increases. Therefore, σ_p can be estimated by using RP values; this is very positive,

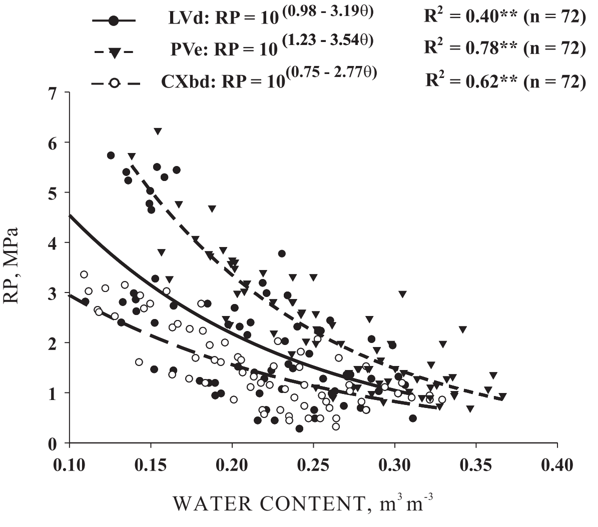

Figure 3. Penetration resistance models of a Typic dystrophic Red Latosol (LVd), a Typic eutrophic Red Argisol (PVe), and a Typic dystrophic Haplic Cambisol (CXbd) cultivated with coffee and pasture at the top layer (0–5 cm) in Capituva's River microbasin, Coqueiral EPA.

since RP analyses are cheaper, simpler, and less time consuming.

Preconsolidation pressure values (σ_p) (soil CSC estimate) correlates significantly and positively with penetration resistance values (RP) in different volumetric water contents in soils (θ). The ratio between estimated σ_p values (measured in kPa) and RP (measured in MPa) for the soils in this study followed the models below, for water content between 0.1 and 0.4 $m^3 m^{-3}$.

LVd: $\sigma_p = 179$ RP; $R^2 = 0.99$
PVe: $\sigma_p = 177$ RP; $R^2 = 0.98$
CXbd: $\sigma_p = 216$ RP; $R^2 = 0.87$

The observed ratios were 5.6:1; 5.7:1; and 4.6:1 for LVd, PVe, and CXbd, respectively. Despite the differences between the soils, no difference was verified for this ratio, regarding σ_p; preconsolidation pressure was 20 % of RP. Canarache et al. (2000) and Mosaddeghi et al. (2003) found a ratio of 10:1 for soils from temperate climates.

A comparative evaluation of σ_p and RP in plots cultivated with coffee or used as pasture within soil classes reflects the type of management to which the soil and the crop have undergone. When soils have the same mineralogy and texture, for instance, the soil under the best management (Oliveira et al., 2003), including the land use history (Kondo & Dias Junior, 1999), will also have the best structural quality.

CONCLUSIONS

1. CSC could be accurately estimated by using RP values for LVd, PVe, and CXbd cultivated with coffee and pasture in the Capituva's River microbasin in the Coqueiral EPA.

2. For the land uses in this study, the CXbd had the lowest CSC and RP values, due to its better management, which results in high physical quality that accounts for higher productivity and environmental sustainability.

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