DETAILED SOIL SURVEY OF AN EXPERIMENTAL WATERSHED REPRESENTATIVE OF THE BRAZILIAN COASTAL PLAINS AND ITS PRACTICAL APPLICATION

Levantamento detalhado de solos de uma microbacia hidrográfica experimental representativa dos Tabuleiros Costeiros brasileiros e sua aplicação prática

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ABSTRACT

This paper presents a detailed soil survey of an experimental watershed with representative pedoclimatic characteristics of the Coastal Plains in Espírito Santo State and its practical applications. For the pedological survey, 35 observation sites and three soil profiles were sampled and described, which were morphologically characterized and subjected to physical (particle size) and chemical analyses (routine and sulfuric acid digestion). The soil map was made using the geographic information system ArcGIS 9.3. This GIS software was also used to generate the digital elevation model (DEM) for identifying the slope classes. SAGA software was used to calculate the topographic wetness index (WI) which aided in a more accurate separation of Haplic Organosol from other soils. The predominant soil class in the watershed was the dystrophic/dystrocohesive Yellow Argisol (97%), containing morphological, chemical and physical characteristics representative of the most expressive Coastal Plains soils. Geoprocessing tools and techniques aided to make the watershed soil map.

Index terms: Soil map, geoprocessing, GIS.

RESUMO

Neste trabalho, apresenta-se o levantamento detalhado de uma microbacia hidrográfica experimental representativa das características pedoclimáticas dos Tabuleiros Costeiros brasileiros e sua aplicação prática. Para o levantamento pedológico, foram descritos morfologicamente e amostradas 35 microtrincheiras e três perfis modais, cujas amostras foram submetidas a análises físicas (textura) e químicas (fertilidade e ataque sulfúrico). A confecção do mapa de solos foi realizada, utilizando-se o sistema de informação geográfica ArcGIS 9.3, no qual foi gerado o modelo digital de elevação (DEM) para a separação das fases de relevo. Utilizou-se também o programa SAGA GIS, para a geração do índice topográfico de umidade (WI) que auxiliou na separação mais precisa do Organossolo Háplico dos demais solos. A classe de solo predominante na microbacia foi o Argissolo Amarelo distrófico/distrocoeso (97%), com características morfológicas, químicas e físicas representativas dos solos mais expressivos dos Tabuleiros Costeiros. Ferramentas e técnicas de geoprocessamento auxiliaram na confecção do mapa de solos da microbacia.

Termos para indexação: Mapa de solos, geoprocessamento, SIG.

INTRODUCTION

Soil survey constitutes one of the first stages of the physiographical and geomorphological study of a watershed, being the basis for several types of work, as can be seen in Costa et al. (2009a), Menezes et al. (2009) and Tonello et al. (2006), not only because soil is considered the main natural resource for land use planning, but also because soil classes stand out as an appropriate environmental stratifier at a local level (Curi, 2000). However, Brazil lacks detailed soil surveys (McBratney; Mendonça-Santos; Minasny, 2003), once the existent ones commonly present scales smaller than 1:250,000. For planning of areas that require a higher level of detail, such as watersheds, map scales at 1:50,000 or greater are necessary (Menezes et al., 2009). In that sense, the use of geotechnologies such as GPS, digital maps, digital elevation models (DEM) and geographical information systems (GIS), along with modern geoprocessing techniques and tools, aid the production of greater scale soil maps, facilitating a more precise delimitation of the soil classes (McBratney; Mendonça-Santos; Minasny, 2003; Costa et al., 2009b; Horta et al., 2009).

Watersheds constitute a fundamental unit of work, environmental studies and for conservationist planning, because they represent a “closed” ecosystem and might be

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pedo-hydrologically monitored (Cardoso et al., 2006). The watershed under this study is an experimental area whose purpose is to host various scientific research activities. It is located in the Coastal Plains, which present an estimated area about 20 million hectares. As an indicative of the importance of that environment, it contains about 50% of the population of the Brazilian Northeast region (Moreau et al., 2006).

The soils of the Coastal Plains originated from pre-weathered sediments of the Barreiras Formation and their main land uses are sugarcane, livestock, silviculture, and orchards (Souza et al., 2004; Fonsêca et al., 2007; Costa et al., 2009c). The dominant soil class is Yellow Argisol (Carvalho Filho; Curi; Fonseca, 2013), presenting chemical and physical properties somewhat restrictive to management. Chemically, the restriction is caused by the low cation exchange capacity and nutrient contents, due to the essentially kaolinitic nature of the Barreiras Formation sediments and the weathering-leaching processes, while the physical restrictions are related to the low permeability and cohesive subsurface horizons that prevent plant root deepening, thus limiting water and nutrient absorption by the roots (Fonsêca et al., 2007), as a natural consequence of reducing the effective soil depth explored by the root system. However, these constraints can be minimized through management practices, mainly for perennial crops, such as the use of fertilizers and subsoilers to overcome the chemical and physical constraints, respectively. The great challenge is the management of annual crops because the Coastal Plains soils are strongly affected by frequent soil revolving, which leads to degradation of the surface soil horizon, with intense rate of sheet erosion, even when they occur on gentle slopes (Resende; Curi; Santana, 1988).

Based on the mentioned above, the objectives of the present work were to conduct a detailed soil survey (scale 1:10,000) of an experimental watershed using geoprocessing techniques to complement the field work and its practical application.

MATERIAL AND METHODS

The work was carried out in an experimental hydrographic watershed, property of Fibria Celulose S.A., in Aracruz county, Espírito Santo State, central coordinates 40°06'34" WGr and 19° 47'41" S, with 181.7 ha (Figure 1). The climate is Aw (tropical climate with a dry season in winter), according to the Köppen classification. The average annual temperature is 23° C, with precipitation of 1,400 mm year^{-1}. The geology comprises sediments of the Barreiras Formation (Duarte et al., 2000). The predominant native vegetation is represented by semiperennial tropical forest. However, most of the watershed has been planted with eucalyptus (135 ha).

In the field work, a planialtimetric survey of the watershed at a 1:2,500 scale was used as base-map, with vertical distance among contour lines equals to 1 m. Prospections throughout the area were carried out using the free walking method, being 22 prospections (small trenches) in the area under eucalyptus cultivation and 13 prospections in the preservation area, with a sampling density of 0.19 prospections ha^{-1}. For the small trenches, a 40 x 40 x 40 cm pit was dug for observation and description of the A horizon and surficial samples collection. For deeper observations and collections, up to 1.20 m, a Dutch auger was employed. All of the prospections were georeferenced with a GPS. Samples were collected, at depths from 0 to 20 cm, 40 to 70 cm and 100 to 120 cm for chemical and physical analyses (Empresa Brasileira de Pesquisa Agropecuária - Embrapa, 1997) to support field physical and chemical characterizations, as well as for soil mapping.

After the morphological description and collection of samples, areas were chosen to represent the variability of the soils to be described as modal profiles (deep trenches), where morphological descriptions and soil sample collections were conducted according to Lemos et al. (2013), being the soils classified according to Embrapa (2013). In the modal profiles, besides the soil physical and chemical characterizations, the quantification of Si, Al, Fe, Ti and P was determined in the fine air-dried soil fraction after sulfuric acid digestion, according to Embrapa (1997).

For definition of the soil mapping units (MUs), drainage, textural gradient, mottling, gravels, rockiness, among other soil attributes were considered as main features.

To prepare the soil map, the ArcGIS 9.3 software (ESRI) was used. First, the digital elevation model (DEM) was created through the topo-to-raster function, using the elevation of the contour lines. Starting from the DEM, the topographical wetness index (WI) was generated in the SAGA GIS 2.0.7 software, which aided the more precise separation of Haplic Organosol from the other soils, because WI reflects the tendency of the water to accumulate in some point of the drainage basin. For the definition of the other MUs limits, eucalyptus plantation was separated from the preservation area (steeper relief). For each of these two conditions, a raster of probability was created to identify the places more likely to represent each condition, with pixel values ranging from 0 to 1 for each MU, using the inverse distance squared interpolation method through the Geostatistic package of ArcGIS 9.3.

Then, the two rasters of probability of the MUs were superimposed, using the highest position tool of ArcGIS, and, for each specific place, the raster that presented highest probability would be classified according to its corresponding MU, thus delimiting the MUs boundaries. After these procedures, DEM was used to define the following slope classes: plain (0-3%), gently undulated (3-8%), undulated (8-20%) and strongly undulated (20-45%), that were cross-referenced with the MUs. Small adjustments were manually made through the advanced editing tool of ArcGIS.

RESULTS AND DISCUSSION

Detailed soil survey

Figure 2 and table 1 present the soil map and the geographical expression of MUs, respectively, for further information and complete descriptions of the profiles, additionally to the analytical results of the small trenches, consult Santos (2012). It can be seen that 96.4% of the watershed soils belong to the distrophic/distrocohesive Yellow Argisol class and, according to Carvalho Filho; Curi; Fonseca (2013), the main soils of the Brazilian Coastal Plains are Yellow Argisols. The MUs chosen for having a soil pit dug and a modal profile described were PA1, PA2 and PA4. These three MUs count for approximately 95% of the watershed area (Table 1). The complete classification of the modal profiles is presented in table 2.

Only 3.6% of the soils of the watershed do not belong to the Yellow Argisol class (PA), being them classified as Haplic Organosol (OX), whose formation is related to environments subject to waterlogging and organic matter accumulation (Resende et al., 2007). This fact is confirmed by their occurrence in the low elevation parts of the watershed, where the highest values of the topographical wetness index (WI) are concentrated. The WI value used to separate OX from other MUs was 15, a value consistent with field observations.

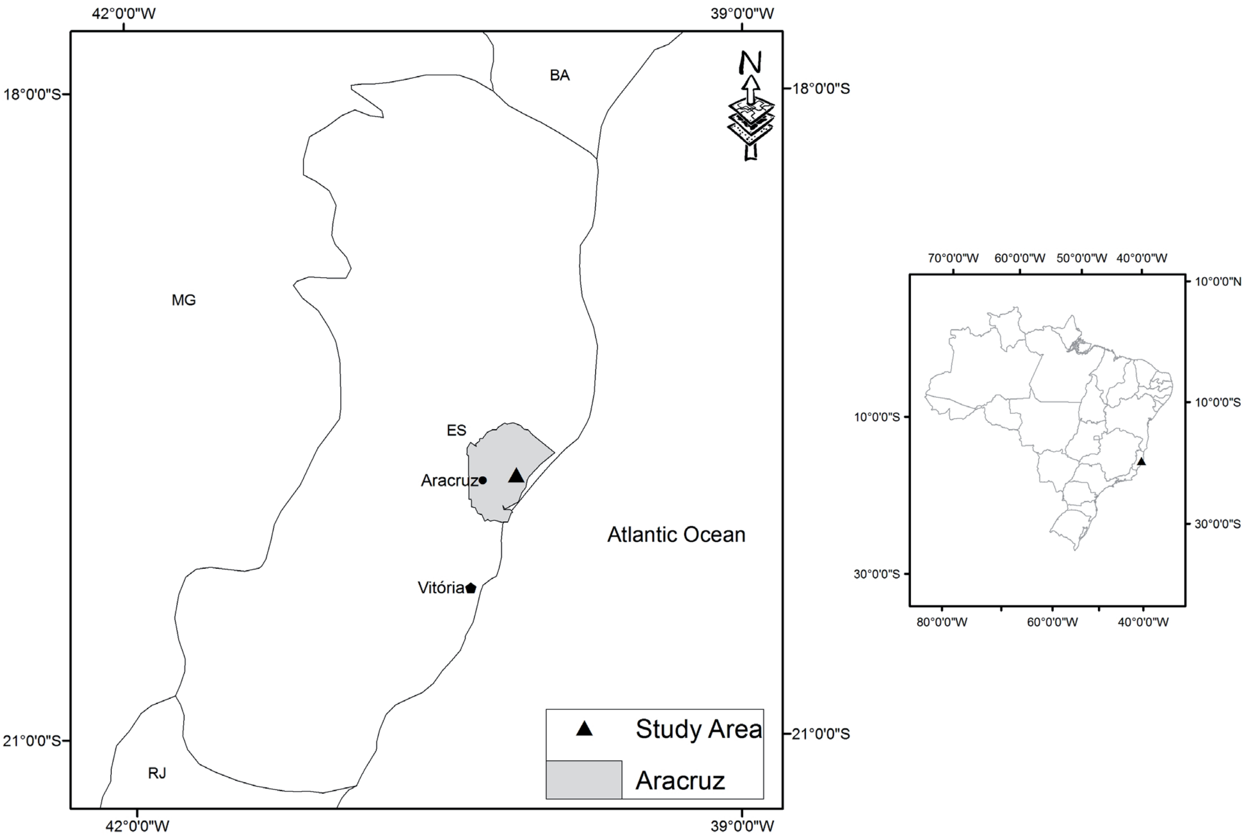

Figure 1 – The study area location in Aracruz county, Espírito Santo State, Brazil.

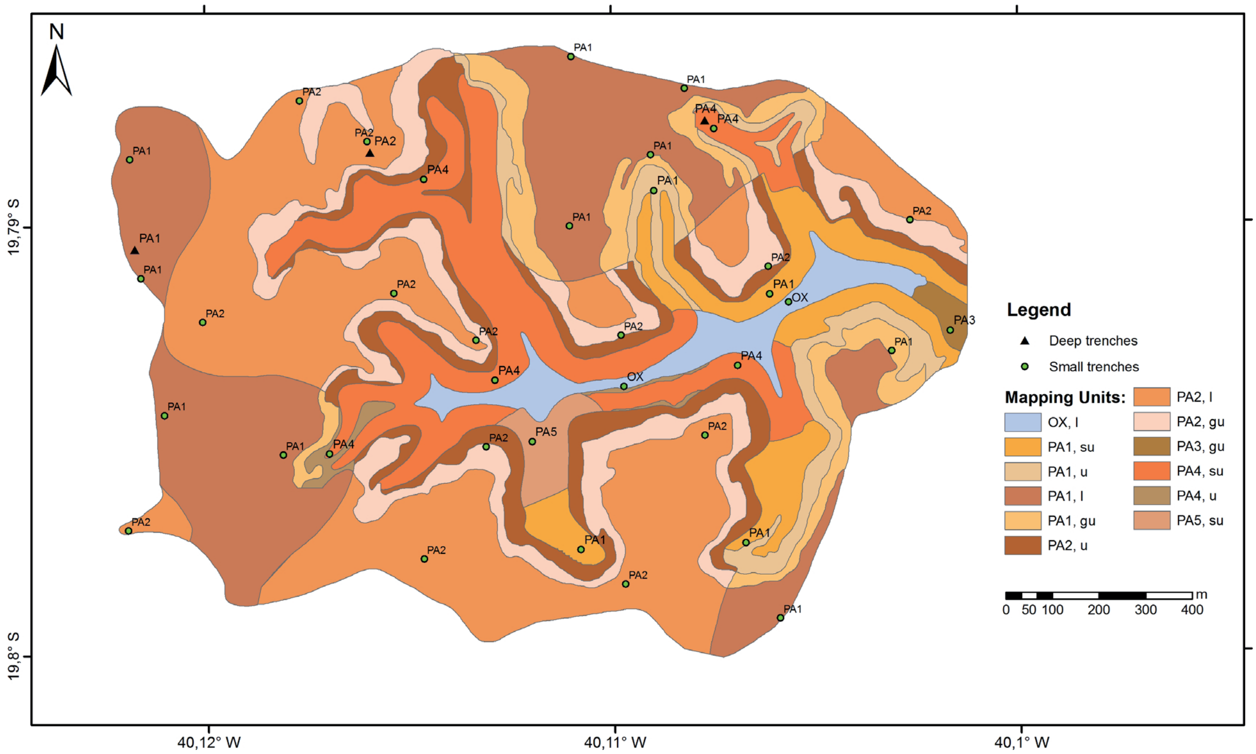

Figure 2 – Soil map of the experimental watershed in the Coastal Plains of Espírito Santo State. OX - Haplic Organosol; PA1 - Well-drained typic dystrophic/distrocohesive Yellow Argisol; PA2 – Moderately drained typic dystrophic/ dystrocohesive Yellow Argisol; PA3 – Imperfectly drained typic dystrophic Yellow Argisol; PA4 - Well-drained rocky typic dystrocohesive Yellow Argisol; PA5 - Well-drained moderately rocky typic dystrophic Yellow Argisol; l - level; gu – gently undulated; u - undulated; su- strongly undulated.

Morphological and physical characteristics of the soils

Table 3 presents the summarized morphological and physical characteristics of the modal profiles.

The soils present predominantly yellowish colors in the hues 10YR and 7.5YR, which are due to the low Fe_2O_3 content (Duarte et al., 2000; Moreau et al., 2006), indicating extremely kaolinitic mineralogy (Ferreira et al., 1999). In the modal profile 2, mottling increases at depth, going from common to abundant, and in the Bt3 and Bt4 horizons the soil matrix becomes 7.5YR (somewhat redder than 10YR of the above horizons). It possibly happens because the current pedogenetic environment allows the maintenance of inherited kaolinite and at the same time promotes goethite formation, dissolving and removing hematite from the surface horizons. These processes favor the yellowing at the top of those soils (Duarte et al., 2000).

The structure is predominantly subangular blocky in the Bt horizon with a weak degree of development (cohesive massive aspect *in situ*), peculiar characteristic of Argisols and Latosols developed from sediments of the Barreiras Formation (Corrêa et al., 2008a), as are those ones of the present study. The BA and Bt horizons presented cohesive massive aspect *in situ* in all of the modal profiles. The origin of the cohesive horizons in the Brazilian Coastal Plains is still controversial (Giarola et al., 2009), being associated with multiple, interrelated factors (Corrêa et al., 2008a; Giarola et al., 2009; Lima Neto et al., 2009; Vieira et al., 2012). According to some authors, the wide prevalence of large kaolinite crystals in the clay fraction of these soils can contribute to their cohesion, because the laminar shape of the kaolinite particles enables a face-to-face fit in the horizons with lower organic matter and Fe and Al oxides content (Lima et al., 2005; Resende et al., 2007; Martins et al., 2011; Resende et al., 2011). On the other hand, other authors have demonstrated that the illuviated fine clay content in these horizons can be a preponderant factor in the genesis of the cohesive feature

(Corrêa et al., 2008a; Giarola et al., 2009; Lima Neto et al., 2010). However, in the analyzed modal profiles, clay skins, indicators of clay illuviation (Resende et al., 2007), were not observed during the field work.

Table 1 – Geographical expression of the soil mapping units of a pilot watershed in the Coastal Plains of Espírito Santo.

Mus	Area (ha)	Area (%)
OX, level	6.6	3.6%
PA1, level	37.6	20.7%
PA1, gently undulated	9.5	5.2%
PA1, undulated	7.4	4.1%
PA1, strongly undulated	11.9	6.6%
PA2, level	48.3	26.6%
PA2, gently undulated	18.9	10.4%
PA2, undulated	14.9	8.2%
PA3, gently undulated	0.9	0.5%
PA4, undulated	1.1	0.6%
PA4, strongly undulated	22.2	12.2%
PA5, undulated	2.3	1.3%
Total	181.7	100.0%

MUs - Soil mapping units, OX - Haplic Organosol; PA1 - Well-drained typic dystrophic/distrocohesive Yellow Argisol; PA2 – Moderately drained typic dystrophic/dystrocohesive Yellow Argisol; PA3 – Imperfectly drained typic dystrophic Yellow Argisol; PA4 - Well-drained rocky typic dystrocohesive Yellow Argisol; PA5 - Well-drained moderately rocky typic dystrophic Yellow Argisol.

The plant roots in the cohesive horizons varied from few to rare. The high penetration resistance of those horizons, specially when dry, prevents root growth in depth and the roots tend to concentrate at the soil surface (Santana et al., 2006; Lima Neto et al., 2009), thickening and growing parallel to it (Carvalho Filho; Curi; Fonseca, 2013). Portela et al. (2001) pointed out that, although the soils of the Coastal Plains are deep, they present a few roots in depth due to the presence of cohesive horizons, particularly in areas with pronounced dry season.

In all of the modal profiles (Table 3) and observed small trenches, excluding OX, there was an increase in the clay content at depth, ranging from medium to clayey texture. Such clay increment at depth was enough to classify the soils as Argisols (Embrapa, 2013). The occurrence of textural gradients in the Argisols from the Coastal Plains is mainly due to the preferential removal of finer particles from the upper horizons (Universidade Federal De Viçosa - UFV, 1984). Furthermore, a clay destruction process can occur along with that removal, increasing even more the textural differentiation of the horizons (Corrêa et al., 2008a).

The studied profiles presented low silt content and low silt/clay ratio. The low silt/clay ratio of the Coastal Plains soils occurs because such soils originate from pre-weathered sediments. In that sense, the low silt/clay ratio is characteristic of Barreiras Formation sediments and does not well express the genetic maturity of the soil (Moreau et al., 2006). The highest silt/clay ratios occurred in the surface horizons (A, AB, and BA), and they are probably due to the relative loss of clay in the surface (Silva et al., 2002) and/or dispersion problems in the laboratory.

The clay content dispersed in water is higher in the upper horizons, in accordance to the higher organic matter content. The deeper horizons present 100% of the clay flocculated, a behavior that was also observed by Moreau et al. (2006) and Silva; Carvalho (2007).

Fertility characteristics of the soils

Results of the fertility analyses for modal soil profiles are presented in table 4. Both in the modal profiles and in most of the small trenches the results presented low nutrient availability with high Al saturation, low sum of

Table 2 – Complete classification of the modal soil profiles of the experimental watershed in the Coastal Plains of Espírito Santo State.

Modal Profile	Classification
Profile1	Plain relief medium/clayey texture well-drained moderate A typic distrocohesive Yellow Argisol
Profile2	Plain relief medium/clayey texture moderately drained moderate A typic distrocohesive Yellow Argisol
Profile3	Strongly undulated relief medium/clayey texture well drained stony moderate A typic distrocohesive Yellow Argisol

MUs – Maping units.

bases, low bases saturation, acidic pH, low available P and low cation exchange capacity (CEC). The low CEC values, smaller than 8 $cmol_c$ kg^{-1}, reflect the kaolinitic mineralogy of the clay fraction. These results were similar to others found in soils of the Coastal Plains (Duarte et al., 2000; Moreau et al., 2006 ; Corrêa et al., 2008a, 2008b; Giarola

Table 3 – Morphological and physical characteristics of modal soil profiles of experimental watershed in the Coastal Plains of Espírito Santo.

Horizon	Depth (cm)	Color Moist	Structure	Sand	Silt	Clay	WDC	FI
				-------------------g kg^{-1}-------------------				
Plain relief medium/clayey texture well-drained moderate A typic distrocohesive Yellow Argisol – PA1 (Native Forest)								
O	2-0							
A1	0-15	10YR 4/2	1 Sm Gr and SG	680	80	240	220	8
A2	15-23/15-35	10YR 5/3	1 a 2 Sm Gr and SG	640	80	280	280	0
BA	23-65/35-65	10YR 6/4	1 Blsa*	480	70	450	0	100
Bt1	65-98	10YR 6/4	1 Blsa*	470	60	470	0	100
Bt2	98-127	10YR 6.5/4	1 Blsa*	450	70	480	0	100
Bt3	127-159	10YR 7/4	1 Blsa*	420	20	560	0	100
Bt4	159-200+	10YR 7/4	1 Blsa*	350	70	580	0	100
Plain relief medium/clayey texture moderately drained moderate A typic distrocohesive Yellow Argisol – PA2 (Eucalyptus)								
O	10-0							
A1	0-5/0-20	10YR 4/2	1 Vs to Sm Gr and SG	710	50	240	170	29
A2	5-27/20-35	10YR 5/3	1 a 2 Vs to Sm Blsa and SG	650	90	260	200	23
AB	27-45/35-45	10YR 6/3	1 Blsa*	620	80	300	240	20
BA	45-61	10YR 6/4	1 Blsa*	570	40	390	140	64
Bt1	61-105	10YR 6/4	1 Blsa*	410	50	540	0	100
Bt2	105-162	10YR 6.5/4	1 Blsa*	360	40	600	0	100
Bt3	162-191	7.5 YR 6/6	1 Blsa*	330	70	600	0	100
Bt4	191-200+	7.5 YR 6/6	1 Blsa*	340	60	600	0	100
Strongly undulated relief medium/clayey texture well-drained stony moderate A typic distrocohesive Yellow Argisol – PA4 (Native Forest)								
O	8-0							
A	0-13	10 YR 4/2	1 M to Sm Gr and SG	640	60	300	220	27
AB	13-43	10YR 5/3	1 to 2 Blsa and Gr	620	70	310	240	22
BA	43-61	10YR 6/6	1 Blsa*	430	80	490	340	31
Bt1	61-85	10YR 5/6	1 Blsa*	380	40	580	0	100
Bt2	85-193	9YR 6/6	1 Blsa*	380	50	570	0	100
BC	193-225	7.5YR 5/6	1 Blsa*	420	70	510	0	100
C	225-251/225-316	7.5YR 7/4	1 Blsa*	310	130	560	0	100
Cx	251-329+/316-329+	Variegated	1 Blsa*	490	80	430	0	100

Structure: 1 - Weak; 2 - Moderate; Blsa* - Subangular blocks with cohesive massive aspect *in situ*; Vs – Very Small; Sm - Small; M - Medium; Gr - Granular; SG – Single Grains; Blsa - Subangular blocks. WDC – Water-dispersible clay and FI - Flocculation index .

et al., 2009; Lima Neto et al., 2009). The chemical poverty of the Brazilian Coastal Plains soils is the result of a highly (pre)weathered parent material (Lima Neto et al., 2009), in addition to the loss of nutrients during transport and deposition of sediments.

It was observed that approximately 20% of the area planted with eucalyptus presented epieutrofism (V > 50% at the surface), where Ca and Mg predominated as the major components of sum of bases, and low Al saturation in surface. This is due to enrichment by applications of fertilizers and correctives during soil preparation for eucalyptus plantation. According to Resende; Curi and Santana (1988), plain relief and low water infiltration rate make this pedoenvironment conservative of nutrients, although with low natural fertility.

Table 4 – Results of fertility analyses of modal soil profiles in an experimental watershed in the Coastal Plains of Espírito Santo State.

Hor	pH H_2O	Ca^{2+}	Mg^{2+}	K^+	Al^{3+}	H^++Al^{3+}	CEC	V	m	P	SOM
		---------------------- $cmol_c$ dm^{-3}	----------------------					----%----		$mg\ dm^{-3}$	$g\ kg^{-1}$
Plain relief medium/clayey texture well-drained moderate A typic distrocohesive Yellow Argisol – PA1											
A1	5.1	1.1	0.7	0.18	0.2	3.6	5.6	35.4	9.2	2.6	21
A2	5.0	0.7	0.5	0.12	0.4	4.0	5.4	24.6	23.3	2.6	18
BA	4.8	0.2	0.2	0.03	0.7	2.6	3.0	14.2	62.1	1.2	6
Bt1	4.9	0.1	0.6	0.01	0.5	2.1	2.8	25.5	41.3	0.7	4
Bt2	4.9	0.1	0.7	0.02	0.5	1.9	2.7	30.7	37.8	1.0	1
Bt3	4.8	0.1	0.6	0.04	0.5	2.1	2.8	26.2	40.5	1.0	1
Bt4	4.8	0.1	0.5	0.02	0.6	2.1	2.7	23.1	49	1.0	<1
Plain relief medium/clayey texture moderately drained moderate A typic distrocohesive Yellow Argisol – PA2											
A1	5	0.9	0.2	0.06	0.5	4.5	5.7	20.4	30.1	7.8	27
A2	4.4	0.1	0.1	0.02	1.4	6.3	6.5	3.4	86.2	2.9	20
AB	4.3	0.1	0.1	0.02	1.2	5.0	5.3	4.1	84.7	2.6	12
BA	4.3	0.1	0.1	0.01	1.2	4.0	4.2	4.9	85.2	2.3	6
Bt1	4.2	0.1	0.1	0.01	1.3	4.0	4.2	4.8	86.4	1.5	3
Bt2	4.8	0.2	0.2	0.01	0.7	2.3	2.7	14.8	63.4	1.2	1
Bt3	4.6	0.1	0.2	0.01	0.6	2.1	2.4	12.8	66.4	1.5	1
Bt4	4.4	0.1	0.1	0.01	0.5	1.9	2.1	9.9	71.0	1.8	2
Strongly undulated relief medium/clayey texture well-drained stony moderate A typic distrocohesive Yellow Argisol – PA4											
A	4.7	1.1	0.6	0.11	0.6	5.6	7.4	24.3	24.9	2.9	29
AB	4.6	0.3	0.4	0.07	0.9	5.6	6.4	12	53.8	2.9	19
BA	4.6	0.1	0.2	0.06	1.0	4.5	4.9	7.4	73.5	2	1
Bt1	4.8	0.1	0.1	0.04	1.0	4.0	4.3	5.5	80.9	2	9
Bt2	5.0	0.1	0.2	0.01	0.5	2.3	2.6	11.6	62.2	1.5	1
BC	4.9	0.1	0.2	0.01	0.5	2.1	2.4	12.8	62.2	1.2	<1
C	4.8	0.1	0.2	0.01	0.9	2.9	3.2	9.5	74.8	1.5	<1
Cx	4.8	0.1	0.1	0.01	1.0	2.6	2.8	7.3	83.1	1.5	<1

SOM – Soil Organic Matter.

Sulfuric acid digestion

Table 5 presents the results of the sulfuric acid digestion of the modal soil profiles samples. Low Fe_2O_3 content (< 80 g kg^{-1}) is observed in all of the samples, a striking characteristic of the Coastal Plains soils (Corrêa et al., 2008b; Duarte et al., 2000; Lima et al., 2004) that reflects the low Fe content of the parent material of these soils and the loss of this element during transport and deposition of sediments, framing them as hipoferric (Embrapa, 2013). It is noticed that the Fe_2O_3 content tends to increase at depth, as well as the clay content (Table 3). That is probably a result of clay selective loss in the upper horizons (UFV, 1984).

In the Coastal Plains soils, goethite is the dominant Fe oxide, being common the absence of hematite. Hematite can be found in deep B horizons, where the current pedogenetic conditions, which are unfavorable for its maintenance in the system, have not acted enough for completing its total dissolution (Duarte et al., 2000). This trend can be observed by less yellow hues of deeper B horizons of PA2 and PA4 modal profiles, respectively 7.5YR and 9YR. This reddening commonly occurs more in the C horizon, here achieved only in the description of the profile PA4 (7.5 YR color).

Table 5 – Results of sulfuric acid digestion and Ki, Kr and Al_2O_3/ Fe_2O_3 ratios of the modal profile horizons.

Hor	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	P_2O_5	Ki	Kr	Al_2O_3/Fe_2O_3
	----------------------- g kg^{-1} -----------------------							
Plain relief medium/clayey texture well-drained moderate A typic distrocohesive Yellow Argisol – PA1								
A1	109	100	18	26	0.1	1.9	1.7	8.7
A2	135	109	18	29	0.1	2.1	1.9	9.3
BA	210	188	25	37	0.1	1.9	1.8	11.5
Bt1	219	185	20	35	0.1	2.0	1.9	14.4
Bt2	228	188	23	35	0.1	2.1	1.9	12.7
Bt3	232	183	32	34	0.1	2.2	1.9	8.9
Bt4	250	232	38	37	0.1	1.8	1.7	9.5
Plain relief medium/clayey texture moderately drained moderate A typic distrocohesive Yellow Argisol – PA2								
A1	94	93	18	20	0.1	1.7	1.5	8.2
A2	125	105	21	28	0.1	2.0	1.8	7.8
AB	139	104	20	27	0.1	2.3	2.0	8.0
BA	165	156	25	33	0.1	1.8	1.6	9.6
Bt1	246	203	40	36	0.2	2.1	1.8	8.0
Bt2	259	224	39	37	0.3	2.0	1.8	9.0
Bt3	269	242	39	39	0.2	1.9	1.7	9.6
Bt4	271	242	44	40	0.2	1.9	1.7	8.6
Strongly undulated relief medium/clayey texture well-drained stony moderate A typic distrocohesive Yellow Argisol – PA4								
A	129	120	38	30	0.2	1.8	1.5	5.0
AB	168	147	45	36	0.2	2.0	1.6	4.9
BA	199	146	56	39	0.2	2.3	1.9	4.1
Bt1	245	216	67	39	0.2	1.9	1.6	5.1
Bt2	221	207	71	37	0.2	1.8	1.5	4.6
BC	220	205	59	35	0.4	1.8	1.6	5.5
C	294	271	79	44	0.5	1.8	1.6	5.2
Cx	207	170	19	28	0.3	2.1	1.9	13.9

The Ki index of all modal profiles reflects the kaolinitic nature of the clay fraction (EMBRAPA, 2013). That fact indicates a relatively advanced weathering stage, a result consistent with several other studies (Lima et al., 2004; Moreau et al., 2006; Lima Neto et al., 2009).

Practical applications

Considering that the soils of the Brazilian Coastal Plains are not suitable for annual crops, mainly for large areas, eucalyptus is a viable choice (Carvalho Filho; Curi; Fonseca, 2013) and this option is in accordance to the destination of this watershed. Beyond eucalyptus, other forest species, pastures, perennial and semiperennial crops, such as sugar cane, can be potentially used because they promote little soil disturbance. Thus, the major vocation of the Coastal Plains soils is closely related to production of crops with low rate of soil disturbance.

As the soil classification, the morphology, physical and chemical properties of the soils of this watershed are in agreement with the main soils of the Brazilian Coastal Plains, it is worthy to consider that this experimental watershed is highly representative of that environment. Then, the various researches developed there will have a secure and ample geographical representation and therefore justify the choice and the future investments applied in this experimental watershed.

CONCLUSIONS

The most widely predominant soil class in the experimental watershed is the dystrophic/dystrocohesive Yellow Argisol (96.4%), which is also the predominant soil class in the Brazilian Coastal Plains;

Geoprocessing techniques and DEM aided in the more precise delineation of the soil classes in the final pedologic map, complementing the field and laboratory work;

This experimental watershed is a highly representative research unit of the soils of the Brazilian Costal Plains environment.

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REFERENCES

CARVALHO FILHO, A.; N. CURI; S.FONSECA. **Avaliação informatizada e validada da aptidão silvicultural das terras dos tabuleiros costeiros Brasileiros para Eucalipto**. Lavras, MG: Editora UFLA, 2013. 138 p.

CARDOSO, C. A. et al. Caracterização morfométrica da bacia hidrográfica do Rio Debossan, Nova Friburgo, RJ. **Revista Árvore,** 30(2):241-248, 2006.

CORRÊA, M. M. et al. Caracterização de óxidos de ferro de solos do ambiente Tabuleiros costeiros. **Revista Brasileira de Ciência do Solo**, 32(3):1017-1031, 2008a.

CORRÊA, M. M. et al. Caracterização física, química, mineralógica e micromorfológica de horizontes coesos e fragipãs de solos vermelhos e amarelos do ambiente Tabuleiros Costeiros. **Revista Brasileira de Ciência do Solo**, 32(1):297-313, 2008b.

COSTA, A. M. et al. Avaliação do risco de anoxia para o cultivo do eucalipto no Rio Grande do Sul utilizando-se levantamento de solos. **Scientia Forestalis**, 37(84):367-375, 2009a.

COSTA, A. M. et al. Levantamento detalhado da microbacia hidrográfica do horto florestal Terra Dura (RS) e considerações sobre escalas de mapeamento. **Ciência e Agrotecnologia**, 33(5):1272-1279, 2009b.

COSTA, O. V. et al. Estoque de carbono do solo sob pastagem em área de Tabuleiro Costeiro no sul da Bahia. **Revista Brasileira de Ciência do Solo**, 33(5):1137-1145, 2009c.

CURI, N. Interpretação e decodificação do levantamento de solos das áreas da Aracruz Celulose S.A no Espírito Santo e sul da Bahia para o cultivo de eucalipto. In: EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA. **Levantamento generalizado e semidetalhado de solos da Aracruz Celulose S.A. no Espírito Santo e sul da Bahia para o cultivo de eucalipto**. Rio de Janeiro, 2000. p. 70-80. (Boletim de Pesquisa, 1).

DUARTE, M. N. et al. Mineralogia, química e micromorfologia de solos de uma microbacia nos tabuleiros costeiros do Espírito Santo. **Pesquisa Agropecuária Brasileira**, 35(6):1237-1250, 2000.

EMBRAPA – EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA. **Sistema Brasileiro de Classificação de Solos**. 3. ed. Rio de Janeiro, 2013. 353 p.

EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA-EMBRAPA. **Manual de métodos de análises de solo.** 2. ed. Rio de Janeiro, 1997. 212 p.

FONSÊCA, M. H. P. et al. Uso de propriedades físico-hídricas do solo na identificação de camadas adensadas nos Tabuleiros Costeiros, Sergipe. **Revista Brasileira de Engenharia Agrícola e Ambiental**, 11(4):368-373, 2007.

GIAROLA, N. F. B. et al. Mineralogia e cristalografia da fração argila de horizontes coesos de solos nos tabuleiros costeiros. **Revista Brasileira de Ciência do Solo**, 33(1):33-40, 2009.

HORTA, I. M. F. et al. Levantamento de reconhecimento com apoio digital dos solos do município de Nazareno-MG. **Ciência e Agrotecnologia,** 33(Especial):1940-1947, 2009.

LEMOS, R. C. et al. **Manual de descrição e coleta de solos no campo.** 6. ed. Viçosa, MG: SBCS, 2013. 92 p.

LIMA, H. V. et al. Identificação e caracterização de solos coesos no Estado do Ceará. **Revista Brasileira de Ciência do Solo**, 28(3):467-476, 2004.

LIMA, H. V. et al. Comportamento físico de um Argissolo acinzentado coeso no estado do ceará. **Revista Brasileira de Ciência do Solo**, 29(1):33-40, 2005.

LIMA NETO, J. D. A. et al. Caracterização e gênese do caráter coeso em latossolos amarelos e argissolos dos tabuleiros costeiros do estado de Alagoas. **Revista Brasileira de Ciência do Solo**, 33(4):1001-1011, 2009.

LIMA NETO, J. D. A. et al. Atributos químicos, mineralógicos e micromorfológicos de horizontes coesos de Latossolos e Argissolos dos Tabuleiros Costeiros do estado de Alagoas. **Revista Brasileira de Ciência do Solo**, 34(6):473-486, 2010.

MARTINS, S. G. et al. Erodibilidade do solo nos tabuleiros costeiros. **Pesquisa Agropecuária Tropical,** 41(3):322-327, 2011.

McBRATNEY, A. B.; MEDONÇA SANTOS, M. L.; MINASNY, B. On digital soil mapping. **Geoderma**, 109:41-73, 2003.

MENEZES, M. D. et al. Levantamento pedológico e sistema de informações geográficas na avaliação do uso das terras em sub-bacia hidrográfica de Minas Gerais. **Ciência e Agrotecnologia**, 33(6):1544-1553, 2009.

MOREAU, A. M. S. S. et al. Caracterização de solos de duas topossequências em Tabuleiros Costeiros do Sul da Bahia. **Revista Brasileira de Ciência do Solo**, 30(6):1007-1019, 2006.

PORTELA, J. C. et al. Retenção da água em solo sob diferentes usos no ecossistema tabuleiros costeiros. **Revista Brasileira de Engenharia Agrícola e Ambiental**, 5(1):49-54, 2001.

RESENDE, M.; CURI, N.; SANTANA, D. P. **Pedologia e fertilidade do solo:** interações e aplicações. Brasília, 1988. 81 p.

RESENDE, M. et al. **Pedologia:** base para a distinção de ambientes. 5. ed. Viçosa, MG: NEPUT, 2007. 322 p.

RESENDE, M. et al. **Mineralogia de solos brasileiros:** interpretação e aplicações. 2. ed. Lavras, MG: Editora UFLA, 2011. 206p

SANTANA, M. B. et al. Atributos físicos do solo e distribuição do sistema radicular de citros como idicadores de horizontes coesos em dois solos de Tabuleiros Costeiros do estado da Bahia. **Revista Brasileira de Ciência do Solo,** 30(3):1-12, 2006.

SILVA, A. J. N. D.; CARVALHO, F. G. D. Coesão e resistência ao cisalhamento relacionadas a atributos físicos e químicos de um Latossolo Amarelo de tabuleiro costeiro. **Revista Brasileira de Ciência do Solo**, 31(5):853-862, 2007.

SILVA, M. S. L. et al. Adensamento subsuperficial em solos do semi-árido: Processos geológicos e, ou, pedogenéticos. **Revista Brasileira de Engenharia Agrícola e Ambiental**, 6(2):314-320, 2002.

SOUZA L. D. et al. Avaliação de plantas cítricas, em diferentes profundidades de plantio, em latossolo amarelo dos tabuleiros costeiros. **Revista Brasileira de Fruticultura**, 26(2):241-244, 2004.

VIEIRA, J. M. et al. Contribuição de material amorfo na gênese de horizontes coesos em Argissolos dos Tabuleiros Costeiros do Ceará. **Revista Ciência Agronômica**, 43(4):623-632, 2012.

TONELLO, K. C. et al. Morfometria da bacia hidrográfica da Cachoeira das Pombas, Guanhães - MG. **Árvore**, 30(5):849-857, 2006.

UNIVERSIDADE FEDERAL DE VIÇOSA. **Caracterização de solos e avaliação dos principais sistemas de manejo dos tabuleiros costeiros do baixo Rio Doce e da região norte do Estado do Espírito Santo e sua interpretação para uso agrícola**. Viçosa, MG: UFV, CVRD, 1984. 153 p.