Ciências Agrárias
SEMINA

DOI: 10.5433/1679-0359.2021v42n3Supl1p1511

Soil catenas in a pilot sub-basin in the region of Itajubá, Minas Gerais state, Brazil, for environmental planning

Catenas de solo em sub-bacia piloto na região de Itajubá, Minas Gerais, Brasil, para planejamento ambiental

Olívia de Lima[1]*; Eliane Guimarães Pereira Melloni[2]; Rogério Melloni[2]; Marcelo Ribeiro Barison[3]; Nilton Curi[4]

Highlights

Representative soli catenas play as a drainage-basin management model.
Predominance of the Red and Red-Yellow Argisols classes in the studied sub-basin.
Common occurrence of Bw horizon below Bt horizon in Argisols in a rugged relief.

Abstract

Systemic studies that allow the environmental characterization of pilot sub-basins are essential to guide their management, which are the basis for adequate environmental planning. The José Pereira sub-basin has an area of approximately 40 km² and is located in the municipality of Itajubá, south of the state of Minas Gerais, Brazil. This area was chosen as a pilot sub-basin for this study because it holds an important forest remnant, the Serra dos Toledos Biological Reserve, and part of the urban area of the municipality in the process of expansion, as well as a rural area where inappropriate and intensive agricultural activities are practiced. In this scenario, this atudy examined the soil catenas of this sub-basin to serve as an important instrument of planning for this unit. Eight soil catenas distributed into three topo-morphological compartments were studied. According to the generated soil map, Haplic Cambisols occupy 26% of the sub-basin, in mountainous relief; Red and Red-Yellow Latosols, 6% of the area, predominating in the flat-to-undulating relief; Haplic Gleysols, 7% of the area, in the lowlands, in flat relief and at the footslope. Finally, Red and Red-Yellow Argisols were the predominant classes, occurring in almost 50% of the sub-basin, under undulating and strongly undulating reliefs. Based on the combined results, a model of local evolution of the

[1] Msc, Environment and Water Resource Postgraduate Program, UNIFEI/IRN, Itajubá, MG, Brazil. E-mail: olivialimaprana@gmail.com
[2] PhD, Profs. at Federal University of Itajubá, UNIFEI, Natural Resources Institute, IRN, Itajubá, MG, Brazil. E-mail: elianegp@unifei.edu.br; rmelloni@unifei.edu.br
[3] PhD, Prof. at Federal University of Alfenas, UNIFAL, Poços de Caldas Campus, Institute of Science and Technology, ICT, Poços de Caldas, MG, Brazil. E-mail: marcelo.barison@unifal-mg.edu.br
[4] PhD, Prof. at Federal University of Lavras, UFLA, Department of Soil Science, DCS, Lavras, MG, Brazil. E-mail: ntcuri@gmail.com
* Author for correspondence

Received: Sept. 04, 2020 - Approved: Jan. 16, 2021

sub-basin soils was proposed: the younger soils, Haplic Cambisol and Haplic Gleysol, occupy the positions of convex top and floodplain, respectively. In the upper and lower thirds of the landscape, the predominance of Red Argisol is related to constant renewal of soil material, preventing it from reaching the latosolic stage. In addition, part of these Argisols has a Bw horizon below Bt horizon in rugged relief. Moreover, in the landscape lower third, Latosols are present, even in areas with steep slope.
Key words: Environmental characterization. Pedological map. Soil toposequences.

Resumo

Estudos sistêmicos que possibilitem a caracterização ambiental de sub-bacias hidrográficas pilotos são essenciais para direcionar sua gestão, sendo fundamentais para um adequado planejamento ambiental. A sub-bacia José Pereira possui uma área aproximada de 40 km² e se insere no município de Itajubá, sul do Estado de Minas Gerais, Brasil. Esta área foi escolhida como sub-bacia piloto para este estudo, pois possui um importante remanescente florestal, a Reserva Biológica Serra dos Toledos, assim como parte da área urbana do município em processo de expansão, além de uma área rural com uso de práticas agropecuárias inadequadas e intensivas. Desta forma, o presente trabalho teve como objetivo estudar as catenas de solos desta sub-bacia, para servir como importante instrumento de planejamento desta unidade. Oito catenas de solos distribuídas em três compartimentos topomorfológicos foram estudadas. De acordo com o mapa de solos gerado, os Cambissolos Háplicos ocupam 26% da sub-bacia, estando sob relevo montanhoso; os Latossolos Vermelho e Vermelho Amarelo, 6% da área, predominando no relevo plano a ondulado; os Gleissolos Háplicos, com 7% da área, estando nas baixadas, em relevo plano e nos sopés das encostas; e as classes dos Argissolos Vermelho e Vermelho Amarelo foram as predominantes, distribuídas por 56% da sub-bacia, ocupando relevo ondulado e forte ondulado. Com base nos resultados conjuntos obtidos propôs-se um modelo de evolução local dos solos da sub-bacia: os solos mais jovens, Cambissolo Háplico e Gleissolo Háplico, ocupam as posições de topo convexo e a planície de inundação, respectivamente. Nos terços superior e inferior da encosta ocoree o predomínio de Argissolo Vermelho, o qual está relacionado à renovação constante de material do solo, impedindo que o estágio latossólico seja atingido. Além disso, parte significativa desses Argissolos apresenta horizonte Bw abaixo do horizonte Bt sob relevo acidentado. Ainda, no terço inferior da paisagem, pode-se notar a presença de Latossolos, até mesmo em áreas com declividade acentuada.
Palavras-chave: Caracterização ambiental. Mapa pedológico. Topossequências de solos.

Introduction

According to Lepsch (2010), soil is the result of the action of five formation factors: climate and organisms on the parental material, over time, under the influence of the relief. These factors condition soil formation processes, causing constant variations in its attributes, in a dynamic and subsequent processes.

From the tectonic perspective, the occurrence of cyclic uplifts in a region enables the incision of the local drainage network, since, in search of rebalancing with the regional base level, river courses tend to flow vertically into valleys (incision), triggering an increase in the hillslope gradient (Figueiredo, Varajão, Fabris, Loutfi, & Carvalho, 2004).

The model of Bertrand and Bertrand (2007), which emphasizes the temporal dimension in the development of soils in the landscape, suggest the existence of a phase of environmental instability followed by another phase of stability (Tricart, 1977). In the first phase, erosion and deposition processes that can reach only some areas predominate; in the second, there is a predominance of pedogenetic processes that, by operating in the sediments deposited in the previous period, will constitute new soil profiles (Moreira, 2019). According to this author, if they do not undergo removal or collapse, soil profiles will be subjected to new pedogenetic processes influenced by new climatic conditions, or may even be partially covered while pedogenesis operates.

Depending on environmental conditions, there is an internal redistribution of the soil material, both vertically and laterally. Therefore, we may state that the pedological cover is constantly evolving. If environmental conditions change in space and/or time, sufficiently so that the pedoclimatic conditions escape from the equilibrium domain of elementary organizations, they become unstable and are transformed to give rise to new structures in equilibrium with the new sequences of elementary organizations, which may conflict with the initial cover (Moreira, 2019). In this respect, the relief of the José Pereira stream sub-basin, situated in the municipality of Itajubá, Minas Gerais state, Brazil, is mostly uneven, which causes the intensity of the pedogenetic processes to be strongly influenced by the transport of material (removal/accumulation), thereby rejuvenating the deposition surfaces and causing spatial variability in soil attributes. Thus, investigating these attributes through soil catenas we can determine variations in soil properties caused by the position of the soil profiles in the landscape.

Specifically, the José Pereira stream sub-basin, a tributary of the Sapucaí river in its middle region, is located entirely in the municipality of Itajubá, south of the state of Minas Gerais, Brazil, between the meridians of 45°27′31″ and 45°20′ 57″ W and parallels of 22°23′18″ and 22°26′ 57″ S. The José Pereira stream is born in the Serra dos Toledos Biological Reserve Conservation Unit, crosses urban neighborhoods and flows into the Sapucaí river. The sub-basin has the two variations of the altitude tropical climate: the Cwa type, predominant in most of the area; and the Cwb, restricted to a small portion to the northwest of the sub-basin (Köppen-Geiger). The region under study is part of the Atlantic Forest biome, with its native vegetation being defined as Seasonal Semideciduous Forest (Instituto Brasileiro de Geografia e Estatística [IBGE], 1992). The geological constitution of the sub-basin comprises an association of crystalline rocks from the Paleoproterozoic/ Archean era (Serra dos Coelhos granite), Neoproterozoic metasediments (paragneiss and migmatitic orthogneiss) and Quaternary deposits (alluvial deposits) (Trouw, Nunes, Castro, Trouw, & Matos, 2008).

According to the geodiversity chart prepared by Silva (2008), the area under study can be divided into three geomorphological units: the Mountainous Domain (34% of the area), the Hills and Low Hills Domain (56% of the area), and River Plains (9.3% of the area). The drainage pattern of the José Pereira stream sub-basin is predominantly dendritic to sub-dendritic in the Mountainous and Hills and Low

Hills domains, whereas in the river plain, the tortuous to semi-straight meandering pattern predominates.

The study area is at an altitude between 840 and 1,760 m. The western portion of the sub-basin is situated at the lowest altitudes, where the river plains and the urbanized part of the sub-basin are located. In the east are the mountains in the higher elevations, such as Serra do Juru and Serra dos Toledos.

Thus, the José Pereira stream sub-basin has a tropical climate. In other words, it is subject to high temperatures and high rainfall, which favors weathering-leaching processes, especially those of chemical nature, responsible for the transformation of primary minerals. This chain of events ultimately results in relatively well-developed soils. According to the soil map of the State of Minas Gerais, with a scale of 1:650,000 (FEAM-CETEC-UFV-UFLA, 2010), the predominant soil mapping units of the sub-basin are Red-Yellow Argisols, with 28.6%, and dystric Red Argisols, with 71.4% of the area.

To develop the topo-morphological map of the José Pereira sub-basin, the regional and local structural configuration was analyzed together with the topographic and morphometric information of the level curves, which resulted in the interpretation of the morphography of the area under study. The structural study began with the analysis and interpretation of the geological map of Itajubá, which was based on the lithostratigraphic description of Folha Itajubá - SF.23-YB-III, on a scale of 1:100,000, developed by the Brazil Geology Program of the Serviço Geológico do Brasil [CPRM] (2008), in partnership with the Federal University of Rio de Janeiro - UFRJ. The topographic and morphometric interpretation of the level curves was based on information extracted from Folha Itajubá, produced by IBGE (1971), on a 1:50,000 scale.

The initial identification of the soil in the study area was based on the exploratory soil map of the RADAM Project (BRASIL, 1983) and the soil recognition map of the State of Minas Gerais (FEAM-CETEC-UFV-UFLA, 2010), checked by field evaluation. In addition to serving as a base, these maps could be used as a comparison to the map generated in the current study so that some scale issues could be investigated.

Thus, the present study aimed to examine representative soil catenas of the José Pereira stream sub-basin, an important source of water supply for the municipality of Itajubá, Minas Gerais state, Brazil, and their landscape evolution model. Knowledge of the soils of this pilot sub-basin can provide information on its natural resources and thus contribute to the environmental planning of this important sub-basin situated in Serra da Mantiqueira Range.

Material and Methods

The soil profiles were chosen according to the catena method. Eight soil catenas were selected. They encompassed various forms of slopes and types of relief, allowing the correlation of soils and geomorphic surfaces. Trenches, road cuts and pits were performed at the landscape top, upper, middle and lower thirds, and on the foodplains, along the soil catenas, always close to the native vegetation condition.

In each soil profile, the horizons were identified and described morphologically and soil samples were collected following the

Manual of Description and Collection of Soil in the Field, as proposed by R. D. Santos, Lemos, Santos, Ker and Anjos (2005). The soil samples were sent to the Soil Laboratory of the Federal University of Itajubá (Unifei) for physical characterization; and to the Soil Fertility Laboratory of the Federal University of Lavras for chemical characterization. Laboratory analyses were carried out in accordance with the Manual of Methods for Soil Analyses (Empresa Brasileira de Pesquisa Agropecuária [EMBRAPA], 1997). In the soil laboratory of Unifei, the disturbed samples were used to complement the field descriptions of the soil horizons in terms of consistency (dry, wet, plasticity and stickiness), according to the cited manual. . The disturbed samples were air-dried, grind, passed through a 2-mm sieve (ADFE), and then the following attributes were determined (in triplicate): particle density, using the Volumetric Flask Method and texture, by the Pipette Method. The undisturbed samples were oven-dried and used to determine bulk density, by the Volumetric Ring Method; and pores total volume, based on bulk and particle densities. For chemical characterization, the ADFE was analyzed for: pH in water at the 1:2.5 ratio (soil:water), by the McLean method (1982); exchangeable Ca^{2+}, Mg^{2+} and Al^{3+}, extracted with 1 mol L^{-1} KCl and analyzed by titration (EMBRAPA, 1997); and P and K^{+}, extracted by the Mehlich-1 method and analyzed by colorimetry and flame photometry, respectively (EMBRAPA, 1997). The total acidity (CEC at pH 7.0) was determined according to EMBRAPA (1997). Organic carbon was determined by colorimetry, using the method of Walkley and Black (1934), described in EMBRAPA (1997). Base saturation (%), sum of bases and aluminum saturation were calculated and the values were compared to the Comissão de Fertilidade do Solo do Estado de Minas Gerais [CFSMG], 1999). Effective cation-exchange capacity (CEC) was obtained indirectly from calculation. Each studied chemical attribute was interpreted according to Alvarez, Novais, Barros, Cantarutti and Lopes (1999).

Based on the morphological, physical and chemical attributes, the soil profiles were classified up to the fourth categorical level, according to criteria established by the Sistema Brasileiro de Classificação de solos (EMBRAPA, 2018).

The soil map of the José Pereira stream sub-basin was generated based on 31 soil profiles classified; on the digital elevation model (DEM); previous knowledge of the soil × landscape relationships in the region; and on the soil map of the state of MG on the scale of 1:650,000 (FEAM-CETEC-UFV-UFLA, 2010). From the DEM, the relief and altitude maps were generated in relation to the river channel, in the ArcGIS 9.2 and SAGA 2.0 software programs, respectively. Based on previous knowledge of the soil-landscape relationships and the soil genesis of the study region, combinations of soil attributes were formulated for creating the soil map, as shown in Table 1.

Table 1
Combinations of land attributes for the creation of the soil map of the José Pereira stream sub-basin

Relief	Altitude relative to the river channel	FEAM-CETEC-UFV-UFLA map	Current map*
Flat	< 5 m	-	GX
Mountainous	-	-	CX
Flat/Gently undulating	> 5 m	PVd1	LV
Undulating	-	PVd1	PV1
Strongly undulating	-	PVd1	PV2
Undulating	-	PVAd8	PVA1
Strongly undulating	-	PVAd8	PVA2
Flat/Gently undulating	> 5 m	PVAd8	LVA

*Where GX: HAPLIC GLEYSOL Flat relief; CX: HAPLIC CAMBISOL Mountainous relief; LV: RED LATOSOL Flat/gently undulating relief; PV1: RED ARGISOL Undulating relief; PV2: RED ARGISOL Strongly undulating relief; PVA 1: RED-YELLOW ULTISOL Undulating relief; PVA2: RED-YELLOW ARGISOL Strongly undulating relief; LVA: RED-YELLOW LATOSOL Flat/gently undulating relief.

The generated map was checked through many in field campaigns and the necessary adjustments were made. A mapable minimum area of 10 ha was considered for the final map, and its scale was 1:25,000.

Results and Discussion

Topo-morphological compartmental model

The morphological configuration of the José Pereira stream sub-basin largely follows the regional structural configuration through the alignments and shear zones belonging to the Mantiqueira Structural Province. These structures conditioned the fitting of the drainage, with subsequent evolution of the relief shape from the vertical incision on the weathered materials and crystalline basement rocks (Marques Neto, 2017).

The presence of contacts between granitoids and shear zones producing topographically differentiated compartments was the first argument for division between the topo-morphological zones. The second argument was the configuration of the level lines and the spacing between them, which resulted in the interpretation of the shapes. Figure 1 shows the map containing the boundaries of the topo-morphological compartments.

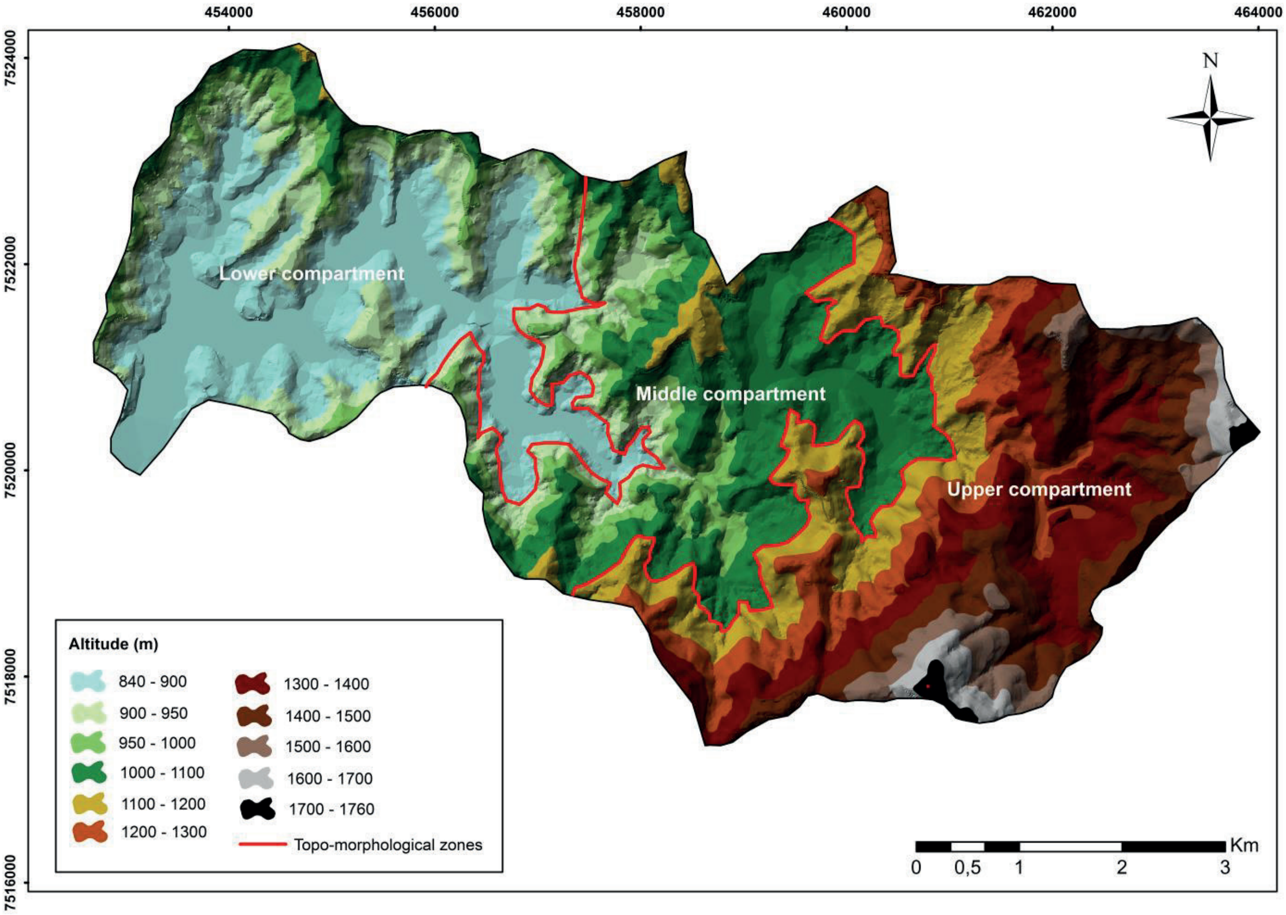

Figure 1. Altitude classes and topo-morphological zones of the José Pereira stream sub-basin.

The level curve of 1,100 m was used to delimit the first compartment, as it defines a morphostructural zone that differs from the others because of higher altitudes and steeper slopes in the sub-basin. In this zone, straight and convex hillslopes and V valleys predominate. The mountainous relief induces a reduction in the weathering mantle of pedogenesis, exposing rock walls along the hillslopes.

Located between the 1100- and 900-m curves, the middle compartment occupies the central portion of the sub-basin. This area marks the presence of concave and convex hillslopes and tops elongated and reduced laterally, behaving like divides that advance perpendicularly into the main drainage, towards the interior of the sub-basin. Restricted tops are also present, resulting from an old erosion surface. The occurrence of a hanging plain, forming a small valley linked to the main drainage, confirms the importance of the structural element in the conformation of the sub-basin (Marques Neto, 2017).

The low compartment was individualized from the alignment belonging to the sinistral transcurrent shear zone of Maria da Fé (MG), a municipality neighboring Itajubá (26 km of distance), since it eventually affected the alignment of the drainage and the movement of the relief and, consequently, the conformation of the landscape. Thus, the low compartment reveals a smoother relief, with altitudes lower than 900 m, without, however, excluding isolated tops at more than 1,000 m. Like in the middle compartment, there are also divides that advance into the sub-basin, ending next to the floodplains of the main channel. Amphitheaters are common and have colluvial wedges in contact with the bottom of the valleys, as a result of the regressive evolution of hillsides from the readjustment of the drainages caused by changes in the local and regional base levels, which in turn resulted from neotectonic activity (Marques Neto, 2017).

Soil Catenas and distribution of soil classes

Figure 2 illustrates the soil profiles selected within the sub-basin. The distribution of soil classes in catenas 1, 2, 3 and 7 reveals young soils at the top, Haplic Cambisols and Regosols, in flat and undulating relief, in slopes leser than 15.7% (Table 2). The position on the slope generates marked erosion and limits the weathering-leaching of the soils, which reflects the presence of incipient B horizons (Cambisols), or even the absence of the subsurface diagnostic horizons (Neosols). The upper and lower thirds of the landscape have a slope of up to 41.7%, and are caused by the dissection of the top portion by erosion cycles. In the landscape upper third, with greater slope and lateral flow of water, there was formation of Red-Yellow and Red Argisols; and in the landscape lower third, Latosols, Argisols and Cambisols. This distribution of soil classes less evolved at the top and more evolved in deposition environments, agrees with the studies done by Martins et al. (2007) and Anjos, Fernandes, Pereira and Franzmeier (1998). In the other soil catenas (4, 5, 6 and 8), there was a predominance of Red and Red-Yellow Argisols.

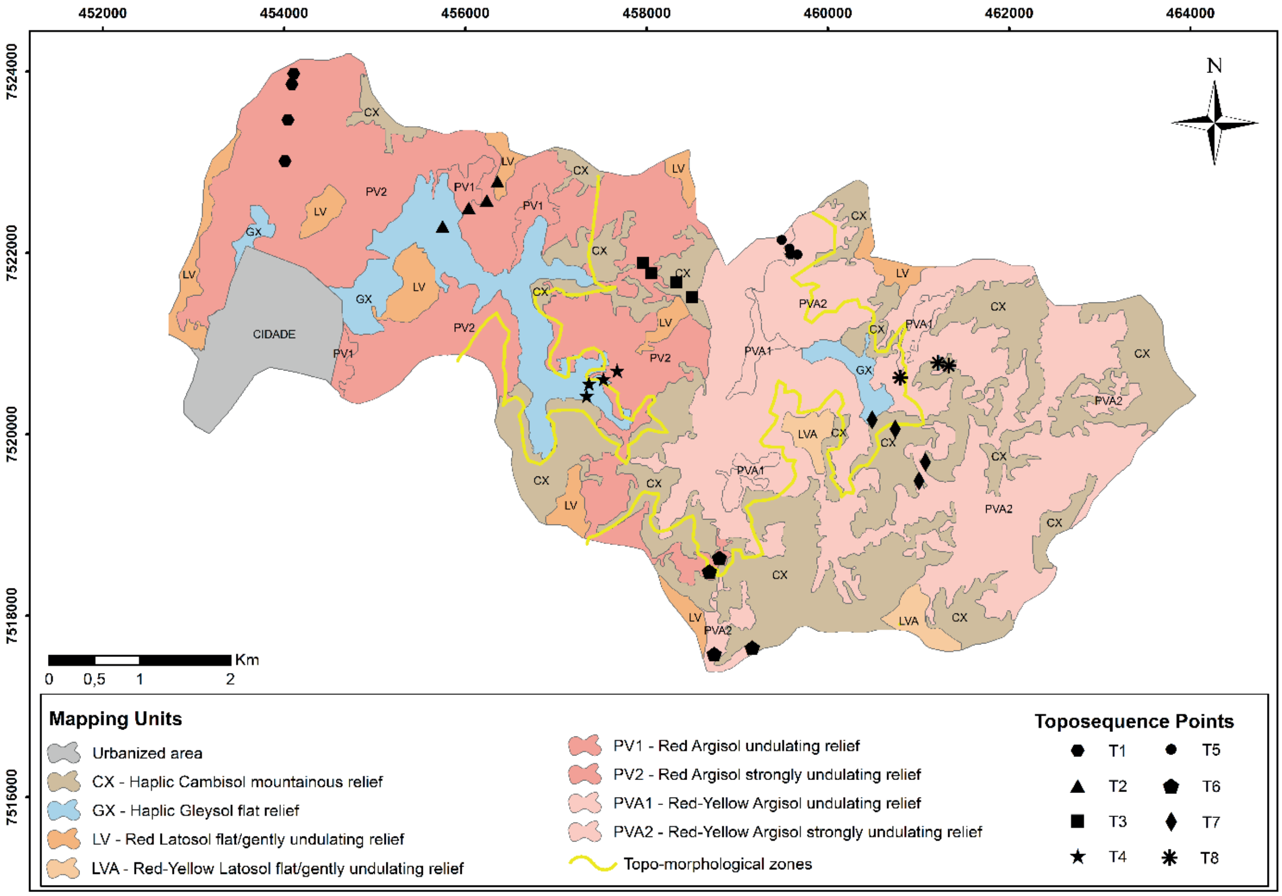

Figure 2. Soil map with the catenas and topo-morphological zones of the José Pereira stream sub-basin

Drainage, in most soil profiles, can be considered good, except in lowland soils. These are present in the bottoms of the valleys, at lower altitudes (863 to 1,097 m), where the topographic conformation allows water accumulation during part of the year. Therefore, these are environments of depositional nature, which predominantly generates Haplic and Melanic Gleysols, both of which have low-activity clays, are dystrophic clay and present colors typical of soils subject to periodic flooding, similar to the soils of wet places studied by Souza et al. (2010).

Table 2
Distribution of soil classes along catenas in the José Pereira stream sub basin

Soil Profile	Soil class	Slope (%)	Altitude (m)	Position in the landscape
CATENA 1				
P1	Moderate A, typic eutrophic Tb HAPLIC CAMBISOL	0.0	1,116	Top
P2	Prominent A, typic eutrophic RED-YELLOW ARGISOL	35.0	1,012	Upper third
P3	Moderate A, typic dysthrophic YELLOW LATOSOL	28.0	911	Lower third
P4	Moderate A, typic dystrophic Tb HAPLIC GLEYSOL	0.0	876	Lowland
CATENA 2				
P1	Moderate A, typic eutrophic REGOLITHIC NEOSOL	0.0	1,010	Top
P2	Moderate A, latosolic dystrophic RED ARGISOL	36.0	963	Upper third
P3	Moderate A, latosolic dystrophic RED-YELLOW ARGISOL	15.1	894	Lower third
P4	Prominent A, typic dystrophic Tb MELANIC GLEYSOL	0.0	863	Lowland
CATENA 3				
P1	Prominent A, typic dystrophic Tb HAPLIC CAMBISOL	15.7	1,195	Top
P2	Moderate A, abrupt eutrophic RED ARGISOL	38.5	1,078	Upper third
P3	Moderate A, typic eutrophic Tb HAPLIC CAMBISOL	41.7	978	Lower third
P4	Moderate A, typic dystrophic Tb HAPLIC GLEYSOL	18.3	943	Lowland
CATENA 4				
P1	Prominent A, umbric dystrophic RED ARGISOL	7.9	1,015	Top
P2	Moderate A, abrupt eutrophic RED ARGISOL	10.6	947	Upper third
P3	Moderate A, typic dystrophic RED ARGISOL	13.0	890	Lower third
P4	Moderate A, typic dystrophic Tb HAPLIC GLEYSOL	0.0	867	Lowland
CATENA 5				
P1	Moderate A, latosolic dystrophic RED-YELLOW ARGISOL	0.0	1,145	Top
P2	Moderate A, latosolic dystrophic RED-YELLOW ARGISOL	23.7	1,116	Upper third
P3	Moderate A, typic dystrophic RED LATOSOL	40.0	1,096	Lower third
P4	Moderate A, typic dystrophic Tb HAPLIC GLEYSOL	10.4	1,055	Lowland

continue...

contuation...

CATENA 6				
P1	Moderate A, abrupt eutrophic RED-YELLOW ARGISOL	13.7	1,456	Top
P2	Prominent A, umbric dystrophic RED ARGISOL	38.8	1,296	Hanging valley
P3	Prominent A, typic eutrophic RED ARGISOL	40.5	1,105	Middle third
P4	Moderate A, typic dystrophic RED ARGISOL	39.0	1,064	Lower third
CATENA 7				
P1	Moderate A, dystrophic Tb HAPLIC CAMBISOL	13.1	1,363	Top
P2	Moderate A, latosolic dystrophic RED ARGISOL	29.0	1,240	Upper third
P3	Moderate A, typic dystrophic RED LATOSOL	33.8	1,116	Lower third
P4	Humic A, typic dystrophic Tb MELANIC GLEYSOL	0.0	1,049	Lowland
CATENA 8				
P1	Humic A, typic dystrophic BROWN LATOSOL	15.4	1,252	Top
P2	Prominent A, typic eutrophic YELLOW ARGISOL	22.7	1,212	Upper third
P3	Prominent A, umbric dystrophic RED ARGISOL	28.8	1,097	Lower third

The predominant superficial horizon in the soil catenas was the moderate A, followed by the prominent A. The predominant parent materials in the sub-basin are represented by granites and gneisses.

Mapping and characterization of soil classes

The collected information was used to build a map on the scale of 1:25,000 (Figure 2), which is a type of survey suitable for providing bases for selecting areas with greater intensive land use potential and identification of localized problems in general soil use and conservation planning (Resende, Curi, Rezende, & Corrêa, 2014). Nine soil classes up to the second categorical level and eight soil mapping units were defined. Some soil classes were observed in the catenas, but were not included in the final map, such as Regolithic Neosol, Melanic Gleysol, Yellow Latosol, Brown Latosol and Yellow Argisol. This occurred because these soil classes occupy areas smaller than the mapable minimum area (10 ha), so they were considered as inclusions of the soil mapping units and so do not appear in the legend of the final map. The Fluvic Neosol class was identified during the field work, but due to its limited geographical expression it was included into the Haplic Gleysols mapping unit, as inclusion.

Haplic Cambisols occur at the mountainous top landscape (Table 2). In these relief conditions, rejuvenation processes (intense erosion) do not allow the deepening of weathering and aging of the soil, which explains the presence of the incipient B horizon with an average thickness of only 30 cm. The most developed Cambisol was found in the lower third of the landscape in catena 3, where colluvial processes acted with great intensity. The texture was medium to clayey, and the natural fertility was variable. The Cambisols occupy 26% of the total area, predominantly in the high and middle topo-morphological compartments (Figures 1 and 2).

In the case of the sub-basin (Table 2), the Regolithic Neosols are shallow, with an effective depth of 50 cm, where water availability is low. The texture varies from clayey to medium, with high base saturation, characterizing eutrophic soils. They are associated to steep, mountainous and rugged reliefs and rock outcrops, being included in the Haplic Cambisols mapping unit. A pedological survey in the Alto Rio Grande (MG) basin also recorded Cambisols and *Neosols* in dissected relief (Menezes, Curi, Marques, Mello, & Araújo, 2009).

Latosols predominated in the flat and undulating reliefs, mainly at hilltops, agreeing with Guerra and Cunha (1995), who emphasized that soils in smoother relief tend to be deeper. According to the analyzed soil profiles (Table 2), this class showed low natural fertility; all profiles are dystrophic and have an average effective depth of 2 m, constituting the class with the most advanced weathering-leaching stage in the sub-basin. The latosolic B horizon, commonly starting from 80 cm deep, revealed mainly granular structure, and clayey texture. The suborders found were Brown, Yellow, Red and Red-Yellow Latosols, the last two of them being included in the soils map legend, making up about 6% of the sub-basin. In a study in the Alto Rio Grande basin, also in the state of Minas Gerais, Cambisols were registered in the more rugged parts and Latosols in the smoother portions of the landscape (Menezes et al., 2009; A. C. Santos et al., 2010).

In the sub-basin, the lowlands form areas of water accumulation, conditioning the soils (formed in situations of flat reliefs at the footslopes) to hydromorphic characteristics. Because the lower compartment covers the lowest altitudes, there is a predominance of the class of Gleysols, which occupy 7% of the sub-basin (Figure 2). In addition, hanging valleys are formed in the sub-basin, where these soils are also found, often with an area smaller than the mapable minimum area (10 ha). For this reason, they were not included in the generated pedological map (Figure 2). Many soils contained in the urban area of the sub-basin are in this class, and despite not being suitable, they have been widely used for civil construction.

The Gleysols profiles studied in the soil catenas (Table 2) have poor drainage, mainly due to the low position in the landscape and the presence of a water table close to the surface, on average at 70 cm depth. The exception is in the soil catena 3, due to the intense colluvial deposition process, which generates a thick Bg horizon (75 cm) and, thus, a greater profile depth (water table at 130 cm depth). Roots are generally limited to the superficial horizons, being rare in the gley horizons, due to anoxic conditions. Soils natural fertility varies from low to medium, characterizing mainly dystrophic soils. They showed massive structure and medium texture, constituting the soil classes with the highest percentage of sand and the lowest clay content. In general, the matrix colors are gray or grayish with reduction mottles. Melanic Gleysols are predominantly included in this soil mapping unit.

Argisols are by far the dominant soil mapping unit in the José Pereira stream sub-basin, representing 56% of the total area. The Red and Red-Yellow Argisols, which occur in the undulating and strongly undulating reliefs (Figures 2 and 3) are the main soil classes.

According to the analyzed Argisol profiles (Table 2), the average effective depth was 160 cm, with a considerable part having a very deep profile, greater than 200 cm. Clay films are present in a moderate-to-strong degree and in a common-to-abundant quantity. In most soil profiles, the presence of the textural B horizon was not an inhibitory factor for root growth, except in P1 of catena 4 and P3 of catena 8, where roots were rare. The predominant structure was subangular blocks followed by angular blocks, both with moderate degree. Most of the soil profiles show medium texture in the surface horizons and clayey texture in the subsurface horizons, mainly due to the process of lessivage or argiluviation, as indicated by the clay films.

As for the B/A horizons texture ratio, about 70% of the profiles exhibited values higher than 1.7. However, abrupt textural changes are present only in profiles P2 of catenas 3 and 4, and in P1 of catena 6. Abrupt textural change is one of the most important diagnostic attributes from an agronomic and geotechnical point of view, as it indicates horizons with contrasting physical behavior, especially when related to the water dynamics (Oliveira, 2008).

In 40% of the Argisols, the Bw horizon was found below the Bt horizon. In these soil profiles, the Bt horizon showed block structure, greater bulk density and moderate clay films on the aggregates, whereas the Bw horizon was friable, with granular structure and weak to absent clay films, characteristics of B-latosolic horizons. Therefore, these Argisols were included in the latosolic subgroup. The specialized literature cites the lateral and basal flows of water as an explanation for this occurrence (Moniz & Buol, 1982a,b). However, in the pedogeomorphological conditions of this sub-basin, the authors believe that the main processes involve the past formation of the Bw horizon in smoothed relief and, after the retaken of erosion, possibly due to a deepening of the local base level, more recent material from steeper slopes and higher altitudes would have been deposited on the top of the B-latosolic horizon. Under the current and/or sub-state conditions of rugged relief, the B-textural horizon was formed above the B-latosolic horizon. Figure 3 shows a representative soil profile present in the study area, which elucidates such pedogenetic processes.

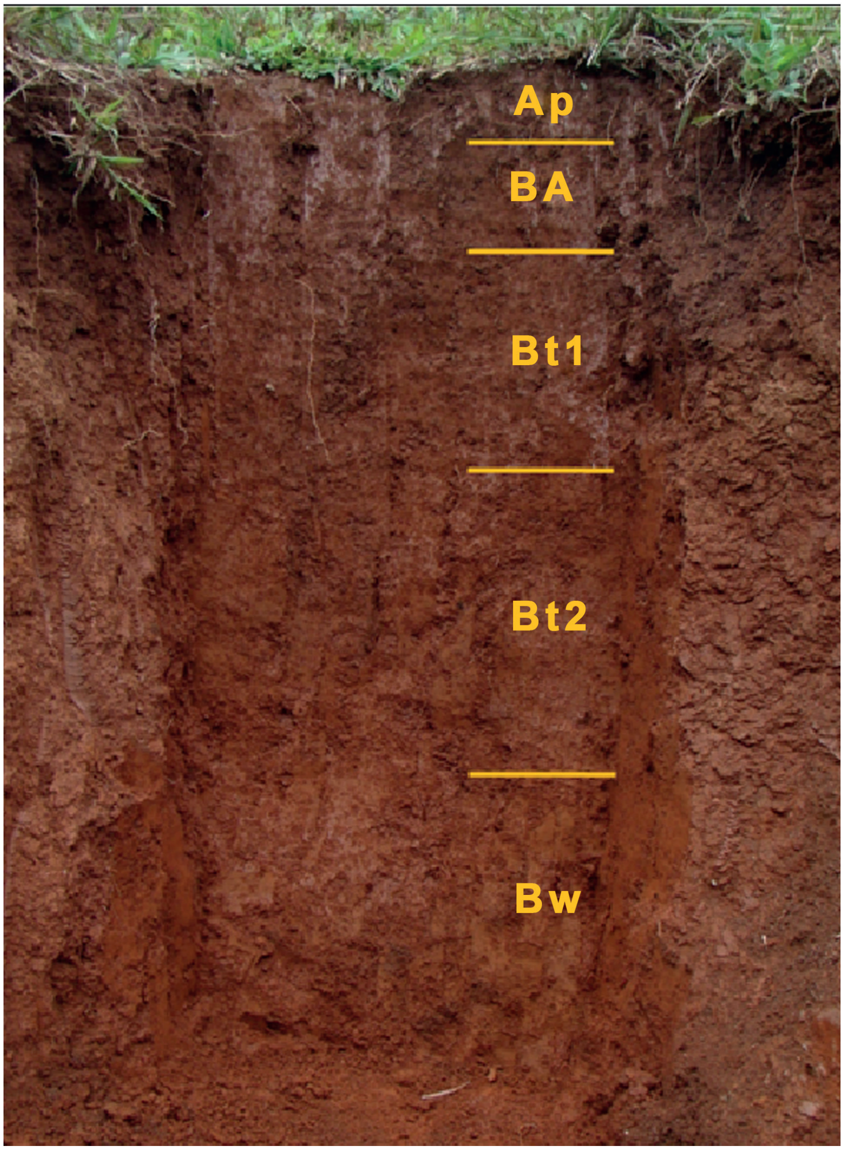

Figure 3. Moderate A, latosolic dystrophic RED ARGISOL, evidencing the presence of the Bw horizon below the Bt2 horizon.

A general comparison of the soil map generated in this study with the maps of FEAM (2010) and the RADAMBRASIL Project (BRASIL, 1983) shows that the dominant soil class in all cases was Argisol, especially the Red and Red Yellow Argisols. Thus, the previous maps, with a smaller scale, produced general information that agrees with the current map, of greater detail. However, due to the small size of the sub-basin relative to the mapping scales of FEAM-CETEC-UFV-UFLA (1:650,000) and RADAMBRASIL (1:1,000,000), the Cambisol and Gleysol classes, significant in the current mapping (26% and 7%, respectively), were not previously considered as mapping units for the respective maps in accordance with the proposals of the latter maps.

In addition, the soil map of RADAM frames most of the soils as eutrophic, while here more than 70% of them were dystrophic, by the same reasons explained above. This gain of additional information is important for the planning of current and future agricultural activities, beyond environmental implications.

Currently, the advancement of geoprocessing programs and the ease of processing the available information can induce the generation of more detailed soil maps only by widening the same database of small-scale maps, without performing the indispensable detailing of corresponding field works. According to Costa, Curi, Menezes, Araújo and Marques (2009), this practice is not advisable and may lead to incorrect interpretations. These authors investigated a sub-basin in the state of Rio Grande do Sul, Brazil, and found that the information generated by the expanded maps identified only one soil mapping unit, while the soils detailed survey identified 12 soil mapping units. The researchers concluded that enlarged small-scale maps are not appropriate to generate information relevant to the forestry suitability of the lands for eucalyptus plantation, the main object of their study.

The lack of soil surveys on an adequate scale results in the misuse of natural resources (Giasson, Inda, & Nascimento, 2006). Therefore, soil maps on a more detailed scale, such as that developed in the present study, generate a better and more real stratification of the environment, thus being more suitable for the planning of soil use and management in municipalities, river basins and sub-basins, and farms (Dalmolin, Klamt, Pedron, & Azevedo, 2004).

It is also noteworthy that pastures constitute the main agricultural use of the sub-basin, with many of them being in stages of environmental degradation, resulting in loss of productivity. Furthermore, the sub-basin is undergoing an intensification of urban expansion. If these activities continue to be carried out without adequate planning and management, land degradation processes will intensify, compromising the sustainability of this important sub-basin (Flauzino, Melloni, Pons, & Lima, 2016). In this way, studies of environmental issues, as the current pedological mapping, are useful for land-use planners, licensing agencies and agriculturalists seeking management techniques that improve their pastures and consequently generate more income and care for the land. The general population should also benefit from the consequent better-protected forest fragments, which ultimately translate into better water quality and reduced cases of flooding.

Conclusions

The selected soil catenas comprise the entire variability of soil classes associated with the past and current soil-landscape relationships in the pilot sub-basin.

There is a widespread predominance of the Argisols class around 56% of the sub-basin and a generalized occurrence of the latosolic B horizon below the textural B horizon in these Argisols profiles.

References

Alvarez, V. V. H., Novais, R. F., Barros, N. F., Cantarutti, R. B., & Lopes, A. S. (1999). Interpretação dos resultados das análises de solos. In A. C. Ribeiro, P. T. G., Guimarães, & V. H. Alvarez (Eds.), *Recomendações para o uso de corretivos e fertilizantes em Minas Gerais* (5ª aproximação, pp. 25-32). Viçosa, MG: Comissão de Fertilidade do Solo do Estado de Minas Gerais.

Anjos, L. H. C., Fernandes, M. R., Pereira, M. G., & Franzmeier, D. P. (1998). Landscape and pedogenesis of an Oxisol-Inceptisol-Ultisol sequence in Southeastern Brazil. *Soil Science Society of America Journal, 62*(6), 1651-1658. doi: 10.2136/sssaj1998.03615995006200060024x

Bertrand, G., & Bertrand, C. (2007). *Uma geografia transversal e de travessias: o meio ambiente através do território e das temporalidades.* Maringá: Massoni.

Comissão de Fertilidade do Solo do Estado de Minas Gerais (1999). *Recomendações para o uso de corretivos e fertilizantes em Minas Gerais* (5ª aproximação). Viçosa, MG: CFSMG.

Costa, A. M., Curi, N., Menezes, M. D., Araújo, E. F., & Marques, J. J. (2009). Levantamento detalhado de solos da microbacia hidrográfica do Horto Florestal Terra Dura (RS) e considerações sobre escalas de mapeamento. *Ciências e Agrotecnologia, 33*(5), 1272-1279. doi: 10.1590/S1413-70542009000500011

Dalmolin, R. S. D., Klamt, E., Pedron, F. A., & Azevedo, A. C. (2004). Relação entre as características e o uso das informações de levantamentos de solos de diferentes escalas. *Ciência Rural, 34*(5), 1479-1486. doi: 10.1590/S0103-84782004000500023

Empresa Brasileira de Pesquisa Agropecuária (1997). *Manual de métodos de análise de solo.* Rio de Janeiro: Ministério da Agricultura e do Abastecimento.

Empresa Brasileira de Pesquisa Agropecuária (2018). *Sistema brasileiro de classificação de solos* (5a ed.). Brasília: EMBRAPA.

Figueiredo, M. A., Varajão, A. F. D. C., Fabris, J. D., Loutfi, I. S., & Carvalho, A. P. (2004). Alteração superficial e pedogeomorfológica no sul do complexo Bação - Quadrilátero Ferrífero (MG). *Revista Brasileira de Ciência do Solo, 28*(4), 713-729. doi: 10.1590/S0100-0683 2004000400012

Flauzino, B., Melloni, E. G. P., Pons, N. A. D., & Lima, O. (2016). Mapeamento da capacidade de uso da terra como contribuição ao planejamento de uso do solo em sub-bacia hidrográfica piloto no sul de Minas Gerais. *Geociências, 35*(2), 277-287.

Fundação Estadual de Meio Ambiente (2010). *Mapa de solos do Estado de Minas Gerais: legenda expandida.* Belo Horizonte:

Universidade Federal de Viçosa; Fundação Centro Tecnológico de Minas Gerais; Universidade Federal de Lavras; Fundação Estadual do Meio Ambiente.

Giasson, E., Inda, A. V., Jr., & Nascimento, P. C. (2006). Estimativa do benefício econômico potencial de dois levantamentos de solos no Estado do Rio Grande do Sul. *Ciência Rural, 36*(2), 478-486. doi: 10.1590/S0103-84782006000200018

Guerra, A. J. T., & Cunha, S. B. (1995). *Geomorfologia: uma atualização de bases e conceitos.* Rio de Janeiro: Bertrand Brasil.

Instituto Brasileiro de Geografia e Estatística (1971). *Carta topográfica de Itajubá, SF23YB III-3. Escala 1:50.000.* Belo Horizonte: IBGE.

Instituto Brasileiro de Geografia e Estatística (1992). *Manual técnico da vegetação brasileira.* Rio de Janeiro: IBGE.

Lepsch, I. F. (2010). *Formação e conservação dos solos.* (2a ed.). São Paulo: Oficina de Textos.

Marques Neto, R. (2017). Meridional Mantiqueira horst: a proposal of morphostructural compartmentalization for its portion in Minas Gerais. *Revista Brasileira de Geomorfologia, 18*(3), 561-577. doi: 10.20502/rbg.v18i3.1118

Martins, E. S., Carvalho, O. A., Jr., Souza, V. V., Couto, A. F., Jr., Oliveira, S. N., Gomes, R. A. T., & Reatto, A. (2007). Relação solo-relevo em vertentes assimétricas no Parque Nacional da Serra dos Órgãos, RJ. *Revista Brasileira de Geomorfologia, 8*(1), 45-62. doi: 10.20502/rbg.v8i1.85

McLean, E. O. (1982). Soil pH and lime requeriment. In A. L. Page, R. H. Miller, & D. R. Keeney, *Methods of soil analysis: chemical and microbiological properties* (2nd ed., pp. 199-223). Madison: ASA.

Menezes, M. D., Curi, N., Marques, J. J., Mello, C. R., & Araújo, A. R. de. (2009). 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. doi: 10.1590/S1413-70542009000600013

Moniz, A. C., & Buol, S. W. (1982a). Formation of an Oxisol Ultisol transition in São Paulo, Brazil: I. Double water flow model of soil development. *Soil Science of Journal American, 46*(6), 1228-1233. doi: 10.2136/sssaj1982.03615995004600060022x

Moniz, A. C., & Buol, S. W. (1982b) Formation of an Oxisol Ultisol transition in São Paulo, Brazil: II Lateral dynamics of chemical weathering. *Soil Science of Journal American, 46*(6), 1234-1239. doi: 10. 2136/sssaj1982.03615995004600060023x

Moreira, R. (2019). A torre e o palimpsesto: Tricart e Ab'Saber olhados pelo olhar da totalidade homem-meio. *Ciência Geográfica, 23*(23), 7-16

Oliveira, J. B. (2008). *Pedologia aplicada.* Piracicaba: FEALQ.

Projeto Radam (1983). *Projeto RADAM Volume 32. Folhas SF 23/24. Rio de Janeiro/Vitória.* Rio de Janeiro: Ministério das Minas e Energia.

Resende, M., Curi, N., Rezende, S. B., Corrêa, G. F., & Ker, J.C. (2014). *Pedologia: base para distinção de ambientes.* (6a ed.). Lavras: Editora UFLA.

Santos, A. C., Pereira, M. G., Anjos, L. H. C., Bernini, T. A., Cooper, M., Nummer, A. R., & Francelino, M. R. (2010).

Gênese e classificação de solos numa topossequência no ambiente de mar de morros do médio Vale do Paraíba do Sul, RJ. *Revista Brasileira de Ciência do Solo, 34*(4), 1297-1314. doi: 10.15 90/S0100-06832010000400027

Santos, R. D., Lemos, R. C., Santos, H. G., Ker, J. C., & Anjos, L. H. (2005). *Manual de descrição e coleta de solos no campo* (5a ed.). Viçosa, MG: Sociedade Brasileira de Ciência do Solo.

Seibert, J., Stendahl, J., & Sorensen, R. (2007). Topographical influences on soil properties in boreal forests. *Geoderma, 141*(1-2), 139-148. doi: 10.1016/j.geoder ma.2007.05.013

Serviço Geológico do Brasil (2008). *Mapa geológico de Itajubá - SF.23-Y-B-III. Escala 1:100.000.2008.* Recuperado de http://geosgb.cprm.gov.br/

Silva, C. R. (2008). *Geodiversidade do Brasil. Serviço geológico do Brasil.* Rio de Janeiro: CPRM.

Souza, R. V. C. C., Ribeiro, M. R., Souza, V. S., Jr., Corrêa, M. M., Almeida, M. C., Campos, M. C. C.,... Schulze, S. M. B. B. (2010). Caracterização de solos em uma topoclimossequência no Maciço de Triunfo - Sertão de Pernambuco. *Revista Brasileira de Ciência do Solo, 34*(4), 1259-1270. doi: 10.1590/ S0100-06832010000400024

Tricart, J. (1977). *Ecodinâmica.* Rio de Janeiro: IBGE.

Trouw, R. A. J., Nunes, R. P. M., Castro, E. M. O., Trouw, C. C., & Matos, G. C. (2008). *Nota explicativa das folhas Varginha (SF.23-V-D-VI) e Itajubá (SF.23-Y-B-III).* Programa geologia do Brasil. Minas Gerais: CPRM.

Vettori, L. (1969). *Métodos de análise de solo.* Rio de Janeiro: Ministério da Agricultura Equipe de Pedologia e Fertilidade do Solo.