Revista Brasileira de Ciência do Solo

Division – Soil In Space and Time | Commission – Soil Survey and Classification

Field Description and Identification of Diagnostic Qualifiers for Urban Soils in Brazil

Jéssica Rafaela da Costa(1), **Fabrício de Araújo Pedron**(2)*, **Ricardo Simão Diniz Dalmolin**(2) **and Ricardo Bergamo Schenato**(2)

(1) Universidade de São Paulo, Departamento de Geografia, Programa de Pós-Graduação em Geografia Física, São Paulo, São Paulo, Brasil.
(2) Universidade Federal de Santa Maria, Departamento de Solos, Santa Maria, Rio Grande do Sul, Brasil.

ABSTRACT: Human activities often alter soils found in urban areas. These alterations affect their environmental functions and potential for use. However, soils from urban areas in Brazil have not been surveyed and identified, which can pose a technical problem for the development of the city. Considering the importance of urban environments and their soils, this study aimed to evaluate the environmental and morphological characteristics and the physical properties of urban soils in Santa Maria, Rio Grande do Sul, Brazil. The purpose was then to organize a protocol for describing urban soils and to identify diagnostic qualifiers to subsidize establishment of an order that allows proper classification of these soils in the Brazilian Soil Classification System. The protocol containing general and environmental notes and morphological notes and qualifiers was organized based on the experience of this study and the relevant literature. The environmental, morphological, and physical analyses carried out supported interpretation of the urban soils of Santa Maria, their classification in the World Reference Base for Soil Resources system, and identification of diagnostic qualifiers proposed for the Brazilian Soil Classification System. The protocol tested in this study was adequate for data collection in the field. Soils had high variation in layer thickness, particle size composition, color, bulk density, saturated hydraulic conductivity, penetration resistance, stoniness, and the presence of artifacts. Considering the establishment of a Brazilian taxonomy for urban soils, the field data led to the proposal for new qualifiers, such as Saprolitic (residual saprolite material), Impervic (sealed/impermeable layer), Multigranic (layers with contrasting textures), Stonic (layers with stoniness), and Saprorockic (layers constituted of transported saprolite), which can be used as diagnostic attributes in the Brazilian Soil Classification System and even contribute to improvement of the order of Technosols in the World Reference Base For Soil Resources system.

Keywords: Anthrosols, Technosols, diagnostic criteria, field protocol.

*** Corresponding author:**
E-mail: fapedron@ufsm.br

Received: June 04, 2018

Approved: March 01, 2019

How to cite: Costa JR, Pedron FA, Dalmolin RSD, Schenato RB. Field description and identification of diagnostic qualifiers for urban soils in Brazil. Rev Bras Cienc Solo. 2019;43:e0180121.
https://doi.org/10.1590/18069657rbcs20180121

INTRODUCTION

Human influence on the environment can be identified in several places of human occupation and soil is one of the main sources with a record of anthropogenic activities, especially those under urban environments, whose attributes have been described in recent years by several authors, such as Jim (1998), Morel and De Kimpe (1998), Pedron et al. (2004), Greinert (2015), Gorbov (2016), and Zalasiewicz (2017). Urban soils are those found in urban areas, formed from changes imposed by the dynamics of cities and that perform typically urban functions (Azevedo et al., 2004; Pedron et al., 2004), even though we can also find natural soil (formed without human influence) in those areas. Urban and suburban areas in Brazil are defined by local legislation and are the space where urban structures are developed.

Anthropogenic materials, technically called "artifacts", found in urban soils significantly change the physical, chemical, and biological properties of these soils (Pouyat et al., 2010) and their morphology (Joimel et al., 2016). The most common and critical modifications in urban soils are related to increased bulk density, promoted by compaction (Schueler, 2000), and changes in texture, porosity, infiltration, and water retention (Rokia et al., 2014).

The methods of soil description and collection are consolidated for natural environments (Santos et al., 2015), whose soil characterization is based on profile description (sequence and depth of horizons, textural class, color, structure, special features, etc.), sample collection, laboratory analysis (chemical and physical analysis), and data interpretation. However, when it comes to urban soils significantly altered by human activities, there is a lack of information (or field protocol) that guides technicians in this work (Pedron et al., 2007), as well as a lack of a Brazilian taxonomic classification to characterize these specific environments. The few studies on this subject in Brazil have been carried out with adaptations of the procedures used for natural soils, without standardization that would allow qualification of the data and later comparison among the studies.

The lack of taxonomic classification affects the progress of studies in disturbed areas (Pedron et al., 2007). Moreover, a new order describing urban soils in the SiBCS is justified, because their functions and services are altered due to the nature of artifacts that can be hazardous to human and animal health and that weather differently. Their internal structure, fertility, water movement, strength, and carbon storage are different from natural soils.

Several national soil taxonomic classification systems have a specific order for classifying urban soils. The international World Reference Base for Soil Resources-WRB system (IUSS Working Group WRB, 2015) has the order of Technosols, in which urban soils are classified based on attributes organized into qualifiers. In Brazil, the order of Anthroposols was proposed by Curcio et al. (2004) to identify soils modified by human actions, including urban soils, but this was not implemented in the Brazilian Soil Classification System (SiBCS); thus, its present edition (Santos et al., 2018) does not provide support for urban soils.

The difficulty of creating a taxonomic classification for urban land stems from a wide range of changes already mentioned for the soils in these environments. The changes in urban soils favor a diversity of properties that do not obey a natural order and frequently do not exhibit spatial dependence. In addition, many technicians from different areas require specific information about the soils in urban environments, which makes it difficult to define the most appropriate attributes to organize a taxonomic classification (Pedron et al., 2006). In this context, this study aimed to evaluate the environmental, morphological, and physical properties of urban soils in Santa Maria, Rio Grande do Sul, Brazil, for the purpose of organizing a protocol to describe urban soils in the field and to identify diagnostic qualifiers to subsidize an order that allows appropriate classification of these soils in the SiBCS.

MATERIALS AND METHODS

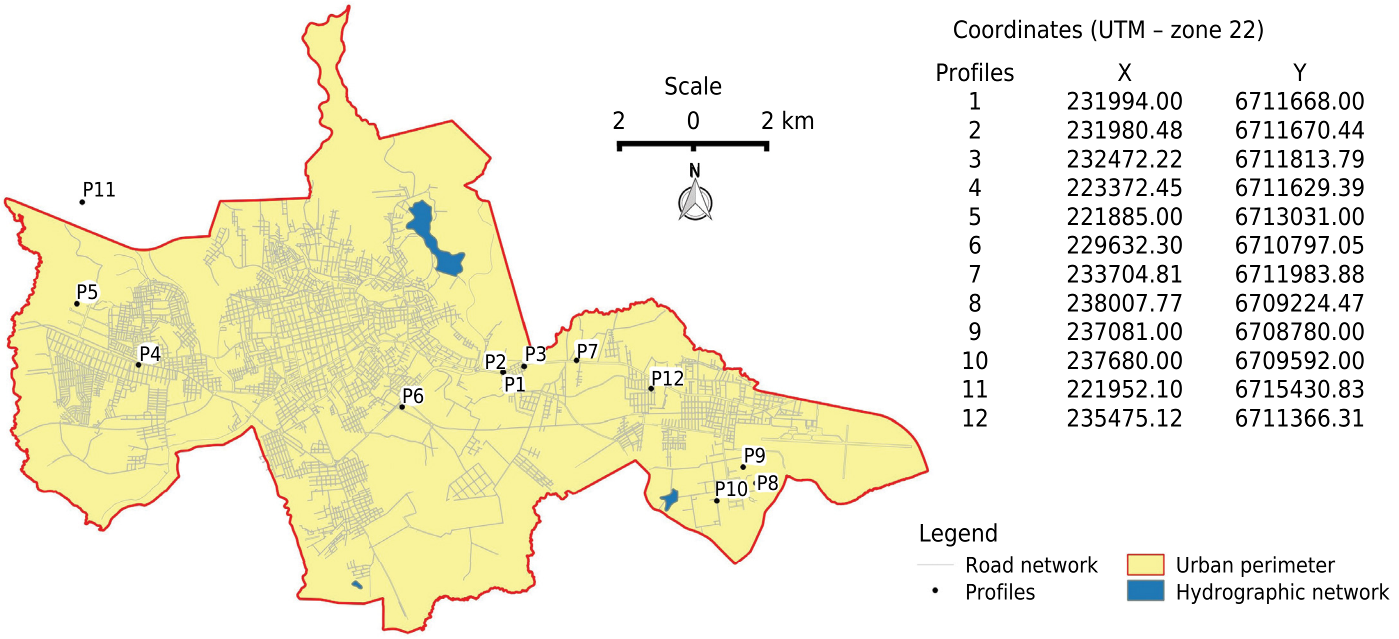
Study area

The study was carried out in the urban perimeter (urban and suburban areas) of Santa Maria, Rio Grande do Sul, Brazil (Figure 1), where 12 soil profiles were described and sampled. The soil profiles were selected from the already existing urban soil survey of Santa Maria (Pedron et al., 2008), considering their representativeness (type of transport/deposition and nature of artifacts). One of the profiles was collected outside the urban perimeter, where the old municipal garbage landfill is located.

The city of Santa Maria began as a military camp in 1797 and became an officially recognized city in 1876 (Marchiori and Noal Filho, 2009). It is regionally known for its universities, colleges, and medical centers and nationally known for its military installations. All these activities express the dynamics of Brazilian urbanization in recent decades, concentrating 93 % of its 280 thousand inhabitants (estimated in 2018) in the urban perimeter (IBGE, 2019). The city is located in the middle of the state of Rio Grande do Sul, the most southern state. The entire urban perimeter has sedimentary rocks, such as sandstones and siltstones, with an elevation between 100-250 m a.s.l. The northern part also has volcanic rocks such as basalt and rhyolite, with elevation ranging from 200-450 m a.s.l. (Sartori, 2009). The surface slope ranges from 0 to 25 % in the sedimentary fields and from 20 to 85 % in the volcanic fields. The local climate is humid subtropical, classified as Cfa by the Köppen classification system. The average annual temperature and rainfall are 19.2 °C and 1,708 mm, respectively (Maluf, 2000).

Protocol for describing urban soils

Due to the lack of standard procedures for the description and collection of urban soils, which are generally affected by anthropogenic alterations, this study proposed the organization of a protocol for describing urban soils (Table 1). The proposal was based on adaptations in the procedures found in the Manual of Description and Collection of Soils (Santos et al., 2015), Pedology Technical Manual (IBGE, 2015), SiBCS (Santos et al., 2018), all of them designed for natural soils, where attributes also important for an urban situation were used, for example, color, texture, structure, depth of soil layer, and percentage of



Coordinates (UTM – zone 22)

Profiles	X	Y
1	231994.00	6711668.00
2	231980.48	6711670.44
3	232472.22	6711813.79
4	223372.45	6711629.39
5	221885.00	6713031.00
6	229632.30	6710797.05
7	233704.81	6711983.88
8	238007.77	6709224.47
9	237081.00	6708780.00
10	237680.00	6709592.00
11	221952.10	6715430.83
12	235475.12	6711366.31

Figure 1. Location of soil profiles evaluated within the urban area of Santa Maria, Rio Grande do Sul State, Brazil.

coarse fragments. The studies of Curcio et al. (2004) and Santos Junior and Lima (2012) were also taken into account. The diagnostic qualifiers were drawn from the WRB system (IUSS Working Group WRB, 2015) and some were identified in fieldwork. The spelling of the qualifiers followed the WRB convention. It is important to state that the idea of this research is primarily to identify the qualifiers (diagnostic attributes), contributing to the establishment of a future order in the SiBCS. The authors do not intend to organize the qualifiers into a principal or supplementary category as in the WRB system.

The designation of “layers” rather than “horizons” for subdivision of the soil profiles was considered more suitable, due to the constant anthropogenic interferences that usually alter the pedogenetic processes or even to the absence of these processes in urban environments (Yuan et al., 2008; Rokia et al., 2014). Layers in the soil profiles were mainly identified/separated through the use of the following criteria: color, texture, and presence of artifacts (type and volume). The attribute “mosaic color” was added to describe material with three or more colors, because the mixture of materials may lead to absence of a predominant matrix.

Determination of the following physical properties was performed to complement the morphological characterization of the soils: saturated hydraulic conductivity (Ks), microporosity (Mip), macroporosity (Map), total porosity (TP), bulk density (BD), penetration resistance (PR), and particle size analysis

In order to determine the Ks, Mip, Map, TP, and BD, undisturbed samples were collected on the surface of the profile with volumetric rings (85 cm^3), according to Teixeira et al. (2017); a Stolf impact penetrometer and the Dutch formula were used to obtain the results (Stolf, 1991). The particle size determination of the fine earth (clay, silt, and sand) was performed with NaOH 1 mol L^{-1} dispersant by the pipette method, according to Teixeira et al. (2017). Quantification of the coarse fraction (>2 mm) was performed through dry sieving and manual separation for identification of the components and determination of the percentile in relation to the total material collected. In the coarse fraction, the anthropogenic materials (artifacts) were counted.

The soil profiles were classified in the WRB system (IUSS Working Group WRB, 2015) and the data were evaluated for the purpose of identifying new diagnostic qualifiers that can contribute to establishment of an order in SiBCS that supports urban soils.

RESULTS

General and Morphological Characterization

The anthropogenic alterations observed in the 12 soil profiles evaluated (Figures 2 and 3) show that the soils analyzed lost their natural properties. The alterations promoted in the environment by human actions are expressed in different properties, such as the existence of well-demarcated layers in soils 3, 7, 10, and 12, in which there is an abrupt change between the layers, characterized by the different nature of their constituents.

Morphological variability of soils occurs in a short distance, as was observed in the comparison between soil 1 and 2, 15 meters distant from each other, and is related to land use in the urban environment. The urban land use class that was most predominant was “urban construction” (soils 1, 2, 3, 4, 6, 9, and 12). In addition, organic and inorganic waste disposal areas (soils 7, 8, 10, and 11) and an area of exploitation of natural resources were identified (soil 5). In the selection of the soil profile areas in the urban soil survey of the city and the field trips made during the study, we could not find altered soils with the following land uses: soil deposition area, urban agriculture area, and permanent preservation area, because most of those areas in Santa Maria still maintain a natural soil cover.

Table 1. Protocol for describing urban soils

GENERAL AND ENVIRONMENTAL NOTES(1)							
Project:		**Persons Responsible:**					
Date:	Slope gradient:	**Penetration resistance**					
Profile No.:	Relief:	Depth	1st	2nd	3rd	4th	5th
Described by:	Natural soil of the area:	0.10 m					
Drainage:		0.20 m					
Location:	GPS coordinates:						
Erosion:	% of surface fragment:						

General profile characterization(2)	**Urban land use**(3)
Natural soil profile	Urban agriculture
Natural soil profile with artifacts	Urban construction
Natural soil profile with outside transported material	Residue disposal
Deposition of outside transported materials	Permanent preservation
Deposition of outside transported materials with addition of artifacts	Exploitation of natural resources
Removed soil	Soil deposition area
Removed soil with deposition of outside transported materials	**Notes:**
Removed soil with addition of artifacts	
Removed soil with deposition of outside transported materials and addition of artifacts	
Mobilized soil	
Mobilized soil with deposition of outside transported materials	
Mobilized soil with addition of artifacts	
Mobilized soil with deposition of outside transported materials and addition of artifacts	

Morphological qualifiers(4)				
Ekranic	Leptic	Siltic	Relictgleyic	Impervic
Linic	Reductic	Loamic	Archaic	Stonic
Urbic	Hyperskeletic	Clayic	Artifact	Saprorockic
Spolic	Transportic	Multigranic	Hyperartifact	
Garbic	Saprolitic	Densic	Skeletic	
Isolatic	Arenic	Gleyic	Stagnic	

MORPHOLOGICAL NOTES (frame for individual layer)(5)

Layer: | **Depth (cm):** | **Root** ( )Yes ( )No | **Porosity:** visible pores ( )Yes ( )No

Moist color: ( ) mosaic color | **Mottle:** ( )No ( )Yes Moist color:

Transition between layers: | Quantity: ( )Few ( )Common ( )Many

Distinctness: ( )Abrupt ( )Clear ( )Gradual ( )Diffuse | Size: ( )Fine ( )Medium ( )Coarse

Topography: ( )Smooth ( )Rolling ( )Irregular ( )Broken | **Number of density samples:**

Struture (shape): ( )Columnar ( )Prismatic ( )Angular blocky ( )Subangular blocky ( )Granular ( )Platy ( )Massive ( )Single Grain

Grade: ( )Structureless ( )Weak ( )Moderate ( )Strong

Size: ( )Extremely coarse ( )Very coarse ( )Coarse ( )Medium ( )Fine ( )Very fine

Texture: ( )Sandy ( )Clayey ( )Very clayey ( )Silty ( )Loamy

Rock fragments: ( )Yes ( )No Kind: ( )Gravel ( )Cobbles ( )Stones ( )Boulders

Shape: ( )Angular ( )Rounded ( )Well rounded

Consistence:

Dry: ( )Loose ( )Soft ( )Slightly hard ( )Hard ( )Very hard ( )Extremely hard

Moist: ( )Loose ( )Very friable ( )Friable ( )Firm ( )Very firm ( )Extremely firm

Wet:

Plasticity - ( )Nonplastic ( )Slightly plastic ( )Plastic ( )Very plastic

Stickiness - ( )Nonsticky ( )Slightly sticky ( )Sticky ( )Very sticky

Artifacts(6)**:**

Material	%	Material	%	Material	%	Material	%	Others:
( )Plaster		( )Glass		( )Rubber		( )Wood		
( )Cloth		( )Concrete		( )Asphalt		( )Stones		
( )Paper		( )Plastic		( )Brick				
( )Ceramic		( )Styrofoam		( )Metal				

(1) Based on the Manual of Description and Collection of Soils (Santos et al., 2015), Pedology Technical Manual: Practical Field Guide (IBGE, 2015), *SiBCS* (Santos et al., 2018). (2) Based on Curcio et al. (2004) and Santos Junior and Lima (2012). (3) Based on the experience of this study. (4) Based on the WRB system (IUSS Working Group WRB, 2015) and the experience of this study. (5) Based on the Manual of Description and Collection of Soils (Santos et al., 2015), Pedology Technical Manual: Practical Field Guide (IBGE, 2015), *SiBCS* (Santos et al., 2018). (6) Based on the experience of this study.

Soils formed from deposition of outside transported materials and addition of artifacts (Table 2) were predominant, with nine profiles evaluated. Removed soil and exposure of saprolite material was the second most frequent condition, with two profiles evaluated.

The transition between the layers was predominantly abrupt, considering not only color as an indicator but also texture (Table 3). Soil 7 was constructed by deposition of soil and saprolite materials and artifacts that made it difficult to identify the predominant color of the layer. That condition was indicated in the protocol as “mosaic color”. The soils had predominantly sticky and plastic consistency and massive and block structure, which were generally strongly expressed. It was only possible to identify effective depth in soils 3, 8, and 9. In the other soils, the average 1.5 m thickness sampled was not enough to expose the original material.

Soil layers have different compositions that were counted within the coarse fraction (Table 4). The variability of particle size within each profile is high, as can be observed in profile 1, where the clay content ranges from 69 g kg^{-1} in layer 2 to 393 g kg^{-1} in layer 4. The percentage of the coarse fraction also varied within each profile. The main coarse fragments found in the soils were rocks, saprolites, tiles, bricks, and concretes. Industrialized materials like plastics and glass were only significant in soil 11, located in the former municipal landfill area.

The coefficient of variation (Table 5) was high for the coarse fraction (95.59 %), Ks (71.95 %), and PR (58.72 %). The amplitude of values (minimum and maximum) highlight the sand, silt, clay, coarse fraction, and PR. The values of standard deviation were higher for sand (164.69), silt (140.47), coarse fraction (278.74), and PR (230.29).

Due to the nature of some soils, it was not possible to collect undisturbed samples, so determination of soil bulk density, hydraulic conductivity, microporosity, macroporosity, and total porosity was only possible in the surface layer of soils 2, 5, 6, 8, and 13, and penetration resistance was only possible in the surface layer of soils 2, 3, 4, 5, 6, and 8.

Soil Classification and Diagnostic Qualifiers

All soil profiles were classified in the reference group “Technosol” (IUSS Working Group WRB, 2015). The data obtained in this study led to the proposal of the following qualifiers (Table 6):

Saprolitic – the presence of layers ≥0.50 m thick formed by residual saprolite material, exposed from the practice of field cuttings, starting within 0.50 m of the soil surface.

Multigranic – the presence of layers ≥0.20 m thick, within 1.00 m from the surface, with contrasting textures (clayey, silty, loamy, or sandy) due to mixing of materials in the same layer;

Stonic – the presence of layers ≥0.20 m thick, within 1.00 m from the surface, with stoniness ≥40 %;

Impervic – the presence of a sealed/impermeable layer within 1.00 m of the soil surface;

Saprorockic – the presence of layers ≥0.20 m thick, within 1.00 m from the surface, constituted of transported saprolite.

DISCUSSION

The urban soils of Santa Maria have some properties that differ from natural soils. Those differences, for example, type and volume of the artifacts introduced in the soil, bulk density, penetration resistance, sequence and thickness of layers, and the dynamics

Figure 2. Soil profiles and landscapes (1 to 6) in the urban area of Santa Maria, Rio Grande do Sul State, Brazil.

Soil 7

Soil 8

Soil 9

Soil 10

Soil 11

Soil 12

Figure 3. Soil profiles and landscapes (7 to 12) in the urban area of Santa Maria, Rio Grande do Sul State, Brazil.

Table 2. Morphological condition of the 12 profiles of urban soils from Santa Maria, Rio Grande do Sul State, Brazil

Soil profile conditions	Profile number
Profile of natural soil with addition of transported material and artifacts	9
Profile with deposition of outside transported materials and addition of artifacts	1, 2, 3, 4, 7, 8, 10, 11, 12
Profile with removed soil	5, 6

Table 3. Morphology of urban soil profiles in Santa Maria, Rio Grande do Sul State, Brazil

Soils	Layers	Moist color	Transition	Depth	Wet consistency	Structure
				m		
1	1	-	abr/cle	0.00-0.10	-	-
	2	5YR 6/2	abr/cle	0.10-0.25	-	-
	3	5YR 3/1	abr/cle	0.25-0.80	plt/sti	mas/pla
	4	5YR 3/1	-	0.80-1.20$^+$	plt/sti	mas/pla
2	1	5YR 2.5/2	abr/irr	0.00-0.27	-	ang/sang
	2	10YR 3/6	abr/irr	0.27-0.45	plt/sti	mas
	3	5YR 4/6	abr/irr	0.45-0.70	plt/sti	mas
	4	5YR 4/6	-	0.70-1.20$^+$	plt/sti	mas
3	1	2.5YR 2,5/4	abr/irr	0.00-0.40/0.50	plt/sti	sang
	2	2.5YR 3/2	grd/smo	0.40/0.50-0.70/0.80	plt/sti	ang/sang
	3	2.5YR 3/2	grd/smo	0.70/0.80-1.05	plt/sti	ang
	4	5YR 6/2	grd/smo	1.05-1.20	plt/sti	mas
	5	2.5YR 5/6	-	1.20$^+$	plt/sti	mas
4	1	-	-	0.00-0.05	-	-
	2	-	-	0.05-0.30	-	-
	3	2.5YR 3/6	abr/smo	0.30-0.55	slplt/slsti	mas
	4	2.5YR 4/4	abr/smo	0.55-0.90	slplt/slsti	mas
	5	2.5YR 3/6	-	0.90-1.50$^+$	slplt/slsti	mas
5	1	5YR 4/6	abr/irr	0.00-1.10	noplt/slsti	mas
	2	5YR 5/4	-	1.10$^+$	noplt/slsti	mas
6	1	5YR 4/4	abr/smo	0.00-0.10	plt/sti	sang
	2	2YR 4/6	-	0.10-1.50	plt/sti	mas
7	1	5YR 3/3	abr/wav	0.00-0.40/0.70	plt/nosti	mas
	2	mosaic	abr/wav	0.40/0.70-0.75/0.90	plt/nosti	mas
	3	mosaic	-	0.75/0.90-1.10	plt/nosti	mas
8	1	10YR 4/4	abr/smo	0.00-0.43	plt/sti	ang/sang
	2	2.5YR 3/2	cle/smo	0.43-0.62	noplt/nosti	ang
	3	2.5YR 3/2	cle/smo	0.62-0.95	noplt/nosti	ang
	4	2.5YR 3/4	cle/smo	0.95-1.21	slplt/slsti	ang
	5	2.5YR 4/4	-	1.21-1.50$^+$	slplt/slsti	ang/sang
9	1	5YR 2.5/2	abr/smo	0.00-0.20	slplt/slsti	pla/mas
	2	2.5YR 3/2	grd/smo	0.20-0.40	slplt/slsti	ang
	3	2.5YR 2.5/4	grd/smo	0.40-0.50	plt/sti	ang/sang
	4	2.5YR 2.5/4	grd/smo	0.50-0.62	plt/sti	ang
	5	2.5YR 2.5/4	grd/smo	0.62-0.80	plt/sti	ang
	6	2.5YR 2.5/4	grd/smo	0.80-1.05	plt/sti	ang
	7	2.5YR 2.5/4	-	1.05-1.30$^+$	plt/sti	ang

Continue

Continuation

10	1	7.5YR 3/4	abr/smo	0.00-0.24	plt/sti	mas
	2	10YR 4/1	abr/smo	0.24-0.36	slplt/slsti	mas
	3	10YR 2/1	abr/smo	0.36-0.64	plt/sti	mas
	4	5YR 3/4	abr/smo	0.64-0.77	plt/sti	mas
	5	10YR 3/1	abr/smo	0.77-0.90	plt/sti	mas
	6	7.5YR 5/3	cle/irr	0.90-1.05	plt/sti	mas
	7	2.5YR 5/4	-	1.05-1.30	slplt/slsti	mas
11	1	10YR 4/1	grd/irr.	0.00-0.40	slplt/slsti	sang
	2	10YR 4/1	-	0.40-1.50	slplt/slsti	sang
12	1	2.5YR 3/1	abr/smo	0.00-0.20	plt/sti	sang/gra
	2	2.5YR 5/6	abr/smo	0.20-0.40	noplt/nosti	sgra
	3	2.5YR 4/1	-	0.40-0.80^{+}	plt/sti	sang/gra

abr = abrupt; irr = irregular; smo = smooth; wav = wavy; cle = clear; plt = plastic; slplt = slightly plastic; noplt = nonplastic; sti = sticky; slsti = slightly sticky; nosti = nonsticky; mas = massive; pla. = platy; gra. = granular; sang = subangular blocky; ang = angular blocky; sgra = single grain.

of profile construction, are essential data for taxonomic and technical interpretation of these soils.

The profiles of the urban soils analyzed, as a consequence of the addition of artefacts in the environment and the actions of turning over and cutting soils and deposition of soils from outside, exhibited different properties, as found in several other studies on this subject (Séré et al., 2010; Gorbov, 2016), reinforcing the perception of the heterogeneity of urban soils. As in Hagan et al. (2012), access to the urban soils was complicated in this study by the existence of continuous buildings and road networks.

The large variability in the number of layers and the thickness of these layers is quite visible, and very well defined boundaries occurred, as in soils 3, 7, 10, and 12. Variability in the number and thickness of the layers is also cited by Simón et al. (2018) in a study of Technosols developed in quarry dumps restored with marble sludge in Spain. The difficulty of identifying the total thickness of the altered soil profile affects the interpretation of the environmental fragility of the area. In the landfill sites, where the area was leveled, the mixing of materials and the formation of soil profiles with uneven characteristics occurs within a small space. In these cases, it is difficult to find a modal profile to characterize the area.

Environmental and morphological attributes used for characterization of natural soils are equally important for urban soils; however, the functionality of some is altered, such as color determination. In the urban sites, the color of the soil was difficult to describe, due to the great mixture of materials, as in the case of layer 1 of soil 7. This situation makes difficult to determine the predominant color, creating the condition of "mosaic color". In low-disturbance environments, one of the utilities of color is indicating the pedogenetic processes (gleization, podsolization, plinthization, etc.) that occur in the area (Campos et al., 2003). In urban soils, the colors indicate depositional differences, both of the time of the deposit and of the materials that constitute these deposits (Obour et al., 2017).

Determination of texture and consistency can also be difficult in urban soils. Their determination demands direct handling of the soil by the tact method (Santos et al., 2015). This sensory analysis may be impaired by the existence of anthropogenic materials that pose a risk to the technician, such as sharp, contaminated, or toxic objects.

Considerable changes in structure and texture from one layer to another were found, a situation well described and discussed by Hiller (2000). Field descriptions indicated that abrupt changes in texture and structure are also common among the various

Table 4. Particle size distribution and composition of the coarse fragments in the urban soils of Santa Maria, Rio Grande do Sul State, Brazil

Soils	Layers	Sand	Clay	Silt	Coarse fragments	Composition of the coarse fragments (artifacts)
			g kg^{-1}		%	
1	1	-	-	-	100	100 % asphalt
	2	792	69	139	95	96 % stones; 4 % tile, brick, ceramic, concrete
	3	176	339	485	49	92 % stones; 8 % tile, brick, ceramic, concrete
	4	155	393	453	45	100 % saprolite
2	1	342	212	445	54	100 % stones
	2	472	193	335	40	100 % stones
	3	657	112	231	84	92 % stones; 7 % tile, brick, ceramic, concrete; 1 % saprolite
	4	199	85	715	69	92 % saprolite with small stones; 8 % stones
3	1	361	192	447	42	97 % stones; 3 % plastic
	2	191	287	522	40	100 % stones
	3	41	568	390	62	100 % saprolite
	4	56	219	725	69	100 % saprolite
	5	92	125	783	74	100 % saprolite
4	1	-	-	-	100	96 % asphalt; 4 % stones
	2	-	-	-	100	100 % stones
	3	612	245	142	1	96 % stones; 4 % saprolite with small stones
	4	565	274	161	1	73 % stones; 27 % saprolite with small stones
	5	601	239	161	2	87 % stones; 13 % saprolite with small stones
5	1	669	143	188	1	100 % stones
	2	692	128	180	3	100 % stones
6	1	196	133	671	35	98 % saprolite; 1 % plastic; 1 % glass
	2	64	89	847	89	100 % saprolite
7	1	339	307	354	54	94 % saprolite; 5 % asphalt; 1 % charcoal
	2	676	117	207	14	100 % stones
	3	326	288	386	51	92 % saprolite; 5 % asphalt; 3 % stones
8	1	405	318	277	17	100 % stones
	2	645	133	222	1	100 % stones
	3	570	184	246	1	70 % stones; 30 % glass
	4	456	300	243	3	100 % stones
	5	375	418	207	1	100 % stones
9	1	356	386	259	49	55 % saprolite with stones; 17 % plaster; 25 % stones; 1 % tile, brick, ceramic, concrete; 1 % charcoal; 1 % plastic
	2	384	183	433	2	100 % stones
	3	327	289	384	1	100 % plastic and styrofoam
	4	306	314	380	0	-
	5	261	400	339	0	-
	6	219	442	339	1	100 % saprolite
	7	183	405	412	1	100 % saprolite
10	1	465	212	324	6	93 % saprolite; 7 % stones
	2	603	281	117	0	-
	3	160	276	564	14	100 % saprolite
	4	458	195	347	29	56 % stones; 31 % saprolite; 13 % tile, brick, ceramic
	5	442	219	340	11	72 % stones; 28 % saprolite
	6	600	230	170	5	100 % saprolite
	7	612	248	140	1	100 % saprolite

Continue

Continuation

11	1	507	187	306	28	88 % Stones; 11 % plastic; 1 % glass
	2	502	197	301	65	52 % saprolite; 27 % stones; 12 % plastic; 1 % glass; 3 % tile, brick, ceramic, concrete; 5 % cloth
12	1	398	338	264	1	100 % stones
	2	300	401	299	1	100 % stones
	3	382	334	284	4	87 % stones; 8 % saprolite; 5 % tile, brick, ceramic, concrete

Table 5. Descriptive statistics of the physical data for the urban soils of Santa Maria, Rio Grande do Sul State, Brazil

Soil properties(1)	Medium	Minimum	Maximum	Standard deviation	Coefficient of variation
					%
Sand (g kg^{-1})	399.07	41.46	792.03	164.69	41.27
Silt (g kg^{-1})	356.12	86.00	846.66	140.47	39.44
Clay (g kg^{-1})	244.88	69.01	568.44	81.23	33.17
Coarse fraction (g kg^{-1})	291.59	0.33	984.90	278.74	95.59
BD (Mg m^{-3})(2)	1.51	1.31	1.66	0.10	6.36
Ks (cm h^{-1})(2)	26.41	13.34	67.76	19.00	71.95
Mip (m^3 m^{-3})(2)	0.41	0.38	0.44	0.01	3.62
Map (m^3 m^{-3})(2)	0.28	0.13	0.36	0.06	20.89
TP (m^3 m^{-3})(2)	0.13	0.06	0.25	0.05	37.01
PR (kgf cm^{-2})(3)	392.17	78.25	873.91	230.29	58.72

(1) Determined according to Teixeira et al. (2017); (2) Analyses performed on samples collected with a volumetric ring in the surface layer of the profiles: 2, 5, 6, 8 and 13; (3) Analysis performed on the surface layer of profiles 2, 3, 4, 5, 6 and 8.

Table 6. Classification of urban soils according to the WRB (IUSS Working Group WRB, 2015) considering only morphological and physical qualifiers

Soils	WRB classification	Suggested qualifiers*
1	Urbic Ekranic Technosol (Densic, Relictgleyic, Skeletic)	Impervic, Multigranic, Saprorockic
2	Urbic Technosol (Skeletic)	Multigranic, Saprorockic
3	Urbic Technosol (Skeletic, Stagnic)	Multigranic
4	Ekranic Technosol (Densic, Loamic)	Impervic, Saprorockic
5	Technosol	Saprolitic
6	Technosol	Saprolitic
7	Urbic Technosol (Loamic)	Saprorockic, Stonic
8	Technosol	Multigranic, Saprorockic
9	Urbic Technosol (Densic)	Multigrani, Saprorockic, Stonic
10	Technosol (Transportic)	Saprorockic, Stonic
11	Garbic Urbic Technoso (Densic, Loamic)	Saprorockic, Stonic
12	Technosol (Transportic)	Multigranic, Saprorockic

* Qualifiers suggested from the data of the 12 profiles evaluated in this study.

packages of materials that may constitute the same layer, as in the layer 4 of soil 10. Annotation of this characteristic is important for the interpretation of soil functions. In a broad sense, sandy or loamy soils increase the propensity of the area to contamination, since they commonly facilitate hydraulic conductivity and contaminant percolation (Basso and Kiang, 2017) that can reach recharge points of aquifers. The same happens when sandstone saprolite layers are exposed by cutting because they compose part of the local aquifer.

The lack of soil structure, indicated in the protocol by the term “massive structure”, found in soils 4, 6, and 10 (Table 3), is a common feature in urban soils (Lefort et al., 2006), affecting physical-chemical soil processes since it alters the circulation of water and gases in the environment (Morel and De Kimpe, 1998).

The collection of undisturbed samples in urban soils is often limited. Although the volumetric ring method is the standard most used in Brazil for analysis of Ks, Mip, Map, TP, and BD, it is not recommended in many urban soils due to the frequent and abundant presence of coarse fragments or surface sealing. In these cases, other methods of collection should be used, such as the paraffin-shaped clod (Teixeira et al., 2017), making the process more complicated and time-consuming.

Although penetrometer resistance data is not proper for classifying soils since resistance is a dynamic property, it is useful for supporting the interpretation of soil compaction. Use of the impact penetrometer was efficient, due to easy handling in the field, making its use possible in areas with a moderate quantity of coarse fragments/artefacts. The device has provided good results in both civil engineering and agronomy tasks (Stolf, 1991). The results show that there is a variation of PR (with high standard deviation) among the urban soils of Santa Maria in the surface layer of the soil profiles. This situation may indicate soil compaction and limitation of the soil in performing environmental services such as plant development and rainwater retention.

The physical properties varied from values commonly found in agricultural and natural soils in a complex way. For example, the Ks had coefficients of variation (CV) higher than developed soils such as Ferralsols, but lower than shallow soils such as Leptosols/Regosols, whereas porosity can have a lower CV and BD a higher CV than Leptosols/Regosols (Pedron et al., 2011). Compared to a Cambisol, the urban soils had the same CV for BD and a higher CV for sand, silt, clay. and TP (Oliveira et al., 2013). Compared to other urban soils from the USA (Pouyat et al., 2007), the CV was the same for clay, higher for sand, and lower for BD. Those variations indicate that the removal, accumulation, and mixing of materials to which urban soils are subjected results in complex layers not always more heterogeneous than agricultural or natural soils.

The international classification system used, the WRB for soil resources (IUSS Working Group WRB, 2015), was able to classify all the altered urban soils in the Technosols reference group. However, for soils 5, 6, 8, 10, and 12, the interpretation was that their surface exposed saprolite or saprolite transported and deposited are considered artifact according to the WRB definition: (1) any substance (solid or even liquid) brought to the surface by human activity from a depth, where it was not influenced by surface processes, and deposited in an environment where it does not commonly occur, with properties substantially different from the environment in which it is placed; and (2) any substance that has substantially the same chemical and mineralogical properties as when first manufactured, modified, or excavated (IUSS Working Group WRB, 2015).

Considering that they are anthropogenic soils typical of urban areas, we highlight their occurrence in Santa Maria, estimated in 20 % of the urban area, and the importance of the qualifier “Saprolitic” to respond to the case of soils 5 and 6 (*in situ* saprolite exposed by human land cuttings with ≥0.50 m thickness, starting within 0.50 m of the soil surface). These profiles have a sedimentary saprolite derived from sandstone (soil 5) and siltstone (soil 6), which are frequently used as deposition material in the urban area. Saprolite is a residual material at a different stage of alteration, generally with the structure of the parent rock and always susceptible to shovel excavation, being designated as a C or Cr horizon under natural conditions. It has significant water retention and does not allow root penetration, except through fractures that tend to be common (Pedron et al., 2015).

Soils 8, 10, and 12 showed layers of mineral material originating from soils, and saprolites from other sites deposited on natural and altered soils. The layers of transported soils were classified as Transportic. The layers of transported saprolite could not be classified as Urbic (presence of rubble and refuse of human settlements), Spolic (presence of industrial waste such as mine spoil, dredgings, slag, ash, rubble, etc.) or Garbic (presence of organic waste) because they do not fit these definitions. It also could not be classified as Transportic since we understand that these materials are included in the definition of artifacts, as explained above. In this case, these layers require a new qualifier, and we propose the use of Saprorockic (presence of layers ≥0.20 m thick with transported saprolite).

Soils 7, 9, 10, and 11 were classified with the Stonic qualifier, suggested here to characterize the profiles where layers (≥0.20 m thick) with high content of stones (≥40 %) can be found within 1.00 m of the soil surface. This information is important because excessive stoniness of the soil can limit many urban activities, especially environmental services such as water retention and plant development (Jim, 1998). Soils 1 and 4 were classified with the Impervic qualifier, which was suggested to indicate that the soil profile has a sealed layer within 1.00 m of its surface. The Ekranic qualifier used by WRB regarding the presence of a technic hard material within 0.05 m of the soil surface does not demand a sealed layer. A sealed layer can affect soil function in urban areas by altering water infiltration, water runoff, soil erosion, and urban flooding (Armson et al., 2013). The sealing of urban soil is one of the most common and limiting problems in cities (Greinert, 2015).

Considering the different qualifiers proposed, the need to evaluate a larger database for construction of a Brazilian taxonomy suitable for urban soils was evident. Although the dynamics of urban development in Brazil are not different from other countries, some particular cultural and environmental aspects are common. The small number of soil profiles described in urban areas in Brazil explains the difficulty in creating a taxonomic proposal. However, the qualifiers used in the WRB and those presented in this study were efficient in diagnosing the 12 altered soil profiles of Santa Maria. They are important not only to support future organization of an order within the SiBCS, but also to contribute to the improvement of the order of Technosols in the WRB system.

CONCLUSIONS

The protocol tested in this study proved to be adequate for the collection of environmental and morphological field data related to urban soils altered by human activities.

The data of the urban soils of Santa Maria showed property variations not considered in the reference group of Technosols (WRB system). The proposal of the Saprolitic, Impervic, Multigranic, Stonic, and Saprorockic diagnostic qualifiers may support improvement in the WRB and future establishment of a Brazilian taxonomy for urban soils.

The definition of a standard protocol to survey urban soil and the new qualifiers identified in the urban soil profiles of Santa Maria are successful products that demonstrate that this study achieved its objective.

ACKNOWLEDGMENTS

The authors would like to thank the Research Support Foundation of Rio Grande do Sul (FAPERGS), the Coordination of Superior Level Staff Improvement (CAPES), and the Brazilian Council for Scientific and Technological Development (CNPq) for funding this research project. The authors are also obliged to the anonymous reviewers and editors who contributed significantly to enhance this text.

REFERENCES

Armson D, Stringer P, Ennos AR. The effect of street trees and amenity grass on urban surface water runoff in Manchester, UK. Urban For Urban Gree. 2013;12:282-6. https://doi.org/10.1016/j.ufug.2013.04.001

Azevedo AC. Funções ambientais do dolo. In: Azevedo AC, Dalmolin RSD, Pedron FA, editores. Solos & Ambiente - I Fórum. Santa Maria: Pallotti; 2004. p. 7-22.

Basso JB, Kiang CH. Retardamento e dispersão hidrodinâmica de cobre, potássio e cloreto em solos residuais do subgrupo Itararé no estado de São Paulo. Águas Subterrâneas. 2017;31:117-33. https://doi.org/10.14295/ras.v31i1.28638

Campos CEB, Lani JL, Resende M, Rezende SB. Indicadores de campo para solos hidromórficos na região de Viçosa (MG). Rev Bras Cienc Solo. 2003;27:1057-66. https://doi.org/10.1590/S0100-06832003000600010

Curcio GR, Lima VC, Giarola NFB. Antropossolos: proposta de ordem (1ª aproximação). Colombo: Embrapa Florestas; 2004. (Documentos, 101).

Gorbov SN, Bezuglova OS, Abrosimov KN, Skvortsova EB, Tagiverdiev SS, Morozov IV. Physical properties of soils in Rostov agglomeration. Eurasian Soil Sci. 2016;49:898-907. https://doi.org/10.1134/S106422931606003X

Greinert A. The heterogeneity of urban soils in the light of their properties. J Soils Sediments. 2015;15:1725-37. https://doi.org/10.1007/s11368-014-1054-6

Hagan D, Dobbs C, Timilsina N, Escobedo F, Toor GS, Andreu M. Anthropogenic effects on the physical and chemical properties of subtropical coastal urban soils. Soil Use Manage. 2012;28:78-88. https://doi.org/10.1111/j.1475-2743.2011.00379.x

Hiller DA. Properties of Urbic Anthrosols from an abandoned shunting yard in the Ruhr area, Germany. Catena. 2000;39:245-66. https://doi.org/10.1016/S0341-8162(00)00081-3

Instituto Brasileiro de Geografia e Estatística - IBGE. IBGE Cidades; 2019 [cited 2019 Jan. 26]. Available from: https://cidades.ibge.gov.br/.

Instituto Brasileiro de Geografia e Estatística - IBGE. Manual técnico de pedologia: guia prático de campo. 3. ed. Rio de Janeiro: IBGE, 2015.

IUSS Working Group WRB. World reference base for soil resources 2014, update 2015: International soil classification system for naming soils and creating legends for soil maps. Rome: Food and Agriculture Organization of the United Nations; 2015. (World Soil Resources Reports, 106).

Jim CY. Physical and chemical properties of a Hong Kong roadside soil in relation to urban tree growth. Urban Ecosystems. 1998;2:171-81. https://doi.org/10.1023/A:1009585700191

Joimel S, Cortet J, Jolivet CC, Saby NPA, Chenot ED, Branchu P, Consalès JN, Lefort C, Morela JL, Schwartz C. Physico-chemical characteristics of topsoil for contrasted forest, agricultural, urban and industrial land uses in France. Sci Total Environ. 2016;545-546:40-7. https://doi.org/10.1016/j.scitotenv.2015.12.035

Lefort C, Schwartz C, Florentin L, Gury M, Morel JL. Determination of model substrates for the study of the pedogenesis of Technosols. In: Workshop on modelling of pedogenesis, 2006 Oct 02-04; Orléans, France. Orléans; 2006. p. 75-6.

Maluf JRT. Nova classificação climática do Estado do Rio Grande do Sul. Rev Bras Agrometeorol. 2000;8:141-50.

Marchiori JNC, Noal Filho VA. A paisagem de Santa Maria na perspectiva de antigos viajantes. Cienc Amb. 2009;38:07-18.

Morel JL, De Kimpe C. Urban and sub-urban soils: a new playground for soil scientists. In: Proceedings XVI World Congress of Soil Science [CD-ROM]; 1998; Montpellier. Montpellier: ISSS; 1998.

Obour PB, Schjønning P, Peng Y, Munkholm LJ. Subsoil compaction assessed by visual evaluation and laboratory methods. Soil Till Res. 2017;173:4-14. https://doi.org/10.1016/j.still.2016.08.015

Oliveira IA, Campos MCC, Soares MDR, Aquino RE, Marques Júnior J, Nascimento EP. Variabilidade espacial de atributos físicos em um Cambissolo Háplico, sob diferentes usos na região sul do Amazonas. Rev Bras Cienc Solo. 2013;37:1103-12. https://doi.org/10.1590/S0100-06832013000400027

Pedron FA, Dalmolin RSD, Azevedo AC, Botelho MR, Menezes FP. Levantamento e classificação de solos em áreas urbanas: importância, limitações e aplicações. R Bras Agrociencia. 2007;13:147-51. http://doi.org/10.18539/CAST.V13I2.1354

Pedron FA, Dalmolin RSD, Azevedo AC, Kaminski J. Solos urbanos. Cienc Rural. 2004;34:1647-53. https://doi.org/10.1590/S0103-84782004000500053

Pedron FA, Dalmolin RSD, Azevedo AC, Poelking EL, Miguel P. Utilização do sistema de avaliação do potencial de uso urbano de terras no diagnóstico ambiental do município de Santa Maria - RS. Cienc Rural. 2006;36:468-77. https://doi.org/10.1590/S0103-84782006000200017

Pedron FA, Dalmolin RSD, Azevedo AC. Solos do perímetro urbano de Santa Maria: características, classificação e potencial de uso. Santa Maria: Orium; 2008.

Pedron FA, Fink JR, Rodrigues MF, Azevedo AC. Condutividade e retenção de água em Neossolos e saprolitos derivados de arenito. Rev Bras Cienc Solo. 2011;35:1253-62. https://doi.org/10.1590/S0100-06832011000400018

Pedron FA, Oliveira RB, Dalmolin RSD, Azevedo AC, Kilca RV. Boundary between soil and saprolite in Alisols in the south of Brazil. Rev Bras Cienc Solo. 2015;39:643-53. https://doi.org/10.1590/01000683rbcs20140229

Pouyat RV, Szlavecz K, Yesilonis ID, Groffman PM, Schwarz K. Chemical, physical and biological characteristics of urban soils. In: Aitkenhead-Peterson J, Volder A, editors. Urban ecosystem ecology. Madison: American Society of Agronomy/Crop Science Society of America/Soil Science Society of America; 2010. p. 119-52.

Pouyat RV, Yesilonis ID, Russell-Anelli J, Neerchal NK. Soil chemical and physical properties that differentiate urban land-use and cover types. Soil Sci Soc Am J. 2007;71:1010-9. https://doi.org/10.2136/sssaj2006.0164

Rokia S, Séré G, Schwartz C, Deeb M, Fournier F, Nehls T, Damas O, Vidal-Beaudet L. Modelling agronomic properties of Technosols constructed with urban wastes. Waste Manage. 2014;34:2155-62. https://doi.org/10.1016/j.wasman.2013.12.016

Santos Junior JB, Lima MR. Caracterização e classificação de solos urbanos em Campina Grande do Sul, Estado do Paraná. Rev Cienc Agrar. 2012;55:98-104. https://doi.org/10.4322/rca.2012.049

Santos RD, Lemos RC, Santos HG, Ker JC, Anjos LHC, Shimizu SH. Manual de descrição e coleta de solo no campo. 7. ed. rev. ampl. Viçosa, MG: Sociedade Brasileira de Ciência do Solo; 2015.

Santos HG, Jacomine PKT, Anjos LHC, Oliveira VA, Lumbreras JF, Coelho MR, Almeida JA, Araújo Filho JC, Oliveira JB, Cunha TJF. Sistema brasileiro de classificação de solos. 5. ed. rev. ampl. [e-book]. Brasília, DF: Embrapa; 2018.

Sartori PLP. Geologia e geomorfologia de Santa Maria. Cienc Amb. 2009;38:19-42.

Schueler T. The compaction of urban soils. Watershed Protection Techniques. 2000;3:661-5.

Séré G, Schwartz C, Ouvrard S, Renat J-C, Watteau F, Villemin G, Morel JL. Early pedogenic evolution of constructed Technosols. J Soils Sediments. 2010;10:1246-54. https://doi.org/10.1007/s11368-010-0206-6

Simón M, García I, Sánchez JA, González V. Atypical morphology of Technosols developed in quarry dumps restored with marble sludge: implications for carbon sequestration. Catena. 2018;160:50-6. https://doi.org/10.1016/j.catena.2017.08.018

Stolf R. Teoria e teste experimental de fórmulas de transformação dos dados de penetrômetro de impacto em resistência do solo. Rev Bras Cienc Solo. 1991;15:229-35.

Teixeira PC, Donagemma GK, Fontana A, Teixeira WG. Manual de métodos de análise de solo. 3. ed. rev e ampl. Brasília, DF: Embrapa; 2017.

Yuan D-G, Zhang G-L, Gong Z-T. Numerical approaches to identification of characteristic soil layers in an urban environment. Pedosphere. 2008;18:335-43. https://doi.org/10.1016/S1002-0160(08)60023-5

Zalasiewicz J, Williams M, Waters CN, Barnosky AD, Palmesino J, Rönnskog A-S, Edgeworth M, Neal C, Cearreta A, Ellis EC, Grinevald J, Haff P, Sul JAI, Jeandel C, Leinfelder R, McNeill JR, Odada E, Oreskes N, Price SJ, Revkin A, Steffen W, Summerhayes C, Vidas D, Wing S, Wolfe AP. Scale and diversity of the physical technosphere: a geological perspective. The Anthropocene Review. 2017;4:9-22. https://doi.org/10.1177/205309616677743