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Scientific paper

Geoprocessing for spatial evaluation of soil variables from Rafard-SP

Aline Marques Genú[1]
José Alexandre M. Demattê[2]
Marcos Rafael Nanni[3]

Abstract

Soil classification depends on the union of a series of chemical, physical, morphological and topographic factors. The understanding of the relationship among these characteristics aids in the knowledge of the landscape and, consequently, in the mapping. This way, the objective of this work was to verify the spatial correlation among soil classes and information about geology, topography and soils attributes. For this, it was generated a data bank with information about soil analysis, contour lines and geology. This information was crossed to verify the contribution of each one on soil map. The relief data were obtained from digital elevation model and the geology from an existing map of the area. It was concluded that there is high correlation among soil attributes and among them with geology and soil map showing that is possible to use these information to delineate soil classes.

Key words: spatial variability, soil map; GIS.

Introduction

Soil is a fundamental natural resource for the development of agricultural and non-agricultural activities and the understanding of its spatial distribution and management is crucial for the maintenance of a productive society. The variability of soils and theirs attributes is directly related to the action of the five factors of soil formation: climate, organisms, source material, relief and time.

Relief and source material are the most easily evaluated. Changes in topography and in geology influence in the movement and storage of water in the surface and subsurface (MZUKU et al., 2005), affecting the distribution of the soil properties in the landscape (SOUZA et al., 2006).

According to CORÁ (1997), soils of the same class, when submitted to different management, may present significant differences in their properties in the space, i.e., there may be differences which would be seen in productivity, precisely by ranges which are not detected by soil mapping. These variations may thus be detected trough geoprocessing methods, aiming to improve the information of the soil map.

The use of geoprocessing tools enable a more solid characterization of the spatial variability and the generation of databases to storage, analyze and generate new information for a better soil management (SCULL et al., 2003).

Thus, the objective of this work was to verify the correlation between soil attributes, geology and topography (elevation and slope) and between them and the soil map, trough the system of geographic information. Due to the correlation between soil attributes, geology and relief, it is expected that they are related to the soil map and may help in its delimitation.

Material and methods

The study area is located in the municipality of Rafard, southeast of the state of São Paulo. It is delimited by the geographic coordinates 23° 0′ 31″ and 22° 58′ 54″ S latitude and 53° 37′ 26″ W Gr longitude. The region climate is classified as mesothermic with dry winter, in which the average temperature of the coldest month is inferior to 18°C and of the hottest mother surpasses 22°C (CENTRO NACIONAL DE ENSINO E PESQUISA AGRONÔMICA, 1960).

The geology of the region belongs to the formation Itararé, Grupo Tubarão (IPT, 1981), constituted by sandstones of heterogeneous granulation, argillites and shale from different colors, from the light to the dark gray. The area still has basalts from the formation Serra Geral, Grupo São Bento and, close to the river, pebble.

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1 Professor of the Department of Agronomy, Universidade Estadual do Centro-Oeste (State University of Mid West - UNICENTRO). Rua Simeão Camargo Varela de Sá 03, CEP 85040-080, Guarapuava (PR). E-mail: agenu@unicentro.br

2 Professor of the Department of Soil Sciences, Escola Superior de Agricultura "Luiz de Queiroz" (ESALQ-USP). E-mail: jamdemat@esalq.usp.br

3 Professor of the Department of Agronomy, Universidade Estadual de Maringá (State University of Maringá - UEM). E-mail: mrnanni@uem.br

The relief, in the most part, is characterized as wavy and softly wavy, being the former with highest area, with values ranging from 475 to 565 m and above the sea level.

It was used data from 184 georeferenced sample points from the sampling in the depth of 0-20 cm for the superficial horizon and 80-100 cm for the subsuperficial horizon. After being collected, the samples were dried in oven at 50 °C for 48 hours and next they were passed trough sieve of 2 mm. Later, in the fraction lower than 2 mm it was performed the physical and chemical analysis.

For the physical analysis, it was determined the contents of sand, silt and clay from the hydrometer method (CAMARGO et al., 1986). For the chemical analysis, it was determined the pH in water and KCl, Ca^{2+}, Mg^{2+}, Al^{3+}, H^{+} + Al^{3+} and the organic matter according to RAIJ and QUAGGIO (1989). From this information, it was obtained the value of sum of bases (S), cation exchange capacity (CEC), base saturation (V%) and aluminum saturation (m%). The total iron (Fe_2O_3), silica (SiO_2) and titanium were determined by sulphuric acid, trough the methodology described by CAMARGO et al. (1986).

The data of the soil analysis and the geographic coordinates from each point were imported for the program Matlab 7.0 (MATHWORKS, 2005), in which it was performed the geostatistics analyses.

Initially, it was generated the semivariogram of the soil attributes to verify the existence of spatial continuity. Next, it was adjusted a statistical model to the data which may be linear, spherical, Gaussian, exponential and with or without nugget effect. Next, based on this information it was performed the interpolation of the sample points through the kriging method and, then, it was generated one map for each attribute.

The attribute maps were exported to the program ArcGIS 9.0 (ESRI, 2005), in which they were divided in classes to improve the comparison as: for organic matter (OM) it was used the classes high (OM > 25 g dm^{-3}), medium (OM between 15 and 25 g dm^{-3}) and low (MO < 15 g dm^{-3}) (TOMÉ JUNIOR, 1997); the total iron (Fe_2O_3) was divided in hypoferric (Fe_2O_3 < 80 g kg^{-1}), mesoferric (Fe_2O_3 between 80 and 180 g kg^{-1}) (SANTOS et al., 2006); the CEC was divided in very low (CEC < 30 $mmol_c\,dm^{-3}$), low (CTC between 30 amd 60 $mmol_c\,dm^{-3}$), medium (CEC between 60 and 100 $mmol_c\,dm^{-3}$), high (CEC between 100 and 150 $mmol_c\,dm^{-3}$) and very high (CTC > 150 $mmol_c\,dm^{-3}$) (TOMÉ JUNIOR, 1997). For the texture, according to the content of clay (CT), it was used the following classes: sandy (CT 150 g kg^{-1}), medium (CT between 150 and 350 g kg^{-1}), clayey (TA between 350 and 600 g kg^{-1}) and very clayey (TA > 600 g kg^{-1}) (SANTOS et al., 2006).

In the evaluation of the relief, it was generated the Digital Elevation Model in the program ArcGIS 9.0 (ESRI, 2005), using as a base the limit of the area of the work and the curves of level of the area, spaced each 5 m, obtained from the planialtimetric maps of Toledos and Costa Rica, both in the scale 1:10.000.

After the generation of the MDT it was performed a division of the elevations in 7 levels, from the lowest to the highest part and it was obtained the slope map, which was divided in the relief classes according to SANTOS et al. (2006). The geology map was obtained from the Instituto de Pesquisas Tecnológicas (Institute for Technologial Research) (IPT, 1981) and the soil map, used in this work, was generated by the conventional method by NANNI (2000).

The comparison between maps was made through the function *raster calculator* of the module *spatial analyst* in the program ArcGIS. Two maps were crossed each time, generating a third map, which had, in the attribute table, the information about the two initial maps. From this table, it was ordered one of the attributes according to its classes and it was verified, in each one, the percentage of the area of occurrence of other attribute classes.

Results and discussion

The soil attribute maps aid in the visualization and evaluation of the space distribution of the soil characteristics and how they are correlated with each other, with geology and the soil classes which occur in the area and also with the local relief.

The distribution of the soil attributes, divided in classes for the crossing of data in the geographic information system ArcGIS and the verification of the space correlation showed similar distribution in the four evaluated attributes: organic matter, total iron, clay and CEC (Figures 1a, 1b, 1c and 1d).

In the comparison between the maps of organic matter and total iron (Figure 1a and 1b), both with three classes, it is verified the correspondence between tem, i.e., the area with low content of organic matter and low content of iron (hypoferric) has 47% of agreement, the mean content of organic matter and iron (mesoferric) have 16.14% and the classes with high content 16.20% of agreement (Table 1).

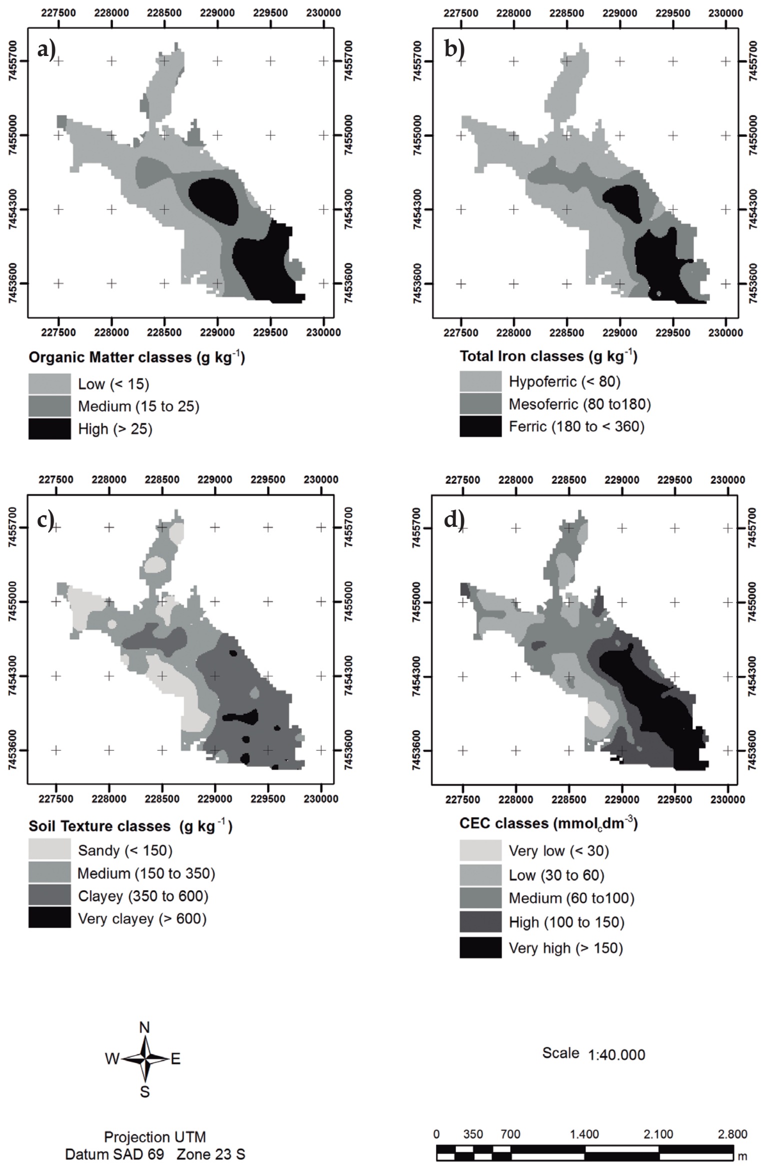

Figure 1. Maps of soil attribute classes: organic matter (a), total iron (b), texture (c) and CEC (d).

In the comparison of the maps of organic matter and clay, the areas with high content of organic matter correspond to the places with higher proportion of soils with clayey and very clayey texture (Figure 1a and 1c, Table 1). The areas with medium content of organic matter prevail also in the areas with medium and clayey texture, while the area with low content corresponds, mainly, to the textures sandy and part of the medium (Table 1).

This occurs due to the decomposition of the organic matter that is slower in clayey soils, different from what happens in sandy soils whose higher aeration and temperature accelerate the process of decomposition, reducing its content (PORTA CASANELLAS et al., 1999). Besides that, the organic matter and the clay act in the formation of the soil aggregated, in which organic matter works as a bridge in the connection between the minerals of clay (SIX et al., 2000).

Table 1. Comparison between the soils attribute maps of the area.

Attribute classes		Texture (1)				OM (2)			Fe2O3 (3)		
		SAN	MD	CLAY	MARG	HI	MD	LO	HF	MF	F
OM (2)	AL	0.00(5)	1.89	20.83	1.85	-(6)	-	-	0.16	8.21	16.20
	MD	0.21	8.59	16.39	0.77	-	-	-	8.43	16.14	1.37
	BA	17.97	26.85	4.66	0.00	-	-	-	47.00	2.49	0.00
Fe2O3 (3)	HF	17.99	34.01	3.93	0.00	0.16	8.43	47.00	-	-	-
	MF	0.00	3.83	22.69	0.55	8.21	16.14	2.49	-	-	-
	F	0.00	0.00	15.03	1.97	16.20	1.37	0.00	-	-	-
CEC (4)	LO	1.78	0.00	0.00	0.00	0.00	0.00	3.58	1.78	0.00	0.00
	VL	14.07	8.29	0.13	0.00	0.00	0.27	43.07	22.27	0.23	0.00
	MD	2.44	21.21	6.43	0.00	0.02	16.49	43.39	24.17	5.91	0.00
	HI	0.00	6.75	14.20	1.24	13.35	22.14	6.40	6.91	10.74	4.52
	VH	0.00	0.84	21.22	1.42	32.65	10.81	0.39	0.28	9.85	13.34

(1) Texture classes: SAN: Sandy, MD: medium, CLAY: clayey, VCLAY: very clayey; (2) Classes of organic matter: HI: high; MD: medium, LO: low; (3) Classes of total iron: HF: hypoferric; MF: mesoferric; F: ferric; (4) Classes of cation exchange capacity: VL: very low; LO:low; MD: medium; HI: high; VH: very high; (5) values presented in % of the total area; (6) comparison between the same maps

It is observed that in the areas with highest content of organic matter, there are also the highest values of CEC (Figures 1a and 1d, since the organic radicals present a wide number of negative charges, increasing the soil CEC (HAVLIN et al., 1999). The comparison between organic matter and CEC, with five classes, shows that the class with low content of organic matter corresponds to the very low, low and medium classes of CEC (Table 1). The medium class of OM corresponds to 16.14% of the high class of CEC and the high class of OM with 16.20% of area which is in accordance with the very high class of CEC (Table 1).

The correlation between total iron and clay was the highest as it can be seen in the maps of these attributes (Figures 1b and 1c). The classes sandy and medium correspond to the class hypoferric, and the mesoferric and ferric classes are mainly in the clayey class (Table 1). This relation exists in the area, because in the places of occurrence of high content of iron and also clay, the origin material is biabase, basic igneous rock which presents in its constitution minerals as ilmenite and magnetite, oxides which present Fe in its structure and, due to that, generate the high contents in iron, as it can be seen in Figure 2c.

The space relation between CEC and total iron (Figures 1b and 1d), despite the different number of classes, demonstrate that the very low, low and medium class of CEC correspond to the class of low iron (hypoferric) (Table 1). The high class of CEC has the most part of its area (10.74%) in the class mesoferric and the very high class in the class ferric (13.34%) (Table 1). This correlation might be considered as a secondary effect, since in the places with higher content of total iron there are also the highest contents of clay and organic matter, the main sources of soil charges, so responsible for the CEC (ALLEONI and CAMARGO, 1995).

In the classes of CEC and clay (Figure 1c and 1d) there is a correspondence between the very low and low classes of CEC in the class of sandy texture (Table 1). The medium CEC class corresponds to the medium texture class and the high and very high CEC classes to the sandy class (Table 1). The CEC and clay relation is high, since as well as organic matter, the minerals of the clay fraction of soils are responsible for the generation of negative charges (HAVLIN et al., 1999).

The relation between elevation and the soil attributes demonstrates that the highest contents of total iron, clay, CEC and organic matter occur in the most elevated places of the area (Table 2, Figures 1 and 2a). BRUBAKER et al. (1993) verified that the CEC, content of Clay and organic matter reduce in the direction of the lowest elevations, and that these changes are related to the processes of formation and erosion of the landscape. In the study area, besides the processes of formation and erosion, geology seems to be of higher influence in the distribution of soil variables, since in the largest parts there is diabase and shale and in the lowest in sandstone and alluvial material (Figure 2c).

Thus, it was verified high correlation between geology and the soil attributes, in the places with more clayey soils, highest content of organic matter, CEC and total iron there was diabase and shale (Table 3, Figures 1 and 2c).

For slope, the result of the comparison of the maps does not show great similarities (Table 3), and it occur to all the class of all the attributes in all the

Table 2. Comparison between the soil attribute maps and the elevation map.

Attribute Classes		Elevation[(1)]						
		1	2	3	4	5	6	7
Texture[(2)]	SAN	4.30(6)	3.90	0.92	2.50	3.61	2.76	0.00
	MD	5.97	13.51	5.83	5.28	3.22	2.31	0.00
	CLAY	0.00	3.06	9.38	11.52	7.07	6.26	5.97
	VCLAY	0.00	0.21	0.02	0.07	0.38	5.97	1.26
Fe2O3[(3)]	HF	10.29	17.32	5.69	6.85	7.35	6.61	0.03
	MF	0.00	3.14	8.34	9.69	4.39	1.40	1.08
	F	0.00	0.21	2.11	2.82	2.54	4.03	6.11
OM[(4)]	HI	8.34	16.21	5.63	5.70	7.09	5.99	0.00
	MD	1.37	3.69	6.13	7.12	3.46	2.55	1.37
	LO	0.00	0.61	4.13	6.65	4.14	3.80	6.03
CEC[(5)]	VL	0.00	0.00	0.00	0.00	0.00	1.65	0.00
	LO	3.68	8.20	1.34	3.54	3.52	2.20	0.00
	MD	4.68	8.43	6.94	4.85	2.97	0.93	1.00
	HI	1.06	3.50	3.53	3.44	2.18	3.98	4.60
	VH	0.00	0.38	3.99	7.62	5.20	3.78	2.80

[(1)]Classes of elevation (in meters): 1: 475 – 485, 2: 486 – 499, 3: 500 – 513, 4: 514 – 527, 5: 528 – 541, 6: 542 – 554, 7: 555 – 565; [(2)] Classes of texture: SAN: Sandy, MD: medium, CLAY: clayey, VCLAY: very clayey; [(3)] Classes of total iron: HF: hypoferric; MF: mesoferric; F: ferric; [(4)] Classes of organic matter: HI: high; MD: medium, LO: low; [(5)] Classes of cation exchange capacity: VL: very low; LO:low; MD: medium; HI: high; VH: very high; [(6)] values presented in % of the total area.

slope classes, however the highest percentages of area of all the attributes occur in the wavy and lightly wavy classes, which are the most representative in the area (Figures 1 and 2b).

The map of soils of the area (Figure 2d) was compared to the attribute maps (Figure 1) and, observing the relation of the soils (Figure 2d) with the texture map (Figure 1c) it is verified that the areas with clayey and very clayey texture are coincident with the soils that, by definition, are clayey as Nitossolo Vermelho eutroférrico típico (NVef), Nitossolo Vermelho eutroférrico latossólico (NVefl) e o Chernossolo Argilúvico férrico típico (MTf)[1] while Argissolo Vermelho-Amarelo eutrófico típico (PVAe), Argissolo Vermelho-Amarelo distrófico típico (PVAd), Argissolo Vermelho-Amarelo eutrófico abrúptico (PVAeab) and Argissolo Vermelho-Amarelo distrófico abrúptico (PVAdab), in the most part, are in the sandy and medium areas (Table 4), due to the lower content of clay which they present in surface.

The soil classes Latossolo Vermelho eutrófico típico (LVe), Cambissolo Háplico Tb eutrófico típico (CXbe), Cambissolo Háplico Ta eutrófico típico (CXve) and Neossolo Litólico eutrófico típico (RLe) have larger area of occurance in the textures clayey and medium, while Neossolo Flúvico psamítico típico (RUq), Neossolo Flúvico Tb eutrófico típico (RUbe), Cambissolo Háplico Tb distrófico típico (CXbd) and Latossolo Vermelho-Amarelo distrófico típico (LVAd) are present in the areas with more sandy textures (Table 4).

In relation to the total iron (Figures 1b and 2d), it is verified that the NVef, NVefl, RLe and MTf are in the areas of the class ferric (Table 4), while LVe, LVAe and CXve are mainly in the mesoferric class, and the other soil classes the hypoferric class prevails (Table 4).

The content of organic matter (Figures 1a and 2d) demonstrate that MTf, RLe, NVef and NVefl are predominantly in the area with higher content of matter (Table 4) while all the other soil classes are distributed in the medium and low content of organic matter.

The behavior of the CEC in relation of the soil classes (Figures 1d and 2d) is similar to what was already observed for the other soil attributes. Thus, MTf, RLe, CXbe, CXve, NVef and NVefl present CEC high to very high (Table 4), while the other soils are predominantly in the classes low and medium.

In the relation between the soil and geology maps, it is verified that most part of the soils is over

1 Brazilian soil classification

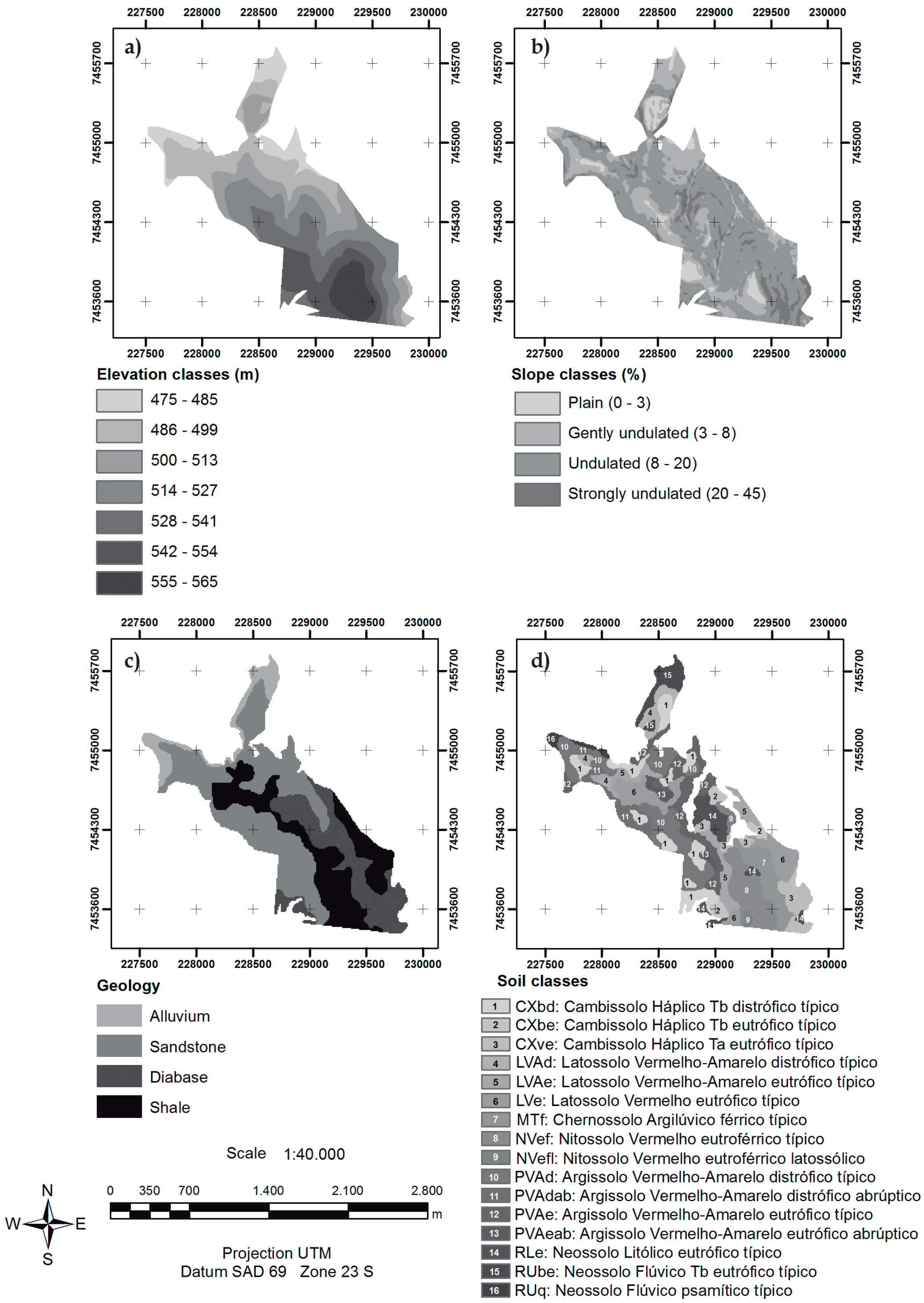

Figure 2. Map of elevation (a), slope (b), geology (c) and soils (d).

Table 3. Comparison between maps of soil attributes and geology and slope maps.

Attribute classes		Geology(1)				Slope(2)			
		AL	SS	DB	FL	PL	LW	W	SW
Texture(3)	SAN	4.04(7)	13.83	0.00	0.04	4.76	6.78	5.99	0.44
	MD	3.39	24.21	4.12	4.42	3.65	13.32	16.84	2.29
	CLAY	0.00	4.73	16.86	21.70	1.96	9.95	27.98	1.98
	VCLAY	0.00	0.00	0.50	2.15	0.15	0.40	1.98	0.13
Fe2O3(4)	HF	7.44	39.85	2.33	4.37	8.62	21.26	22.54	1.72
	MF	0.00	1.62	10.43	16.09	0.55	6.48	18.40	2.60
	F	0.00	1.31	8.72	7.84	1.37	2.71	11.83	1.91
OM(5)	BA	6.17	35.62	1.71	4.99	7.74	19.50	20.54	1.18
	MD	0.85	5.83	6.89	12.33	0.99	6.35	16.83	1.52
	AL	0.00	1.51	12.86	11.22	1.63	4.17	15.98	3.55
CEC(6)	MB	0.00	1.61	0.00	0.00	0.97	0.60	0.08	0.00
	BA	3.17	18.79	0.27	0.57	5.11	8.14	9.06	0.50
	MD	3.42	16.06	0.67	8.48	1.52	11.86	14.53	1.10
	AL	0.24	5.55	5.23	11.55	2.07	7.48	11.69	1.18
	MA	1.05	0.00	15.33	7.99	0.46	1.76	18.44	3.42

(1)Geologic material: AL: alluvial, SS: sandstone, DB: diabase, SH: shale; (2) Declivity classes: PL: plain, LW: lightly wavy, W: wavy; SW: strongly wavy; (3) Classes of texture: SAN: Sandy, MD: medium, CLAY: clayey, VCLAY: very clayey; (4) Classes of total iron: HF: hypoferric; MF: mesoferric; F: ferric; (5) Classes of organic matter: HI: high; MD: medium, LO: low; (6) Classes of cation exchange capacity: VL: very low; LO:low; MD: medium; HI: high; VH: very high; (7) values presented in % of the total area.

the area with sandstone (Figures 2c and 2d). RUbe and RUq are in the areas with alluvial material and sandstone (Table 5), which explains the lower content of clay, total iron, organic matter and CEC of these soils. RLe and MTf, by their turns, are in the area of influence of diabase (Table 5), in accordance with the clayey texture, content of iron between mesoferric and hypoferric, high organic matter and very high CEC (Table 4), which these soils present.

LVAe and LVe, in the comparison with the geology map, demonstrate that the source material is shale, while the one from LVAd is sandstone (Table 5), which explains the differences in the attributes evaluated for these soil classes.

The PVA are all over sandstone material, which is in accordance with the low CEC, content of iron and organic matter and more sandy texture (Figures 2c and 2d). However, parts of the area of this soil class are also verified in places with shale, which explain the percentages of these soils with clayey texture and high CEC (Table 5).

The Cambissolos of clay with low activity are mostly in area with sandstone (Table 5), which is in accordance with the attributes of the CXbd, medium texture, hypoferric, low organic matter and low CEC (Table 4). However, CXbe, despite the low iron and medium content of organic matter, presents high CEC and clayey texture, which is inconsistent to the geology (Table 5). CXve, which has as geology the diabase, is in accordance with the classes of their evaluated attributes. The inconsistence between geology and attributes may be related to the reworking of the several source materials which occur in the study area.

Nitossolos Vermelhos are in most part in the area of sandstone (NVefl) or shale (NVef) and not of diabase, which was expected (Table 5). Despite that, they have high content of iron, high CEC, clayey to very clayey texture and high organic matter (Table 4). This may be a result of the differences between the scale of the soil and geology maps. Since the area of occurrence of Nitossolos is, according to the geology map (Figure 2c) and map of soils (Figure 2d), besides the area of the diabase, it may be that the area of occurrence of this rock is extended to the place of the Nitossolos.

The relation between soils and relief was verified through the crossing of the slope maps and elevation with the soils. Initially, it is observed that most part of the area has wavy relief, so most part

Table 4. Comparison between the attribute maps and the map of soils of the area.

Soil Classes(1)	Attribute classes														
	Texture(2)				Fe2O3(3)			OM(4)			CEC(5)				
	SAN	MD	CLAY	VCLAY	HF	MF	F	LO	MD	HI	VL	LO	MD	HI	VH
PVAe	0.49(6)	8.63	1.45	0.00	9.12	1.44	0.00	5.79	4.29	0.08	0.00	0.63	6.29	3.14	0.00
PVAd	10.65	4.24	0.00	0.00	14.89	0.01	0.00	14.91	0.28	0.00	1.54	11.02	2.79	0.00	0.00
PVAeab	0.00	0.92	1.03	0.00	0.99	0.95	0.00	1.02	0.98	0.00	0.00	0.21	1.81	0.00	0.00
PVAdab	1.42	2.19	0.00	0.00	3.61	0.00	0.00	3.84	0.08	0.00	0.00	2.02	2.04	0.00	0.00
NVefl	0.00	0.00	1.20	0.35	0.00	0.17	1.37	0.00	0.40	1.22	0.00	0.00	0.00	0.97	0.67
NVef	0.00	0.00	7.83	1.08	0.00	1.66	7.23	0.00	1.97	7.19	0.00	0.00	0.00	4.97	4.34
CXbd	2.70	7.13	0.79	0.00	10.62	0.01	0.00	9.96	0.54	0.00	0.17	4.39	4.58	1.21	0.01
CXbe	0.00	0.83	2.01	0.00	1.74	1.04	0.05	0.86	1.62	0.39	0.00	0.00	0.21	2.27	0.41
CXve	0.00	0.61	4.79	0.14	0.21	4.34	0.99	0.00	2.49	2.74	0.00	0.00	0.03	0.50	4.56
LVAe	0.12	2.19	4.97	0.45	3.03	4.60	0.10	2.84	4.23	0.55	0.00	0.80	3.05	3.22	0.46
LVAd	1.11	2.36	0.00	0.00	3.47	0.00	0.00	3.25	0.16	0.00	0.00	1.93	1.42	0.00	0.00
LVe	0.01	2.10	8.42	0.00	1.47	8.75	0.31	2.79	4.72	3.00	0.00	0.51	4.78	3.04	2.14
RLe	0.00	1.05	3.65	0.45	0.39	1.69	3.08	0.40	0.13	4.81	0.00	0.00	0.01	0.88	4.54
RUq	0.54	0.81	0.00	0.00	1.35	0.00	0.00	0.96	0.36	0.00	0.00	0.44	0.58	0.27	0.00
RUbe	1.82	2.31	0.00	0.00	4.13	0.00	0.00	3.35	0.42	0.00	0.00	1.64	2.02	0.00	0.00
MTf	0.00	0.20	6.72	0.29	0.00	2.00	5.20	0.00	1.96	5.43	0.00	0.00	0.00	0.15	7.33

(1) Soil classes: PVAe: Argissolo Vermelho-Amarelo eutrófico típico, PVAd: Argissolo Vermelho-Amarelo distrófico típico, PVAeab: Argissolo Vermelho-Amarelo eutrófico abrúptico, PVAdab: Argissolo Vermelho-Amarelo distrófico abrúptico, NVefl: Nitossolo Vermelho eutroférrico latossólico, NVef: Nitossolo Vermelho eutroférrico típico, CXbd: Cambissolo Háplico Tb distrófico típico, CXbe: Cambissolo Háplico Tb eutrófico típico, CXve: Cambissolo Háplico Ta eutrófico típico, LVAe: Latossolo Vermelho-Amarelo eutrófico típico, LVAd: Latossolo Vermelho-Amarelo distrófico típico, LVe: Latossolo Vermelho eutrófico típico, LVd: Latossolo Vermelho distrófico típico, RLe: Neossolo Litólico eutrófico típico, RUq: Neossolo Flúvico psamítico típico, RUbe: Neossolo Flúvico Tb eutrófico típico, MTf: Chernossolo Argilúvico férrico típico; (2) Classes of texture: SAN: Sandy, MD: medium, CLAY: clayey, VCLAY: very clayey; (3) Classes of total iron: HF: hypoferric; MF: mesoferric; F: ferric; (4) Classes of organic matter: HI: high; MD: medium, LO: low; (5) Classes of cation exchange capacity: VL: very low; LO:low; MD: medium; HI: high; VH: very high; (6) values presented in % of the total area.

Table 5. Comparison between the soil maps and the geology and slope maps.

Soil classes(1)	Geology(2)				Declivity(3)			
	AL	SS	DB	SH	PL	LW	W	SW
PVAe	0.64(4)	8.20	0.73	1.24	0.47	4.33	4.89	0.96
PVAd	1.59	12.20	0.59	0.01	2.26	6.25	5.67	0.33
PVAeab	0.00	1.11	0.00	0.74	0.08	0.43	1.33	0.01
PVAdab	0.00	3.58	0.00	0.37	0.40	1.02	2.37	0.09
Nvefl	0.00	0.88	0.11	0.54	0.00	0.30	1.19	0.04
Nvef	0.00	0.00	1.35	7.44	1.36	2.27	4.86	0.32
CXbd	0.65	8.62	1.31	0.31	2.16	4.55	3.92	0.25
Cxbe	0.00	1.59	0.41	0.74	0.00	1.10	1.60	0.04
Cxve	0.00	0.00	4.80	1.42	0.04	0.76	4.11	1.28
LVAe	0.00	2.22	0.65	4.50	0.27	2.38	4.61	0.18
LVAd	0.53	2.95	0.00	0.00	1.22	1.14	0.92	0.23
Lve	0.00	0.84	0.52	9.05	0.30	3.81	6.19	0.15
Rle	0.00	0.33	4.44	0.47	0.00	0.64	4.05	0.52
Ruq	1.12	0.13	0.00	0.00	0.35	0.47	0.28	0.14
Rube	3.48	0.69	0.00	0.00	1.53	1.88	0.69	0.07
MTf	0.00	0.00	5.35	1.56	0.00	0.03	5.22	1.68

(1) Soil classes: PVAe: Argissolo Vermelho-Amarelo eutrófico típico, PVAd: Argissolo Vermelho-Amarelo distrófico típico, PVAeab: Argissolo Vermelho-Amarelo eutrófico abrúptico, PVAdab: Argissolo Vermelho-Amarelo distrófico abrúptico, NVefl: Nitossolo Vermelho eutroférrico latossólico, NVef: Nitossolo Vermelho eutroférrico típico, CXbd: Cambissolo Háplico Tb distrófico típico, CXbe: Cambissolo Háplico Tb eutrófico típico, CXve: Cambissolo Háplico Ta eutrófico típico, LVAe: Latossolo Vermelho-Amarelo eutrófico típico, LVAd: Latossolo Vermelho-Amarelo distrófico típico, LVe: Latossolo Vermelho eutrófico típico, LVd: Latossolo Vermelho distrófico típico, RLe: Neossolo Litólico eutrófico típico, RUq: Neossolo Flúvico psamítico típico, RUbe: Neossolo Flúvico Tb eutrófico típico, MTf: Chernossolo Argilúvico férrico típico; (2) Geological material: AL: alluvial. SS: sandstone, DB: diabase, SH: shale (3) Declivity classes: PL: plain, LW: lightly wavy, W: wavy; SW: strongly wavy; (4) values presented in % of the total area.

of the soil classes are in the slope of 8 to 20% (Figure 2a, b and d).

The RUq and RUbe occur, in highest percentage, in plain to lightly wavy relief and with low altitude (Tables 5 and 6), while RLe occurs in wavy relief, with altitudes ranging from 500 to 527 m (Table 5 and 6).

LVe and LVAe occur, mainly, in areas lightly wavy to wavy, although in different altitudes (Tables 5 and 6), LVAe is in lower places, from 486 to 513m, while LVe between 514 and 527 m. LVAd is present in plain to lightly wavy relief and in the same altitudes that the o LVAe (Tables 5 e 6). SOUSA JUNIOR (2005) observed for soils of the region of Ibaté that Latossolos occur in slopes lower than 16% while LACERDA et al. (2005), for soils of cerrado, verified the presence of Latossolos in slopes up to 10%.

Cambissolos (CXbd, CXbe and CXve) are present in the slopes between 3 and 20% (lightly to wavy) and with altitudes ranging from 486 to 554m (Tables 5 and 6), in accordance with SOUSA JUNIOR (2005) who obtained similar results for this soil class.

Nitossolos (NVef and NVefl) are, mainly, in lightly wavy relief, however, NVef is found in higher percentage in higher altitudes, from 555 to 565 m while NVefl is found from 500 to 513 m (Tables 5 and 6). MTf for its turn is in wavy to strongly wavy relief with altitudes ranging between 528 and 554m (Tables 5 and 6).

PVAeab and PVAdab occur mainly in wavy relief with altitudes from 500 to 527 m (Tables 5 and 6), while the other Argissolos (PVAe e PVAd) are in areas with lightly wavy to wavy relief and varying in altitude between 475 and 499, in the most part. SOUSA JUNIOR (2005) verified that the behavior of soils in relation to the slope is variable, and one soil may occur in different slopes.

Table 6. Comparison between the soil and the elevation maps.

Soil classes (1)	Elevation(2)						
	1	2	3	4	5	6	7
PVAe	2.27(3)	3.62	1.14	1.59	1.56	0.49	0.00
PVAd	2.53	4.13	0.08	2.43	2.80	2.54	0.00
PVAeab	0.00	0.00	1.11	0.03	0.71	0.00	0.00
PVAdab	0.29	1.08	1.01	1.50	0.00	0.00	0.00
NVefl	0.00	0.08	0.91	0.00	0.00	0.10	0.43
NVef	0.00	0.00	0.00	0.46	0.72	1.91	5.71
CXbd	0.79	3.90	0.55	0.80	2.63	2.22	0.00
CXbe	0.00	0.59	0.74	0.42	0.06	0.94	0.00
CXve	0.00	0.75	1.81	3.14	0.48	0.00	0.00
LVAe	0.00	2.07	2.04	0.50	1.46	1.02	0.35
LVAd	0.37	2.01	1.12	0.00	0.00	0.00	0.00
LVe	0.00	0.62	2.48	5.65	0.89	0.62	0.18
RLe	0.00	0.08	1.43	2.60	0.59	0.22	0.30
RUq	1.24	0.00	0.00	0.00	0.00	0.00	0.00
RUbe	2.86	0.80	0.51	0.00	0.00	0.00	0.00
MTf	0.00	0.00	0.05	0.80	3.06	2.61	0.40

(1) Soil classes: PVAe: Argissolo Vermelho-Amarelo eutrófico típico, PVAd: Argissolo Vermelho-Amarelo distrófico típico, PVAeab: Argissolo Vermelho-Amarelo eutrófico abrúptico, PVAdab: Argissolo Vermelho-Amarelo distrófico abrúptico, NVefl: Nitossolo Vermelho eutroférrico latossólico, NVef: Nitossolo Vermelho eutroférrico típico, CXbd: Cambissolo Háplico Tb distrófico típico, CXbe: Cambissolo Háplico Tb eutrófico típico, CXve: Cambissolo Háplico Ta eutrófico típico, LVAe: Latossolo Vermelho-Amarelo eutrófico típico, LVAd: Latossolo Vermelho-Amarelo distrófico típico, LVe: Latossolo Vermelho eutrófico típico, LVd: Latossolo Vermelho distrófico típico, RLe: Neossolo Litólico eutrófico típico, RUq: Neossolo Flúvico psamítico típico, RUbe: Neossolo Flúvico Tb eutrófico típico, MTf: Chernossolo Argilúvico férrico típico; (2) Classes of elevation (in meters): 1: 475 – 485, 2: 486 – 499, 3: 500 – 513, 4: 514 – 527, 5: 528 – 541, 6: 542 – 554, 7: 555 – 565; (3) Values presented in % of the total area.

Conclusions

1 – The space variability of the attributes total iron, CEC, clay and organic matter are similar and with high correlation;

2 – The geological map had a strong correlation with the attributes clay, organic matter, CEC and total iron;

3 – The map of soils presented highest relation with the maps of texture, total iron and geology;

4 – It may be inferred that the space evaluations of the soil and geology attributes may be used to determine an initial delimitation of soil classes.

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