Spectroradiometric data as support to soil classification

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The use of spectral remote sensing is a reality for the determination of soil attributes. This study aimed to evaluate the soil spectral curves of a dataset and infer the possibility of their use for management purposes. For this, soil samples were collected at Rafard/SP in a regular grid of 100 m of edge, totaled 185 points. These samples were submitted to physical, chemical, mineralogical and spectral analyses in individual laboratories. From the results of the analysis was performed to soil classification and organization chart containing the spectral curves for each soil class. Through visual and statistics evaluations were determined, among the 18 land units of area, groups of classes with similar characteristics for both the surface layer and subsurface. These groupings refer, among other attributes, to the original material, constitution textural, mineralogical composition, etc. It is fundamental to the characterization of the area and formulates practicable strategies for better use of it. Thus, it was noted that the analysis of spectral curves can indeed generate information of great practical importance for the management of soils in this region.

Keywords: Spectral curve, soil management, remote sensing.

INTRODUCTION

The demand for soil analysis to increase agricultural and environmental efficiency projects it is growing every day. Thus, new methods that provide reliable results for several soil properties, quickly and cost need to be developed (Viscarra-Rossel et al., 2006).

The land use planning projects follow well defined steps which include the soil sampling form to the fertilizers amount applied in a given culture, and other management practices. The soil sampling density is usually dependent to how management should be employed in field, may be 15 to 20 samples for 12 to 20 ha (van Raij et al., 1996), one sample per hectare underutilization of precision agriculture (Wolkowski and Wollenhaupt, 1994), or any other understood to be the most suitable design for a particular purpose.

However, the larger sample volume required for planning to management system will be also higher costs, sample handling time and waste dumped amounts. Demattê et al. (2001) argue that soil analysis costs in precision farming systems are very high in comparison with conventional methods of agricultural management. Thus, the search for more affordable alternatives to determining soil properties are needed, also the use of new and modern technologies (Demattê and Nanni, 2006).

The use of remote sensing exploring different ranges of the electromagnetic spectrum in determination of soil attributes quickly and has appeared as a nondestructive alternative to this demand (Madeira Netto, 1996; Demattê et al. 2004; Nanni and Demattê, 2006; Demattê and Florio, 2009; Chicati et al., 2010).

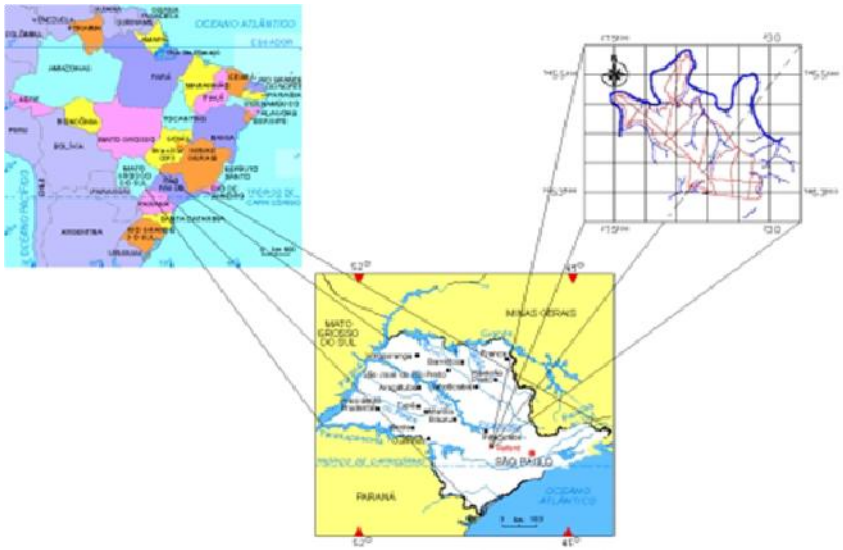

Figure 1. Location map of study area in the state of Sao Paulo.

Sheppard and Walsh (2002) developed a methodology for spectral data libraries using in the flash and not destructive estimate soil attributes using diffuse reflectance spectroscopy. The spectral reference libraries composition are essential for correct estimation of the attributes, since each soil has a specific spectral signature, individual and dependent on its physical, chemical, mineralogical and biological composition agents being the main interference attribute as organic matter and iron oxides (Dalmolin et al., 2005; Ben-Dor et al., 2009).

Thus, objective study was to evaluate a dataset obtained by spectral remote sensing and present the applicability of the same as support decision within a soil system classification and management.

MATERIAL AND METHODS

The study area is located on southwest state of São Paulo, bounded by the geographical coordinates 23°0´31,37´´- 22° 58´53,97´´ South latitude and 53°39´47,81´´- 53°37´ 25,65´´ West Longitude in the region called Depression Paleozoic (IPT, 1981). As part of the basin of the Tiete River, this area is bordered by Capivari River, near the municipality of Rafard. The study was conducted on 185 hectares in an area of approximately 198 hectares, used for the sugar cane cultivation (Figure 1)

Geologically, the area lies on Itararé Formation, part of Tubarão Group. This formation presents predominant sandstone lithology, granulation heterogeneous with presence of feldspathic sandstone and arkoses. Mudstones and shales of varying colors, from light gray to dark, complement the lithology of this formation with frequent occurrence. The region shows evidence of eruptive Serra Geral Formation, including intrusive bodies of the same composition as the tholeitic basalts (Nanni et al., 2004).

The soil samples collection to evaluate the spectral response in the laboratory was performed on 185 points, comprising a regular grid with 100 meters distance between the points. Each point was marked properly with the use of an Electronic Distance Meter with beams of infrared systems and prism reflectors. At each sampling point were obtained by the geographical coordinates of the global positioning system (GPS) and subsequently corrected by the DGPS system (Differential Global Positioning System), for greater accuracy of location. Soil samples were collected with a Dutch auger type, for each point from two depths, representing the diagnostic horizons in surface and subsurface.

Sent to the laboratory, samples were dried in forced circulation at 45° C and sifted in sieves of 2.0 millimeters to evaluate the physical, chemical and mineralogical. The soil textural groups were defined according to EMBRAPA (2006). By the hydrometer method (Camargo et al., 1986), was determined the levels of total sand, silt and clay. Ca, Mg, K and sum of bases (S) were determined as Raij and Quaggio (1989). Organic matter (OM), exchangeable acidity and pH in water and KCl, cation exchange capacity (CEC), basis saturation (V%) and aluminum saturation (m%) were determined according to EMBRAPA (1997). The levels of total Fe, Si and Ti were determined by sulfuric acid attack as a method recommended by EMBRAPA (1997).

To identify the spectral response in the laboratory, dried and sieved samples were properly packed in Petri dishes of 9 centimeter diameter. By proper control environment, radiometric readings were performed using the IRIS spectroradiometer, Infra-Red Intelligent Spectroradiometer (GER, 1996), with spectral resolution of 2 nm (300-1000 nm) and 4 nm (1000-2500 nm). The geometry of data acquisition had: (a) standard white plate with 100% calibrated reflectance (Labsphere, 1996); (b) distance from target to the sensor, 27 cm; (c) distance from light source to the target, 61 cm; (d) light source: 650 W halogen lamp with a parabolic reflector and collimated beam is not turned into a source of stabilizing high accuracy with 220 V input and output set at 110 ± 0.5 V rated voltage and 5.2 Amp. The geometry of the procedures followed Valeriano et al. (1995), Galvão et al. (1995), Galvão et al. (1997), Galvão and Vitorello (1998) and Demattê et al. (1998). Although these authors have not commented on the height between the floor and the light source was adopted for this work, the height of 1.20 meters, due to the need for standardization of the lighting system and greater system performance.

Were performed for each sample, three spectral readings by rotating the Petri dish about 120 degrees between each reading, so that was scanned from different points on the board, from which was drew the average to be used in discussions (Nanni & Demattê, 2006). Thus, was obtained the spectral bidirectional reflectance factor, which expresses the ratio of spectral radiant flux reflected by the body surface and the spectral radiant flux reflected by a reference standard, under the same lighting conditions and geometry of reading (Nicodemus et al., 1977).

The reflectance data were tabulated into spreadsheets and then used for the construction of graphs relating the relationship between the spectral bands. These bands were selected by observation of spectral curves in its main points of inflections and bulges, and references observed by authors such as Madeira Netto (1996) and Demattê and Garcia (1999). Thus, 22 bands were delimited within the electromagnetic spectrum analyzed in this study (350 - 2500 nm), as follow: BD1 (350-481); BD2 (481); BD3 (481-596); BD4 (596-710); BD5 (710-814); BD6 (814-975); BD7 (975-1350); BD8 (1350-1417); BD9 (1417); BD10 (1417-1449); BD11 (1449-1793); BD12 (1793-1831); BD13 (1895-1927); BD14 (1927); BD15 (1927-2102); BD16 (2102-2139); BD 17 (2139-2206); BD18 (2206); BD19 (2206-2258); BD20 (2258); BD21 (2258-2389) e BD22 (2389-2500).

For statistical data analysis, was previously used the Statistical Analysis System (SAS, 2006). In this, the DISCRIM procedure was used for separation of the bands with greater significance in the soil types and Tukey ($p > 0.05$) clusters evaluation of these same classes.

RESULTS AND DISCUSSION

The soil attributes on study area varied considerably over short distances due to the original material. Clay portions are extended for areas filled with shale substrate or diabase. There are places in the trenches and samples that great extension of the area covered by a higher clay content in B horizon were covered by portions of sand, which characterizes the presence of textural differences in these areas and hence the appearances of soils texture gradient.

The geological analysis such that Campbell et al. (1987) of the combined area and Brazilian soil classification criteria adopted by EMBRAPA (2006), allowed the identification of 18 units or soil classes (Table 1).

Table 2 shows the mean results of the attributes: clay, silt, sand, total organic matter (OM), total bases (S), cation exchange capacity (CEC), basis saturation (V) and total iron (Fe_2O_3) collected for the horizons A and B. Table 2

The followings are the mean spectral curves obtained in the laboratory for each soil class and its relationship to the attributes measured. Were identified five groups that can meets different soil classes by visual analysis of the surface layer mean spectral curves (Figure 2).

The classes formed the first group RYbd, CXbd1, CXbd2, PVA1, and PVA2 RLe2. The two formed the group classes CXe1, and PVA3 PVA4. The group was formed by three classes and CXve2 LVAe2. Group 4 Classes MXF CXve1, LVAe1, and RLe1 PVAe and the group were formed by five classes LVe and PVe.

For the case of soils with high clay and iron-rich (groups 4 and 5) the intensity of reflectance was low, with a spectral curves almost horizontal trend. The soil classes that were in the surface layer, the greater contribution of the sand fraction curves levels tend to have more intensity and more intense absorption features (groups 1 and 2). All, however, had between 350 and 600 nm, inflection of concave shape. The feature on this track, as pointed out by Mathews et al. (1973), Vitorello & Galvão (1996), Demattê and Garcia (1999) and Wu et al. (2007), refers to the presence of iron oxides. As the content of total iron found in the surface was varied, the intensity of absorption or the curve was also.

Lower intensities of reflectance for the optical spectral range studied were for soils with higher iron levels (groups 4 and 5), with values around 4.2 to 6.5% as shown in Figure 2. From this point, the range of 500 to 600 nm, all spectral curves taken tilted upward trend up to about 790 nm for all soils. From this point on, every curve showed differential characteristics, some going to be descendants, assuming concavity average for most soils in the range from 820 to 1050 nm (groups 3, 4 and 5) maintaining or increasing trend (groups 1 and 2) with very slight concavity. From 1100 nm, the curves took

Table 1. Soil units present in study area

Soil Unit	Soil unit description
PVAe	Argissolo Vermelho-Amarelo Eutrófico A moderado textura muito argilosa
PVe	Argissolo Vermelho Eutrófico A moderado textura muito argilosa
MXf	Chernossolo Háplico Férrico textura argilosa pouco profundo
RLe1	Neossolo Litólico Eutrófico A moderado e chernozêmico textura argilosa substrato saprolito da intemperização do diabásio
RLe2	Neossolo Litólico Eutrófico A moderado textura média substrato saprolito proveniente da intemperização de folhelho da formação Itararé
LVe	Latossolo Vermelho Eutrófico A moderado textura argilosa
LVAe1	Latossolo Vermelho-Amarelo Eutrófico A moderado textura argilosa
LVAe2	Latossolo Vermelho-Amarelo Epieutrófico A moderado textura média
CXe	Cambissolo Háplico Eutrófico A moderado textura argilosa substrato regolito do retrabalhamento de arenito e diabásio
CXve1	Cambissolo Háplico Ta Eutrófico A moderado textura média, argilosa e muito argilosa substrato saprolito proveniente da intemperização de folhelho da formação Itararé
CXve2	Cambissolo Háplico Ta Eutrófico A moderado e chernozêmico textura argilosa e muito argilosa substrato saprolito da intemperização do diabásio
CXbd1	Cambissolo Háplico Tb Distrófico substrato retrabalhamento do arenito e saprolito de folhelho
CXbd2	Cambissolo Háplico Tb Distrófico A moderado textura média
PVA1	Argissolo Vermelho-Amarelo Tb A moderado textura arenosa/média
PVA2	Argissolo Vermelho-Amarelo Tb A moderado textura arenosa/argilosa
PVA3	Argissolo Vermelho-Amarelo Tb A moderado textura média/argilosa
PVA4	Argissolo Vermelho-Amarelo Tb A moderado textura média/muito argilosa
RYbd	Neossolo Flúvico Tb Distrófico textura arenosa e média

Table 2. Characteristics relating to physical and chemical soil types.

Soil unit	N[1]	Horizon	Clay[2]	Silt[2]	Total Sand[2]	O.M.[2]	S[3]	CEC[3]	V[4]	Fe_2O_3[5]
PVAe	14	A	567,0	158,9	274,1	29,9	112,2	140,7	78,9	200,1
		B	672,9	134,7	192,4	8,6	85,8	93,3	91,7	
PVe	4	A	597,4	173,9	228,7	25,0	88,9	135,4	66,1	187,8
		B	738,0	106,8	155,2	9,5	82,2	100,5	81,7	
MXf	14	A	484,7	207,4	307,9	26,6	211,3	238,1	88,6	194,4
		B	419,5	229,0	344,3	7,4	267,5	281,2	94,6	
CXve2	3	A	412,3	271,0	316,7	18,0	159,7	176,3	88,0	94,3
		B	444,9	270,7	284,3	3,3	228,0	243,4	89,4	
RLe1	9	A	498,7	189,3	312,1	38,8	173,4	212,3	81,4	208,2
		B	383,7	232,5	383,8	20,6	182,9	212,5	85,8	
LVe	20	A	459,8	189,8	350,4	21,2	79,8	117,7	65,3	128,0
		B	573,1	148,5	278,5	8,0	64,4	90,0	68,5	
CXe	5	A	392,6	235,3	372,1	15,0	74,7	113,3	65,0	65,0
		B	448,2	186,5	365,3	3,4	73,4	107,4	69,0	
CXbd1	7	A	288,1	238,2	473,7	12,9	61,2	87,0	67,5	37,3
		B	364,3	248,9	386,8	3,9	42,0	81,1	48,9	
CXve1	9	A	501,2	186,4	312,3	28,6	215,5	240,5	88,1	166,9
		B	467,9	187,2	344,9	15,0	233,3	250,9	92,4	
RLe2	3	A	332,0	282,9	385,0	12,0	156,8	178,5	87,1	50,0
LVAe1	9	A	421,2	197,3	381,5	14,4	62,4	89,7	67,9	83,8
		B	522,3	172,5	305,1	6,1	52,3	80,4	62,1	
LVAe2	6	A	175,0	171,8	653,1	16,5	33,1	60,4	53,2	18,3
		B	249,6	141,7	608,8	8,5	17,9	59,4	31,1	

[1] $g.kg^{-1}$; [2] numbers of samples; [3] $mmol_c.dm^{-3}$; [4] %; [5] total content extract by sulfuric acid attack.

Table 2. Characteristics relating to physical and chemical soil types (continued).

Soil unit	N[1]	Horizon	Clay[2]	Silt[2]	Total Sand[2]	O.M.[2]	S[3]	CEC[3]	V[4]	Fe_2O_3[3,5]
PVA1	31	A	106,3	150,4	743,3	7,6	28,5	46,1	63,8	12,0
		B	248,4	150,0	601,6	4,5	31,4	62,3	52,9	
PVA2	4	A	120,6	100,5	778,9	10,8	31,7	56,7	50,8	12,5
		B	310,8	162,7	526,5	4,0	38,3	78,1	44,5	
PVA3	16	A	227,6	242,9	529,5	14,2	49,5	83,3	57,0	35,0
		B	465,1	232,0	302,9	6,4	60,7	101,8	59,0	
PVA4	4	A	282,2	225,7	492,2	17,3	53,7	91,5	58,1	54,0
		B	635,5	197,4	167,2	5,0	56,0	111,5	50,3	
CXbd2	15	A	177,9	208,1	614,0	9,4	42,8	61,3	70,6	17,1
		B	245,0	180,6	574,4	3,6	25,5	63,3	40,0	
RYbd	11	A	162,7	226,6	610,7	13,0	40,4	65,4	59,6	17,0
		B	182,3	220,8	596,9	5,7	34,3	62,0	54,8	

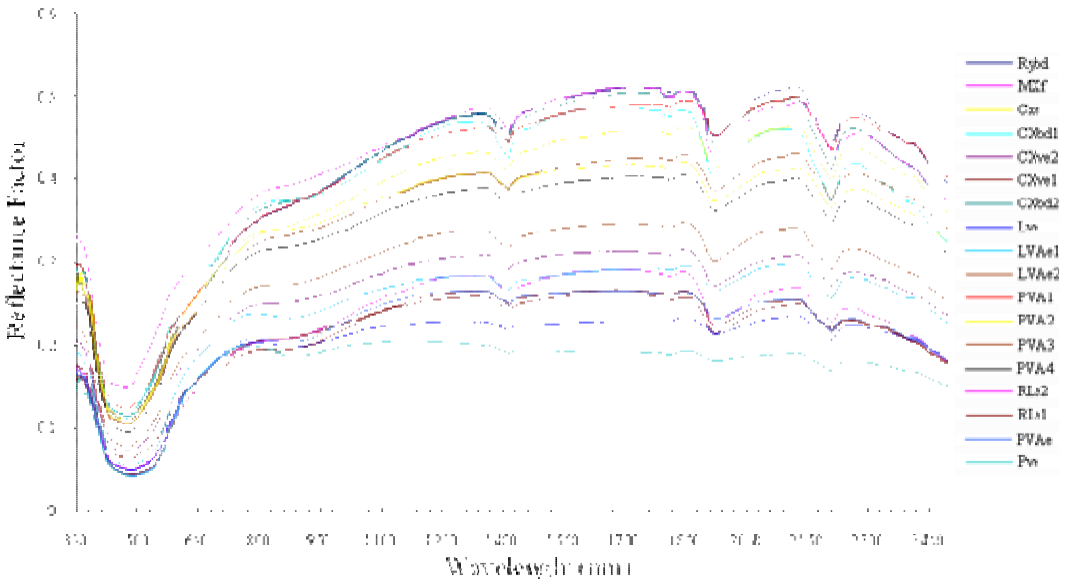

Figure 2. Surface layer mean spectral curves of soil classes in the study area.

tendency to bulge convex-flattened, reaching up to about 1850 nm, thereafter, took a slightly declining trend.

For the soil types curves with higher iron levels (groups 3, 4 and 5), the format was flatter in this range of optical spectrum than those with higher sand content, where the format of the same was more curved. The absorption bands were in the range 1400, 1920 and 2200 nm considered strong, except for land belong with groups 4 and 5, arising from the presence of water molecules, and very weak in 2200 nm due to the presence of kaolinite, also identified by Demattê & Garcia (1999), and very weak, for all soils at 2365 nm, probably due to the presence of MgOH as reported by Vitorello and Galvão (1996) and Clement et al. (2000).

The variations in intensity of reflectance, for the band from 1100 to 2000 nm were quite broad, from 19.23% for class PVe and as much as 50% for classes CXbd2, and PVA1 RLe2, with total range of 30 %. Statistical analysis (Table 3) showed basically three distinct groups of soils by the seven bands chosen for discrimination (BD3, Bd6, BD7, BD11, BD13, BD 17, BD 21). Table 3

The classes formed the first group RYbd, CXe, CXbd1, CXbd2, PVA1, PVA2, PVA3 and RLe2, being that classes PVA2, PVA3 CXe differed statistically only class RLe2 by Tukey test at 5%. The classes formed the second group are PVA4 LVAe2. The class PVA4 resembled CXve2 class, which comprises the group of soils with high clay surface, while the class LVAe2 resembled the sandy soils that composed the first group. The third group is represented by the other classes: PVe,

Table 3. Statistical analysis[1] results of reflectance[2] average from laboratory to the soil surface layer classes for seven bands[3], in order to verify the discrimination of spectral curves shown in Figure 2.

Class	**n[4]**	**BD3[5]**		**Class**	**BD6[5]**		**Class**	**BD7[5]**		**Class**	**BD11[5]**		**Class**	**BD13[5]**		**Class**	**BD17[5]**		**Class**	**BD21[5]**	
		481 – 596			**814 – 975**			**975 - 1350**			**1449 - 1793**			**1865 - 1927**			**2139 - 2206**			**2258 - 2389**	
RLe2	3	0,211	a[6]	RLe2	0,397	a	RLe2	0,445	a	RLe2	0,501	a	RYbd	0,478	a	RYbd	0,474	a	RYbd	0,465	a
PVA1	31	0,174	ab	CXbd2	0,379	a	CXbd2	0,438	a	RYbd	0,500	a	PVA1	0,475	a	PVA1	0,467	ab	PVA1	0,463	a
CXbd1	7	0,172	ab	CXbd1	0,377	a	RYbd	0,437	a	CXbd2	0,495	a	CXbd2	0,471	a	RLe2	0,466	ab	CXbd2	0,443	ab
CXbd2	15	0,169	ab	PVA1	0,377	a	PVA1	0,431	a	PVA1	0,485	a	RLe2	0,463	a	CXbd2	0,450	ab	RLe2	0,442	ab
RYbd	11	0,160	abc	RYbd	0,374	a	CXbd1	0,430	a	CXbd1	0,480	a	LVAe2	0,445	a	PVA2	0,429	ab	PVA2	0,425	ab
PVA2	4	0,156	bc	PVA2	0,349	a	PVA2	0,400	a	LVAe2	0,459	a	PVA2	0,438	a	LVAe2	0,429	ab	LVAe2	0,422	ab
CXe	5	0,155	bc	CXe	0,343	ab	LVAe2	0,396	a	PVA2	0,451	a	CXbd1	0,437	a	CXbd1	0,414	ab	CXbd1	0,401	ab
PVA3	16	0,151	bc	PVA3	0,336	ab	CXe	0,381	ab	PVA3	0,419	ab	PVA3	0,407	a	PVA3	0,404	ab	PVA3	0,397	a
PVA4	4	0,144	cd	LVAe2	0,333	ab	PVA3	0,378	ab	CXe	0,413	ab	CXe	0,393	ab	CXe	0,390	ab	CXe	0,378	ab
LVAe2	6	0,135	d	PVA4	0,322	abc	PVA4	0,362	abc	PVA4	0,398	abc	PVA4	0,382	abc	PVA4	0,374	bc	PVA4	0,365	bc
CXve2	3	0,108	cdef	CXve2	0,255	bcd	CXve2	0,288	bcd	CXve2	0,311	bcd	CXve2	0,291	bcd	CXve2	0,290	cd	CXve2	0,280	cd
CXve1	9	0,090	def	LVAe1	0,238	cd	LVAe1	0,269	cd	LVAe1	0,287	cd	LVAe1	0,280	cd	LVAe1	0,275	cde	LVAe1	0,273	cd
LVAe1	9	0,085	ef	MXf	0,212	d	MXf	0,258	cd	MXf	0,286	cd	MXf	0,253	d	MXf	0,249	cde	MXf	0,233	de
LVe	20	0,075	f	CXve1	0,212	d	PVAe	0,248	d	RLe1	0,264	d	PVAe	0,247	d	CXve1	0,235	cde	PVAe	0,224	de
MXf	14	0,075	f	PVAe	0,207	d	CXve1	0,242	d	PVAe	0,264	d	RLe1	0,243	d	PVAe	0,234	cde	CXve1	0,222	de
RLe1	9	0,068	f	LVe	0,200	d	RLe1	0,242	d	CXve1	0,259	d	CXve1	0,234	d	RLe1	0,234	cde	RLe1	0,221	de
PVAe	14	0,068	f	RLe1	0,198	d	LVe	0,221	d	LVe	0,228	d	LVe	0,222	d	LVe	0,220	cde	LVe	0,217	de
PVe	4	0,066	f	PVe	0,191	d	PVe	0,203	d	PVe	0,194	d	PVe	0,188	d	PVe	0,180	e	PVe	0,177	e

[1]Tukey test p<0,05; [2] averages of reflectance values for the items grouped in each soil class; [3] bands used in the discriminant analysis; [4] numbers of samples; [5] BD: bands in nm; [6] same letters in column indicate no statistical difference at 5%.

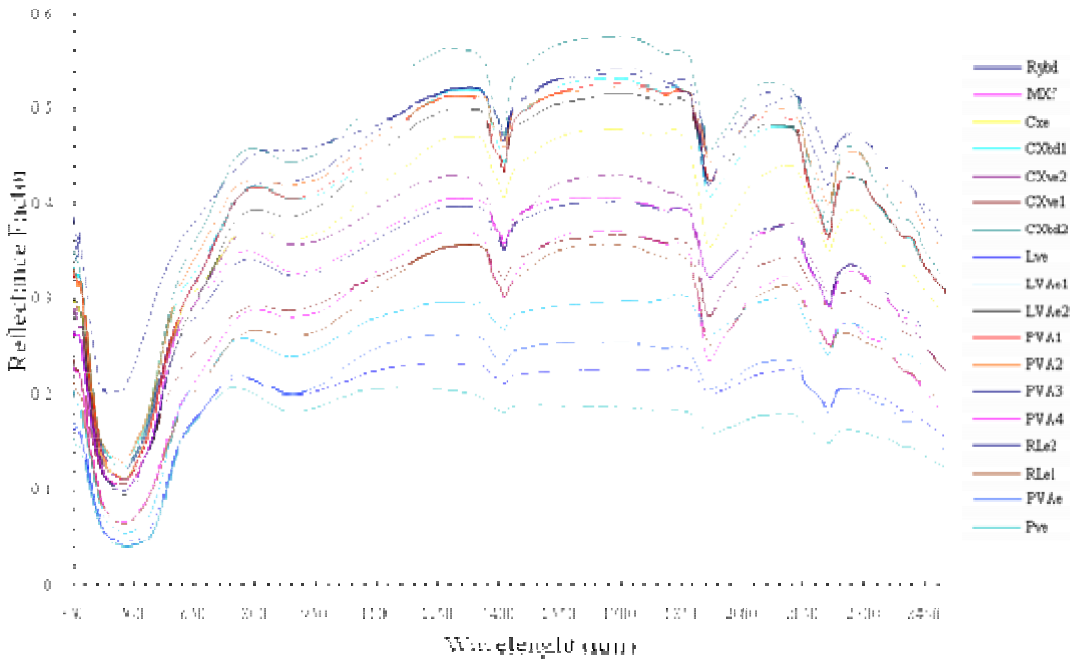

Figure 3. Subsurface layer mean spectral curves of soil classes in the study area.

PVAe, RLe1, MXF, LVe, LVe, CXve1 and CXve2, being that classes CXve2 and LV showed significant difference in class only to PVe.

There is, therefore, statistical analysis revealed that the variable separation of the groups defined by visual analysis, holding some classes in an intermediate stage of spectral response. On the other hand, it should be noted that statistical analysis was performed by the band, where two different soils could be broken by all or by a single band due to their physicochemical characteristics. Although no statistical difference between the classes of the same group, the spectral curves presented qualitative separability (Ben-Dor et al., 2009).

Soils as LVe and PVe should be separated by presenting, here, different levels of iron and higher in Ultisols. Although the analysis shows less total iron for LVe, (128 ± 13.7 $g.kg^{-1}$ against 187.8 ± 39.7 $g.kg^{-1}$ LVe), the organic matter content was similar for two groups (21.2 ± 3.0 $g.kg^{-1}$ to LVe and 25.0 ± 10.3 $g.kg^{-1}$ for PVe), which may have contributed to lowering the reflectance LVe the which agrees to the description of Cohen et al. (2005). In turn, the sandy surface resembled spectrally.

The same way as reported by Demattê and Garcia (1999), such as sand, organic matter and total iron was similar to these soils, their spectral curves are too. In the field, it is difficult to demarcate these lands except by examination of it's subsurface. On the other hand, it is necessary to understand that often the separation of the soil does not necessarily mean having separate management. In practicable terms, and for example the cultivation of sugar cane, how to work with these soils may resemble (Demattê et al., 2004), which also applies to soils originating from diabase.

Worked in the region, the soils can be characterized by management groups, i.e., soils with characteristics that allow grouping them according to agricultural activities. Therefore, the clay soils derived from diabase can be grouped together into one management unit, just as sandy soils. Therefore, with the use of radiometry, it was possible to separate soil classes with different components, but possibly belong with the same management groups, agreeing to observations Demattê and Nanni (2006).

The trend of increased reflectance at 2300 nm leaving the soil with more clay rich in iron and for the most sandy and poor in iron (Figure 1), agrees to observations reported by Demattê et al. (2000), working with soils from the Piracicaba and Lençóis Paulista.

In the second layer, with the reduction in content of organic matter in depth for all classes, there was greater enhancement of absorption bands mainly in the range from 760 to 950 nm, from 1300 to 1420 nm, 1850 to 1950 nm and in track of 2200 nm (Figure 3). It is noted here that there is, in general, higher separability between the curves, distancing him considerably in intensity of reflectance. Trying to group those in the same way that the superficial part, was emphasize again five groups: Group 1 (RYbd, CXbd1, CXbd2, LVAe2, PVA1, and PVA2 RLe2), group 2 (CXe), group 3 (CXve2, PVA4, PVA3), group 4 (MXF, and CXve1 RLe1) and group 5 (LVe, LVAe1, PVAe and PVe).

Relative to the curves obtained for the surface layer,

Table 4. Statistical analysis[1] results of reflectance[2] average from laboratory to the soil subsurface layer classes for seven bands[3], in order to verify the discrimination of spectral curves shown in Figure 3.

Class	N[4]	BD3[5]		Class	BD6[5]		Class	BD7[5]		Class	BD11[5]		Class	BD13[5]		Class	BD17[5]		Class	BD21[5]	
		481 – 596			**814 – 975**			**975 - 1350**			**1449 - 1793**			**1865 - 1927**			**2139 - 2206**			**2258 - 2389**	
RLe2	2	0,279	a[6]	RLe2	0,457	a	CXbd2	0,517	a	CXbd2	0,567	a	CXbd2	0,500	a	RLe2	0,485	a	RLe2	0,454	a
PVA2	4	0,196	ab	CXbd2	0,450	ab	RLe2	0,490	ab	RYbd	0,533	ab	RYbd	0,485	ab	RYbd	0,461	ab	RYbd	0,452	a
CXbd1	7	0,195	abc	RYbd	0,426	ab	RYbd	0,482	ab	RLe2	0,529	ab	PVA2	0,476	ab	PVA2	0,441	abc	PVA2	0,432	ab
CXbd2	15	0,193	abc	PVA2	0,422	ab	PVA2	0,475	abc	CXbd1	0,522	abc	PVA1	0,464	abc	CXbd2	0,436	abcd	CXbd2	0,428	abc
RYbd	11	0,182	bcd	PVA1	0,410	abc	PVA1	0,469	abcd	PVA1	0,518	abc	RLe2	0,462	abc	CXbd1	0,419	abcd	PVA1	0,405	abcd
CXe	5	0,175	bcde	CXbd1	0,409	abc	CXbd1	0,467	abcd	PVA2	0,516	abc	LVAe2	0,460	abc	LVAe2	0,413	abcd	LVAe2	0,403	abcd
PVA1	31	0,174	bcde	LVAe2	0,392	abcd	LVAe2	0,456	abce	LVAe2	0,507	abcd	CXbd1	0,455	abc	PVA1	0,411	abcd	CXbd1	0,402	abcd
CXve2	3	0,173	bcde	CXe	0,366	abcde	CXe	0,425	abcde	CXe	0,470	abcd	CXe	0,403	abcd	CXe	0,395	abcde	CXe	0,372	abcde
PVA4	4	0,161	bcde	CXve2	0,361	abcde	CXve2	0,400	abcdef	CXve2	0,421	abcde	PVA3	0,354	bcde	CXve2	0,340	bcdef	PVA3	0,318	bcdef
PVA3	16	0,156	bcdef	PVA4	0,334	abcde	PVA4	0,374	abcdefg	PVA4	0,403	bcdef	PVA4	0,354	bcde	PVA3	0,330	cdef	CXve2	0,313	cdefg
LVAe2	6	0,151	bcdefg	PVA3	0,329	bcdef	PVA3	0,367	bcdefgh	PVA3	0,397	bcdef	CXve2	0,335	cdef	PVA4	0,327	cdefg	PVA4	0,311	cdefg
CXve1	9	0,151	bcdefg	CXbd2	0,292	cdefg	MXf	0,334	cdefghi	MXf	0,364	cdefg	CXve1	0,316	def	CXve1	0,315	defgh	CXve1	0,293	defgh
MXf	14	0,105	cdefg	MXf	0,285	cdefg	CXve1	0,329	defghi	CXve1	0,361	cdefg	RLe1	0,292	defg	MXf	0,284	efghi	LVAe1	0,262	efghi
RLe1	5	0,101	defg	RLe1	0,265	defg	RLe1	0,317	efghi	RLe1	0,350	defgh	MXf	0,286	defg	RLe1	0,278	efghi	MXf	0,257	efghi
LVAe1	9	0,089	efg	LVAe1	0,244	efg	LVAe1	0,279	fghi	LVAe1	0,294	efgh	LVAe1	0,281	defg	LVAe1	0,267	fghi	RLe1	0,250	fghi
LVe	20	0,071	fg	PVAe	0,205	fg	PVAe	0,247	ghi	PVAe	0,253	fgh	PVAe	0,225	efg	PVAe	0,205	ghi	LVe	0,198	ghi
PVAe	14	0,064	g	LVe	0,203	fg	LVe	0,224	hi	LVe	0,226	gh	LVe	0,213	fg	LVe	0,204	hi	PVAe	0,193	hi
PVe	4	0,063	g	PVe	0,187	g	PVe	0,202	i	PVe	0,188	h	PVe	0,170	g	PVe	0,163	i	PVe	0,158	i

[1]Tukey test $p<0,05$; [2] averages of reflectance values for the items grouped in each soil class; [3] bands used in the discriminant analysis; [4] numbers of samples; [5] BD: bands in nm; [6] same letters in column indicate no statistical difference at 5%.

the intensity between 350 to 600 nm, remained low for those soils with high iron contents, with values below 7%. For sandy soils, these values came to exceed that range, 13%, reaching 20% as was the case in class RLe2. According to Schwertmann and Taylor (1977), soils have redder colors, with hues of 5R to 2.5 YR in Munsell Color Chart have a predominance of hematite, and those with a predominance of goethite present hues of 7.5 YR to 10YR.

The curve shape remained concave; width could vary from narrow to wide for soils with higher content of goethite and hematite, respectively, confirming the observations of Demattê and Garcia (1999). Furthermore, soils with higher contents and hematite absorb more energy and have lower intensity of reflectance, as seen in Figure 3.

All maintained an upward between 500 and 800 nm and that thence to 870 nm, the curves become descendants, with concave inflection whose intensity varied with the concentration of total iron present. From 870 nm curves again became ascendant to 1000 nm for the soils with higher contents of iron and up to 1300 nm for soils with low iron levels. The groups followed from these wavelengths, convex planed for soils in groups 1 and 2 and convex for others, up to 2200 nm, where all presented, spectrally, descending curves.

Statistically, it is observed from Table 4 that the separability of these classes was higher when compared to the superficial, the same happened, as mentioned, with the purely visual and descriptive curves, although the soil discrimination was smaller (Table 4).

The groups were not as well defined on the surface, with successive discrimination within each class. But overall, the soils were separated by the clay content, total iron or organic matter. The first two attributes come from the source material, which may also contribute to the permanence of OM higher levels due to the conditions of the moisture regime that remains in the system, as observed also by Robinson et al. (2008). Three groups were distinguished using statistical analysis, the bands selected by discriminant analysis.

The classes formed the first group RYbd, CXe, CXbd1, CXbd2, PVA1, and PVA2 RLe2, being the classes CXve2 and PVA4 associated themselves with this group, statistically, the bands Bd6 and BD7. The class PVA3 joined this group only by the band BD11.

Statistically, the band met BD3, in group 1, only the classes RLe2, PVA2, CXbd1 CXbd2 and leaving in another group classes RYbd, CXe with classes and CXve2 PVA4. This band represents the portion of the optical spectrum from 481 to 596 nm, and is characterized by the presence and activity levels of iron oxides as reported by Vitorello and Galvão (1996) and Demattê and Garcia (1999).

The classes formed the second group MXF RLe1, LVAe1, LVe, PVAe and PVe, and the class CXve1 joined this group only for the bands and BD3 Bd6, differing with PVe class for the other bands. The class MXF differed statistically by class PVe in the band BD11. This band, representing wide range of optical spectrum (1449 - 1793 nm, with average values at 1621.27 nm), can be influenced, as in the whole spectrum, with the levels of organic matter and clay. Of these attributes, the clay showed greater difference between the two classes for the subsurface horizon with 738.0 ± 55.1 g.kg-1 to 419.5 ± 107.3 PVe and g.kg-1. The class MXF also presented the highest content of total sand (344.3 ± 105.3 g.kg-1) relative to other classes of this group.

Separately these two groups presented appeared, sometimes associated with one then with another group, the classes PVA3, PVA4, and CXve2 CXve1. It is understood, therefore, the usefulness of using sampling to differentiate these subsurface soils by their spectral signature, which together with the superficial part, can discriminate among different classes, as also described by Demattê and Focht (1999), may be valuable in the analysis of spatial units, and therefore in soil surveys, as observed by Galvão et al. (1997).

CONCLUSION

The analysis of the data set in the city of Rafard is possible to infer that the analysis of spectral curves are efficient for the differentiation of soils, particularly of large groups for discrimination, either by material originating in the class of soil texture or appearance.

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