ISSN : 1812-5379 (Print)
ISSN : 1812-5417 (Online)
http://ansijournals.com/ja

JOURNAL OF AGRONOMY

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Journal of Agronomy 13 (3): 100-109, 2014
ISSN 1812-5379 / DOI: 10.3923/ja.2014.100.109

Soil Mapping by Laboratory and Orbital Spectral Sensing Compared with a Traditional Method in a Detailed Level

[1]Marcos Rafael Nanni, [2]José Alexandre Melo Demattê, [1]Carlos Antonio da Silva Junior,
[1]Franciele Romagnoli, [1]Anderson Antonio da Silva, [1]Everson Cezar and [1]Aline de Carvalho Gasparotto
[1]Department of Agronomy, Maringá State University, Maringá, Paraná, 87020-900, Brazil
[2]Department of Soil Science and Plant Nutrition, University of São Paulo,
Escola Superior de Agricultura "Luiz de Queiroz", Piracicaba, São Paulo, 13418-900, Brazil

Abstract: The objective of this study was to evaluate the use of a laboratory and an orbital sensor on the classification of soils in a complete 180 ha bare soil area located in Brazil. The 180 points were located as a regular grid of 100×100 m (one point per ha). In each point, soil samples were georreferenced (GPS) and collected (0-20 and 80-100 cm depths). Based on the traditional soil analysis and field work (with 18 profile evaluation), a detailed soil map was developed as to be our "real pattern". This soil map determined 18 soil classes and 53 polygons. Other soil maps were developed based on the following described methods. The first method was based on the orbital image (landsat) interpretation. It was used a color composition 5R, 4G, 3B. Based on the visual interpretation it was determined 16 classes of soils and 35 polygons. A statistical method was used to compare the traditional soil map with the color composition soil map. The traditional soil map was more accurate although the color composition had several. The second method was performed with laboratory sensor information. Spectral data (400-2500 nm) was acquired from soil samples (both depths of each point). Data was modelized and cluster analysis grouped the spectral curves. The third method consisted on the evaluation of the surface soil information (obtained in laboratory but convoluted for the landsat spectral bands). With this method 9 groups were discriminated. The fourth method was determined by quantitative analyses of each pixel information extracted from a processed and reflectance transformed landsat image. The number of groups determined were nine. The main conclusion was: Any sensor method reached the detailed soil map information.

Key words: Digital soil mapping, reflectance, orbital, terrestrial sensor

INTRODUCTION

Soils inventory can be realized by traditional methods using aerial photographs on the soil limits identification. The main problem of the soil mapping method is time consumption and high costs. A possible solution for these points is the integration of remote sensing techniques as informed by many studies (Dematte *et al*., 2001). Agbu *et al*. (1990) already described the orbital image incorporation and its significance on soil mapping.

In countries with great areas and variability, such as Brazil and Africa, monitoring of soils by images can be of important assistance. Although, few works have described soil characterization by orbital images in high taxonomic levels. The high taxonomic level is mostly used for agricultural land management. Besides this, the use of remote sensing on soil mapping can assist future works on Precision Agricultural management.

Thus, this study has the objective to use different strategies to evaluate the potential of terrestrial and orbital remote sensing technique on the determination of a soil map at high scale.

MATERIALS AND METHODS

Study area characterization: The studied area was located in Rafard county, southwest of São Paulo State, Brazil, in a Paleozoic depression, 23°0' 31,37" to 22° 58' 53,97" S and 53° 39' 47,81" to 53° 37' 25,65" W. The area is part of the Tietê river watershed and covers an area of 198 ha. Of this total, 184 ha were utilized in this study. Of the 12 orders of Soil Taxonomy (Soil Survey Staff, 1998), five were found in this region: Oxisols, Entisols, Alfisols, Ultisols and Inceptisols (Dematte *et al*., 2004).

The region has a mesothermic climate which consists of dry winters and wet summers. The average

Corresponding Author: Carlos Antonio da Silva Junior, Departament of Agronomy, State University of Maringa, Av. Colombo, 5790-Bloco J45, Maringá, Paraná, Postal Code: 87020-900, Brazil

temperature in July is 18 and 22°C in February. Usually, the annual rainfall in this region is between 1100-1700 mm.

Geologically, the area studied is situated in the Itararé formation of the Tubarão group (IPT, 1981). The predominant lithologies consist of immature psammite with a heterogeneous granulation, leading to feldspathic psammite and even arkosic sandstone as well as a small contribution of intrusive bodies of tholeitic basalts.

Spectral data acquisition: Spectral curves were obtained for all soil samples collected at the two depths with a laboratory spectroradiometer (400-2500 nm), thus obtaining spectral curves. Initially 22 bands and 13 heights were extracted in the spectral curves interval obtained of the soil samples according to methodology described by Nanni and Dematte (2006).

Digital Number values (DN) obtained from the Thematic Mapper sensor (TM) Landsat images were transformed into SR and properly adjusted for atmospheric effects (Thome *et al*., 1997; Dematte and Nanni, 2003). Processing the interactions between solar radiation, the atmosphere and soil compounds, the image was corrected, band-to-band, where the atmospheric effects were eliminated and then digital numbers were converted into "real" SR values.

Cluster analyses: The cluster analysis was performed by SAS software. This methodology was used for orbital and laboratorial soil map production. This method defines homogeneous groups by the cells union based on its quantitative spectral values from all bands simultaneously. The Average Linkage method was used to perform the analysis. The utilization of this method allows the construction of hierarquic groups and dendograms. Each cell (pixel) was identified as its respective soil group, thus performing a map. This was done for laboratory and orbital data separately.

Soil analysis: The collected soil samples were taken to laboratory where they were dried at 45°C for 48 h and sieved to 2 mm. The following analyses were performed: Particle Size Distribution (PSD); total Fe_2O_3, SiO_2 and TiO_2 extracted by sulfuric acid digestion (Camargo *et al*., 1986); Sum of Cations (SC); Cation Exchange Capacity (CEC); Cation Saturation (CS); Aluminum Saturation (AS); Clay activity (T) and Organic Matter (OM) (Van Raij and Quaggio, 1983):

$$CS = \frac{SC}{CEC} \times 100$$

$$AS = \frac{\text{Aluminum}}{\text{SC+Aluminum}}$$

$$T = \frac{CEC}{Clay} \times 100$$

Munsell colors were used to characterize the dry and moist soil samples.

Soil maps production and comparison: Soil map determined by different technologies several sequences were used to determine soil map, maps of the same area, as follows:

- **Map 1:** Traditional detailed soil map was realized with the location of 185 points (1 per ha) in a regular 100×100 m grid used to divide the field according to Embrapa method (EMBRAPA, 1999). All points were georreferenced with a precision GPS receptor. Soil samples were collected by boreholes into depths (0-20 and 80-100 cm). The 18 soil profiles were described in representative areas (Dematte *et al*., 2004)

In the Spring software (INPE, 1999) a soil map was produced where each soil class was represented for a different color in the each cell of the regular grid.

- **Map 2:** With soil profiles evaluated and morphologically described, boreholes analysis and an altimetric base map, it was digitized the real basis of the area, a detailed soil map was digitalized in spring
- **Map 3:** This soil map was determined by the fusion of two remote sensing methods, satellite image and aerial photographic image (1:35,000) for soil physiographic interpretation (Goosen, 1968), linking up the dynamic processes of the landscape with the existing soils there. The concept of soil versus relief was used in the determination of the boundaries of the various physiographic units. Later, each delimited area (polygon) was linked to a present soil class
- **Map 4 and 5:** The soil map 4 (laboratory spectral soil map) and soil map 5 (Orbital spectral soil map) was obtained by cluster analysis

For the soil map 4 initially, 22 bands and 13 heights were identified in the spectral curves obtained from the soil samples according to methodology described by Dematte *et al*. (2001) and Nanni and Dematte (2006). The cluster analysis was performed by SAS software (SAS, 1992). Spectrally similar samples were grouped according to different depths. The best grouping was used to generate soil map. Each soil sample was assigned to a particular cluster and was plotted on the map.

For obtaining soil map 5, the reflectance obtained in the laboratory, concerning the spectral bands that simulated bands of Landsat TM, were used.

The use of cluster analysis aimed to define homogeneous groups by joining the cells according to their quantitative analysis and heights of the leading bands of the spectral curves of each sampled point values that were set by statistical analysis as described by Nanni and Dematte (2006). According to Curi (1983), each individual belongs to a multivariate sample can be considered as a point in a multidimensional Euclidean space when they are made into one unit.

Therefore, each individual or sampling point was tabulated and arranged along with the bands and the spectral curves derived heights in a matrix, indicated by expression X = (Xij) whose dimensions are n×p, where n indicates the individuals and p variables.

As the coefficient of similarity or likeness, the Average Euclidean Distance (AED) was used. The method chosen for the group was the "Average Linkage". Use of this method should be the possibility of building hierarchical and agglomerative (dendrograms) groups which through successive mergers of objects n, will be obtained n-1, n-2,..., groups, until all objects are merged into one group.

With the construction of dendrograms, settled group's individuals by similarity coefficient obtained by the pseudo t^2 peaked (SAS, 1992). With the groups defined point of each borehole was identified by a color, SPRING software, yielding the soil map with the spectral data laboratory.

The Geographic Information System, SPRING software, was used to execute the cartographic work. According to INPE (1999), this system has multiple functions and algorithms to process georeferenced databases. A database was established with this system in order to incorporate the geospatialized information from planimetric and altimetric charts and was collected in the field by using GPS receivers and orbital images.

- **Map 6:** The soil map 6 is the combination of all techniques as follows and can be designated as a semi-digital soil map

Soil maps comparison/cross-tabulation: In Spring database, realized a cross-tabulation of soil map 1 with all others 2-6, to see the differences between a detailed soil map with the technologies. As a result, the percentage of error/non-error polygons between the "real" map (Map 1) and the others was obtained (Fig. 1).

In each procedure for obtaining the limits, implemented through a query language and spatial manipulation, called LEGAL (Linguagem Espacial para Geoprocessamento Algébrico), i.e., Space Algebraic Language for GIS (INPE, 1999), a routine to cross between the limits and percentage of trial and error to each crossing between soil units established by different methods. Thus, limits obtained by different methods were also judged by the intersection of this with the map obtained by the conventional rigid grid.

Spectral punctual soil identification evaluation: With the objective to verify punctual spectral information with soil classification, the discriminant linear functions analysis were performed by using SAS System. Laboratory spectral data (using simultaneously surface and undersurface information of each point) was prepared and related with soil classification. The software tested unknown samples with the soil spectral models and indicated its performance. The same was done with orbital data (using only surface spectral information, pixel). Figure 1 illustrates the methodology.

RESULTS AND DISCUSSION

Comparison of soil map 2 and 3: As it is shown in Fig. 2b, the spatial distribution of soil classes was quite heterogeneous, resulting from the conditions pedogenetic gifts. Due to the large variability of source material, combined with the relief conditions and local reworking, eighteen soils were established.

With the aid of planialtimetric chart of the area, settled limits of soils linking up each point with the borehole relief conditions and the observations and notations made in the field. This map is generated by the boundaries shown in Fig. 2a have excelled 53 polygons to 18 mapped classes representing simple mapping units.

For the physiographic maps obtained through image analysis, were established 35 polygons, a figure much lower than that reported for conventional map (Fig. 2b). However, the number of classes remained close, a total of 16 classes allowing, bring satisfactory results, with the possibility of stratification of the study area into homogeneous areas being established. This makes possible the overall planning of field activities and decreases the number of observations which causes reduction of survey work, with increased accuracy of tracing boundaries between soil units.

For comparison between the areas occupied by each class on the two maps obtained by different methods, Table 1 shows the result established by crossing them through SPRING (INPE, 1999).

The analysis of Table 1 showed that even with a smaller number of polygons, map representing was quite

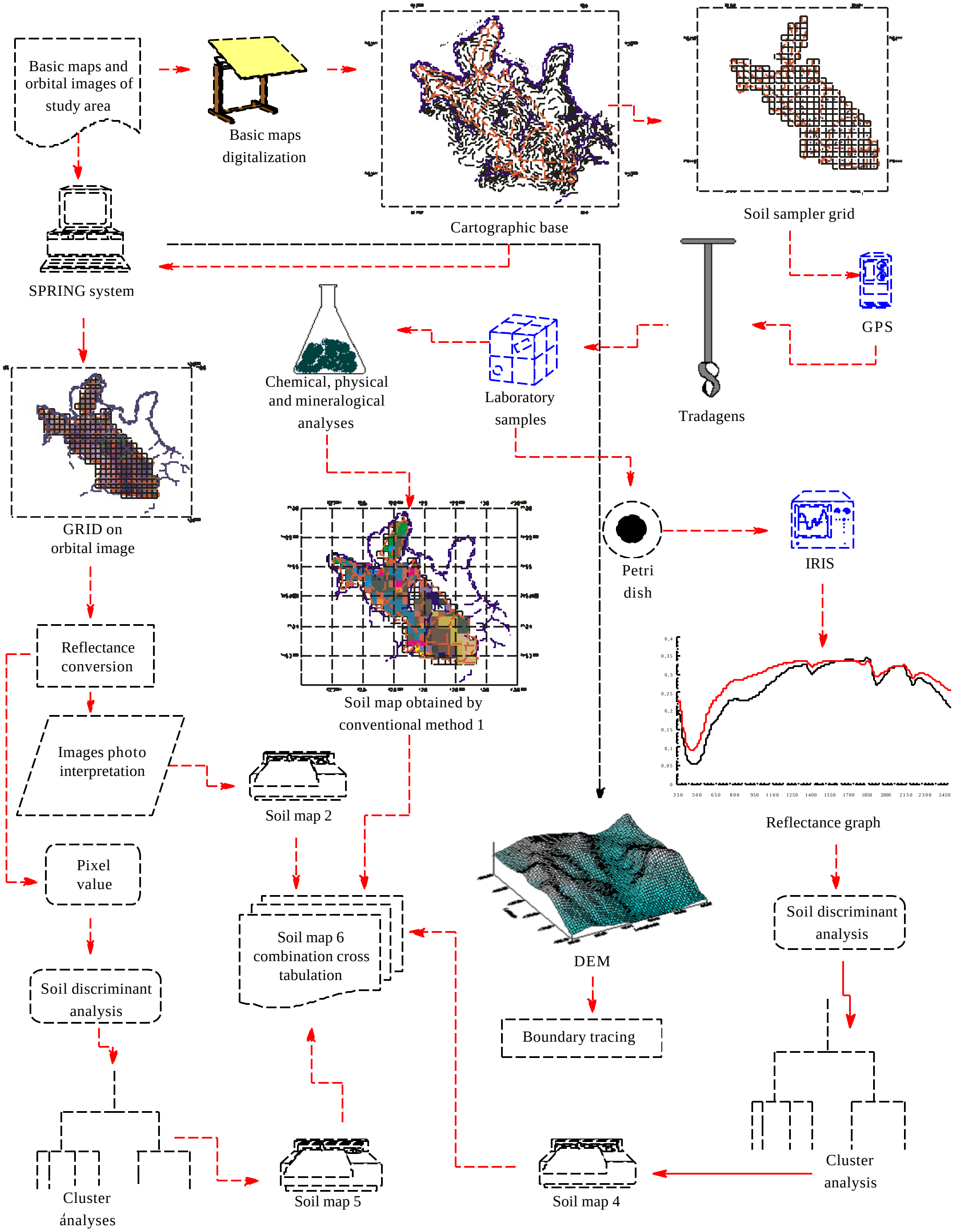

Fig. 1: Representative flow chart of the methodology used to obtain the soil maps by conventional photo-interpretation methods and the reflectance obtained in laboratory and orbital level than the combination of all methods for the generation of the final soil

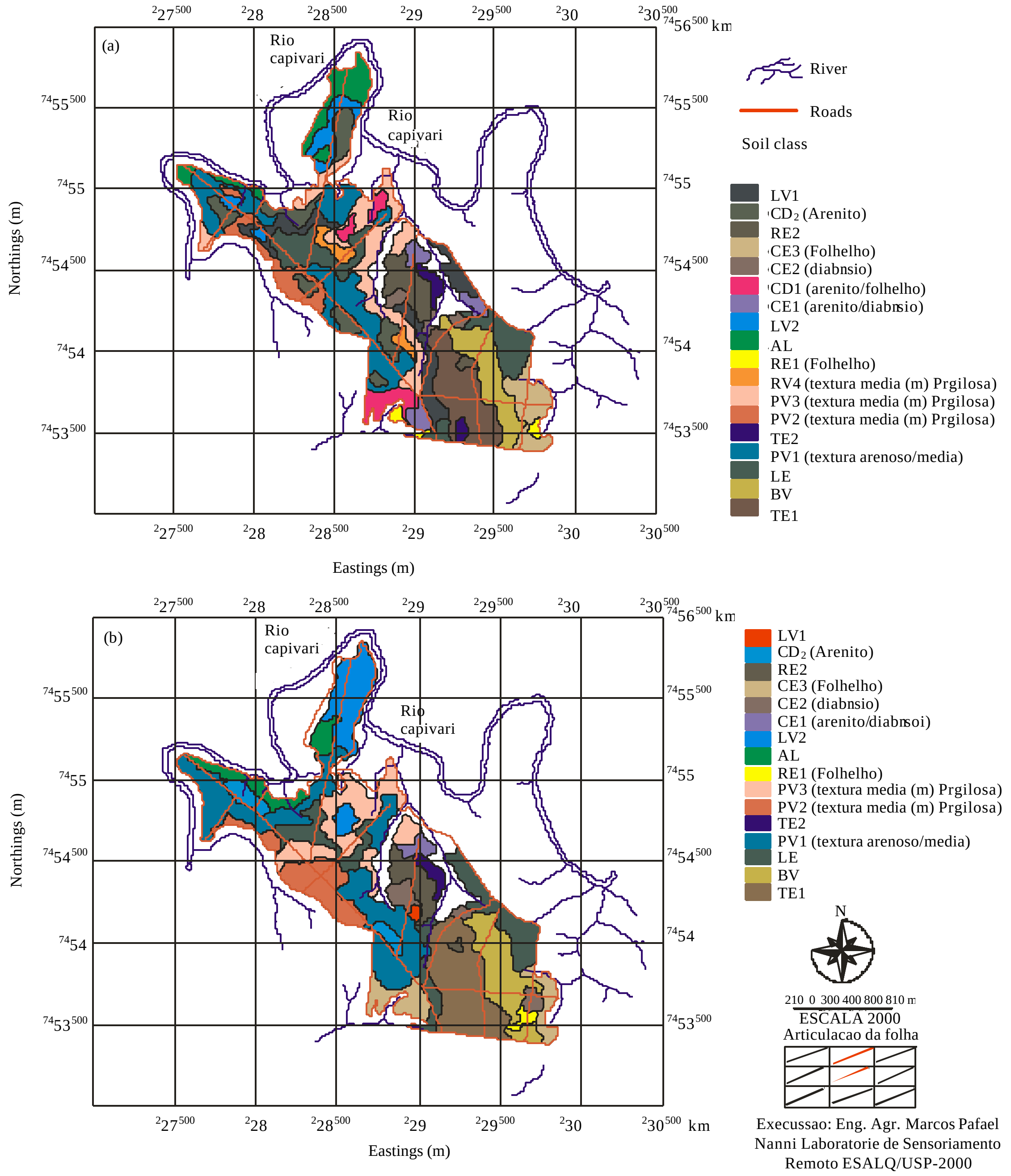

Fig. 2(a-b): (a) Spatial distribution of soil classes contained in the study area and obtained by the usual method and (b) Photointerpretation of orbital images

adequate in almost the entire area (classes present). However, some overlap between classes limits were found. This is the case especially among TE1, BVpp and LE classes. The interpretation of the scene has established limits that have been blurred in these three classes.

Comparison of soil map 1 with remote sensing maps 4: The soil map 1 was obtained by traditional method with a class soil definition for location of 1 soil samples point per hectare. The soil map 4 was obtained by cluster analyses of the soil samples, using the 22 bands and 13 height with analyzed variables.

Table 1: Areas between soil classes obtained by conventional methods

Parameters	TE1[1]	BV	LE	PV1	TE2	PV2	PV3	PV4	RE1	AL	LV2	CE1	CD1	CE3	CE2	RE2	CD2	LV1
TE1[2]	15.04[3]	1.8	1.08	0	0.92	0	0.08	0	0	0	0	0	0	0.04	0	0.72	0	2.88
BV	0.76	9.56	1.8	0	0	0	0	0	0.04	0	0	0	0	0.04	3.28	0.12	0	0
LE	0.04	0.08	12.12	0.16	0	0.04	1.16	0.4	0.4	0	0	1.88	0	0.4	0.4	0	0.24	5.08
PV1	0	0	0.32	14.52	0	0.88	7.88	1.4	0	1.04	1.56	0	0.96	0	0	0	4.76	2.28
TE2	0	0	0	0	1.32	0	0	0	0	0	0	0.12	0	0.04	0	0.64	0	0
PV2	0	0	0.24	4.08	0	4.68	0.12	0	0	0	0.04	0	0	0	0	0	3.08	0.68
PV3	0	0	3.32	2.96	0	1.08	7.04	1.84	0	0	0	0.36	1.2	0	0	0.04	0	0.44
RE1	0.04	0.92	0	0	0	0	0	0	0.04	0	0	0	0	0	0.32	0	0	0
AL	0	0	0	1.76	0	0.12	0.32	0	0	2.28	1.6	0	0	0	0	0	1.16	0.08
LV2	0	0	0.08	0.4	0	0	0.8	0	0	5.36	2.68	0	0.68	0	0	0	2.92	0.2
CE1	0	0	0	0	0	0	0.08	0	0	0	0	1.28	0	0	0	0.52	0	0
CE3	0	0.08	0	0	0	0	0.4	0	0	0	0	0	0	1.8	1.44	0.2	0	0.84
CE2	0	0	0	0.24	0	0	0.24	0	1.2	0	0	1.4	3.56	0	3.56	0	0	0.04
RE2	0.4	0.04	0	0	0	0	0.16	0	0	0	0	0	0	0.12	0	5.6	0	0.24
CD2	0	0	0	2.04	0	0.8	0	0	0	0	0.68	0	0	0	0	0	1.36	0
LV1	0	0	0	0	0	0	0.16	0	0	0	0	0	0	0	0	0	0	0.44

[1]Class present in the soil map obtained by physiographic analysis of Landsat TM image, [2]Classes present in the soil map obtained by evaluating the planialtimetric letter, [3]Area in hectares

Table 2: Number of observations between soil classes obtained by the conventional method and the groups formed by cluster analysis

Parameters	G1[1]	G2	G3	G4	G5	G6	G7	G8	G9	G10	G11	G12
TE1[2]	0[3]	0	0	0	0	0	14	0	0	0	0	0
BV	0	0	0	0	0	0	11	2	1	0	0	0
LE	0	0	0	0	0	0	14	1	5	0	0	0
PV1	8	2	9	0	7	1	0	0	0	0	1	5
TE2	0	0	0	0	0	0	0	0	3	1	0	0
PV2	3	0	6	0	1	1	1	1	0	0	0	5
PV4	1	0	1	0	0	0	0	1	0	0	0	1
RE1	1	0	0	0	0	0	0	0	0	0	0	0
AL	5	2	4	0	0	0	0	0	0	0	0	0
LV2	1	0	4	1	0	0	0	0	0	0	0	0
CE1	1	0	1	0	0	0	0	0	0	0	0	3
CD1	2	2	0	1	0	0	0	1	0	0	0	1
CE3	0	0	0	0	0	0	1	1	0	0	0	1
CE2	0	0	0	0	0	0	4	3	2	0	0	0
RE2	0	1	1	0	0	0	7	1	1	0	0	0
CD2	4	3	3	1	1	0	0	0	0	0	0	3
LV1	0	0	0	0	0	0	6	0	0	0	0	3

[1]Groups generated by cluster analysis, [2]Classes of soils of the study area, [3]No. of observations (cells)

According to Curi (1983), each individual belonging to a multivariate sample can be considerated with a point into the multidimensional Euclidian space, when they, are in the one unit, realized several measures. The dendrogram obtained for the cluster is showed in the Fig. 3a.

By analyzing Fig. 3a, it is observed that for this analysis twelve groups using the similarity coefficient with value 0.33 were separated. This value was established by pseudo t^2 peaked (SAS, 1992) which is presented quite close to that established by Dematte (1999).

After obtaining these groups, each borehole point was identified by a color by Spring system, yielding the map of groups obtained by using clustering analysis as variables and the reflectance data (Fig. 3b).

The number of clusters (12) are smaller than the number of soil types (22), obtained by the conventional method. It should be clear that the cluster analysis does not follow any pre-established classification, i.e., no soil classes involved in the review process but individuals with characteristics that may or may not resemble according to the analysis involved (Curi, 1983). For comparison between the areas occupied for each class on the two maps, Table 2 presents the results established by intersection between them.

It is observed from Table 2 that the G7 group was formed primarily by TE1, BVpp, LE, LV1, CE2 and RE2 classes. Of these only the CE2 was formed by shale parent material. The others, however, have as source material the diabase. The LE and CE2 classes present observations not grouped in the same group, some of them going to the G8 and G9 groups. In this case, this was possible because these groups showed little similarity coefficient (Fig. 3a), with the possibility of confusion.

Few classes were present in nearly all individual groups. As an example, there is the VP1 class who participated in groups 1, 2, 3, 5, 6, 11 and 12. There have, however the observations of other classes that are part of these groups have near surface features, such as in the case of AL, CD1 and CD2 classes.

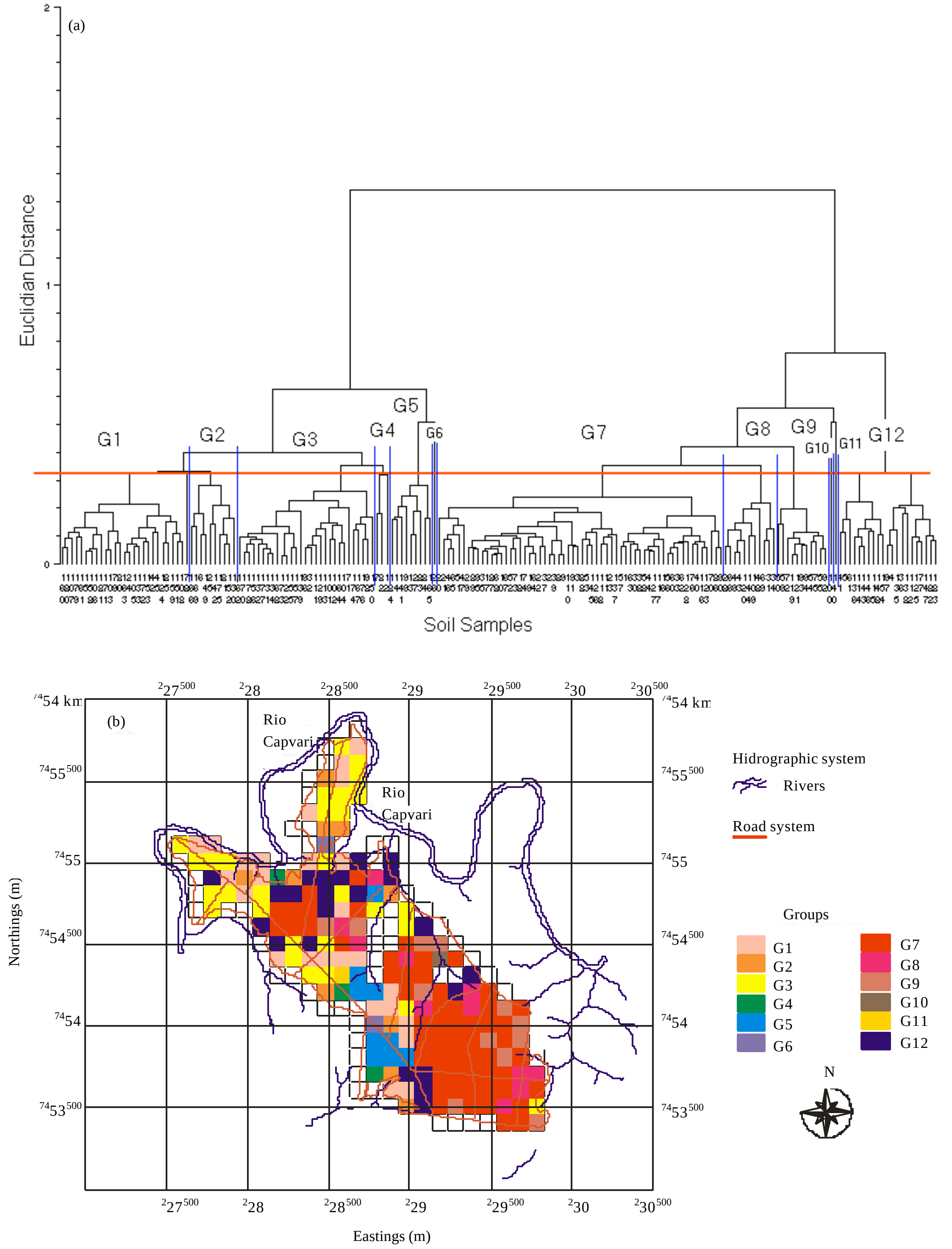

Fig. 3(a-b): Dendrogram related to cluster analysis of the 22 bands and 13 heights (a) Spectral curves obtained in the laboratory for 184 points borehole and (b) Soil maps generated by cluster analysis using, as variables, 22 bands and 13 heights the spectral curves obtained in the laboratory

These junctions between classes or approaches have been highlighted in the discriminant analysis as discussed earlier. It is notorious that express clusters are occurring due to the similarity of their spectral responses of the resulting attributes of the superficial portion of the soils.

It is clear and evident separation of groups of varying geological conditions, i.e., sandstones, shales and diabase. Some confusion between these last two, just as occurred in the discriminant analysis.

Comparison of soil map 1 with remote sensing maps 4: The second map obtained with the use of spectral curves laboratory refers to spectral bands of Landsat TM. To prepare the map obtained through the orbital scene reflectances were used, 184 of observations, only 162 boreholes once the image points with canopy was discarded. In Fig. 4a the dendrogram obtained by cluster analysis of the six spectral bands obtained in the laboratory is presented.

Among the Euclidean distances established to date for completion of cutting the hierarchical tree, it got the highest value (0.45), defined by the highest peak of the pseudo t^2. However, the number groups were similar to that obtained by simulation that is, nine groups. Possession thereof was defined using the Spring system, the spatial distribution of the grouped observations, as shown in Fig. 4b.

Table 3 shows the results obtained by the intersection between the maps for comparison

Table 3: Number of observations between soil classes obtained by the conventional method and the groups formed by cluster analysis using the reflectance obtained at orbital level

Parameters	NA	G1	G2	G3	G4	G5	G6	G7	G8	G9
TE1	4	0	0	0	0	3	11	0	0	0
BV	0	0	0	0	0	11	3	0	0	0
LE	0	0	0	0	0	12	8	0	0	0
PV1	4	7	0	0	8	2	1	0	11	0
TE2	0	0	0	0	0	0	3	1	0	0
PV2	3	6	0	1	3	2	0	0	2	1
PV4	0	2	0	0	0	1	0	0	1	0
RE1	0	1	0	0	0	0	0	0	0	0
AL	4	6	0	0	1	0	0	0	0	0
LV2	1	3	0	0	1	1	0	0	0	0
CE1	1	2	0	0	0	2	0	0	0	0
CD1	1	3	0	0	2	0	0	0	0	1
CE3	0	0	0	0	0	2	1	0	0	0
CE2	3	1	0	0	0	4	1	0	0	0
RE2	0	1	0	0	1	7	2	0	0	0
CD2	3	4	1	0	3	1	0	0	3	0
LV1	0	2	0	0	0	2	5	0	0	0

[1] Groups generated by cluster analysis, [2] Classes of soils of the study area, [3] No. of observations (cells)

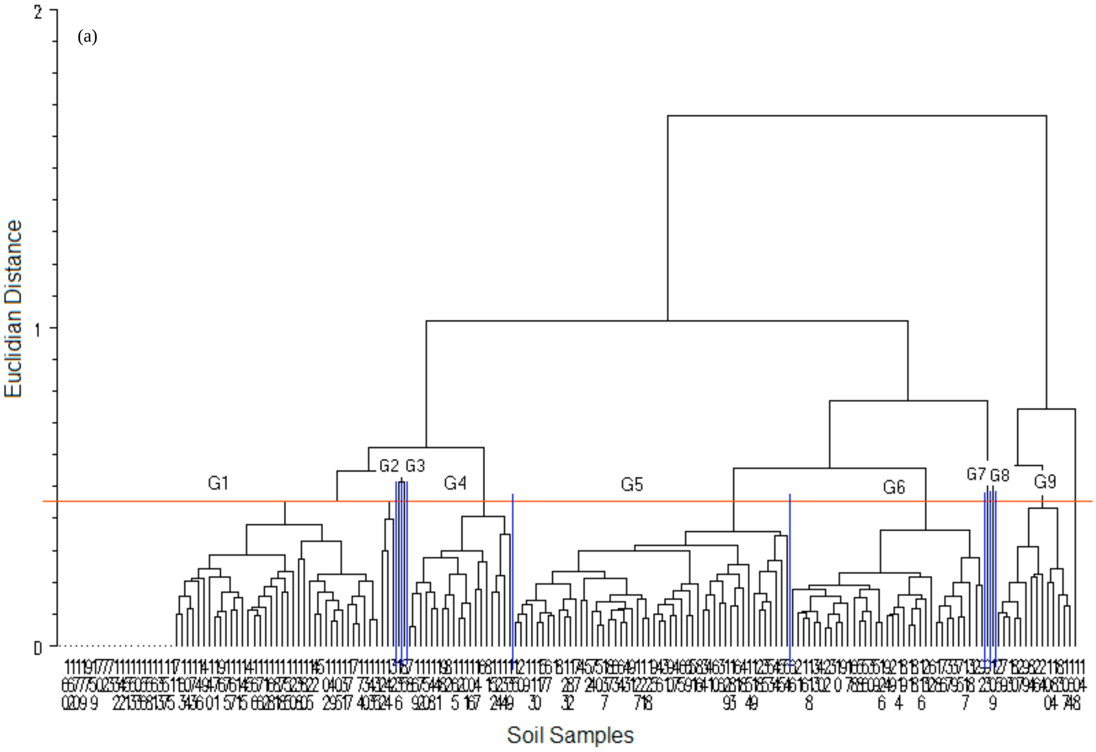

Fig. 4(a-b): Continue

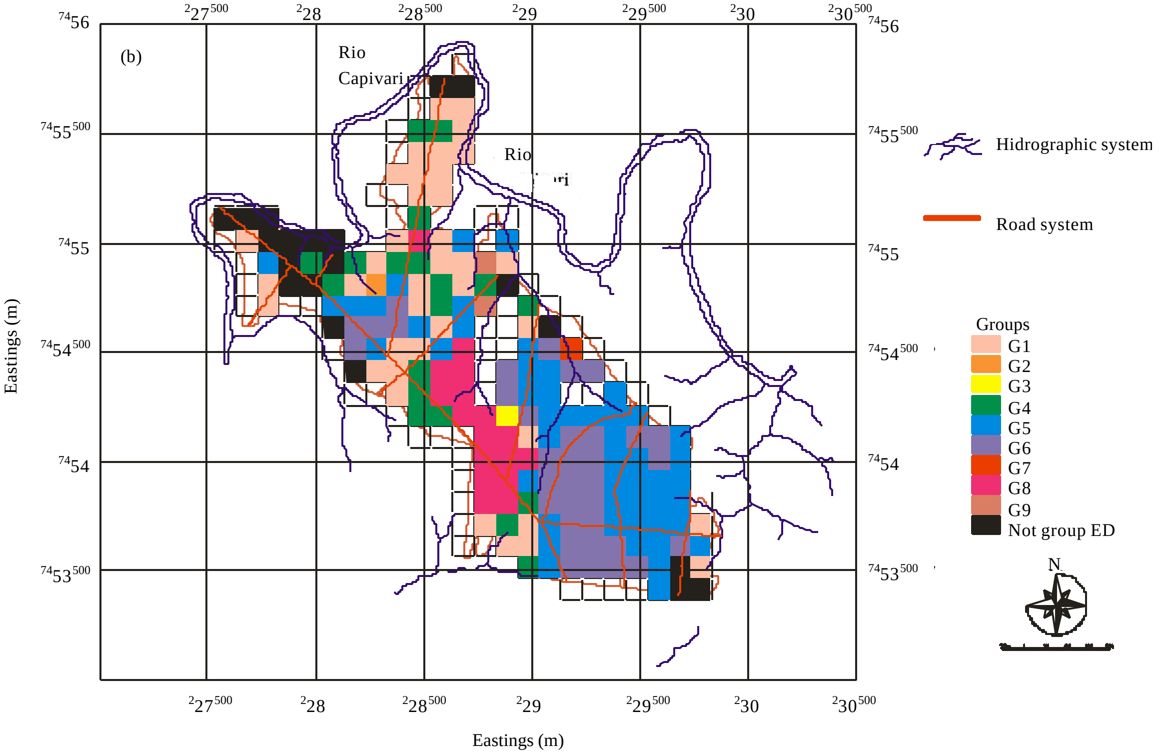

Fig. 4(a-b): Dendrogram related to cluster analysis of the (a) 6 bands of spectral curves obtained from Landsat TM scene, for 162 points borehole and (b) Soil maps obtained by cluster analysis using, as variables, 6 bands of TM sensor

between sites occupied for each class present and settled by the different methods.

The analysis of Table 3 shows that the classes present that originate in diabase were previously grouped in separate group 5 and 6 within the cutting conditions set by the similarity coefficient used. If this value was increased to 0.55, the two groups would merge into a single group. In this case, the groups also 7 and 8 and 1, 2 and 3 would form new groups, with the largest number of individuals. Then were would have only 6 groups instead of 9.

As in the previous analysis, this group also presented with only one or at most two individuals (group 9) which could be reassembled into other sets with the increasing level of court.

It is observed that for the separability of classes whose parent material was not the diabase, the use of reflectance obtained in the orbital level showed satisfactory results despite lower compared to those used in land level. As in discriminant analysis, there was confusion among individuals within groups but luckily, the large data set was separated into 3 major groups, evidently arranged primarily is by the condition of the original material. This against the results, that are obtained in the discriminant analysis and also demonstrated by Dematte (1995) which concluded that, grouping by the parent material for soils he studied, presenting better results than analyzed separately.

These results indicate that the analysis of spectral data can help in different ways for mapping soils. The number of information generated by spectral data may be useful in soil mapping, provided as they take proper care of interpretation.

CONCLUSION

- The soil map obtained by spectral laboratory data using surface and undersurface information, determined the main types of soils in the area but did not reach the high level of a precise mapping. The main confusion of spectral data occurred in areas of transition of soils
- Orbital quantitative data using cluster analysis was less precise than other strategies, although showed

important limits for a less detailed map. Soils developed by similar geological materials can be better discriminated by orbital images. On the other hand, the unsupervised digital classification method presented a substantially better performance reaching 88.4% agreement with real soil map

- The soil map obtained by orbital image interpretation integrated with physiographic information, determined the best similarity with real truth
- In this complex studied area, it was absolutely clear that remote sensing techniques can assist a soil map at high scale but cannot reach its 100%, thus been necessary some field work
- Discriminant analysis spectral method indicated high index of agreement with soil classes (90.7%)

ACKNOWLEDGMENTS

The authors thank CNPq (National Council for Scientific and Technological Development) and CAPES (Coordination of Improvement of Higher Education Personnel) by research grants awarded and to the reviewers and editors for their valuable comments and contributions to improve the manuscript.

REFERENCES

Agbu, P.A., D. Fehrenbacher and I.J. Jansen, 1990. Soil property relationships with SPOT satellite digital data in east central Illinois. Soil Sci. Soc. Am. J., 54: 807-812.

Camargo, O.A., A.C. Moniz, J.A. Jorge and J.M. Valadares, 1986. Methods of chemical, mineralogical and physical analyses of soils. Technical Bulletim of the Agronomic Institute of Campinas, Campinas, No.106, pp: 94, (In Portuguese).

Curi, P.R., 1983. The similarity in cluster analysis: Correlation coefficient and distance. Sci. Culture, 35: 1678-1685.

Dematte, J.A.M., 1995. Relationship between spectral data and physical, chemical and mineralogical characteristics of soils developed from igneous rocks. Tese (Doutorado)-Escola Superior de Agricultura Luiz de Queiroz, Piracicaba, pp: 265.

Dematte, J.A.M., 1999. Spectral reflectance of soils. Tese (Livre Docencia)-Escola Superior de Agricultura Luiz de Queiroz, Piracicaba, pp: 452.

Dematte, J.A.M., J.L.I. Dematte, W.P. Camargo, P.R. Fiorio and M.R. Nanni, 2001. Remote sensing in the recognition and mapping of tropical soils developed on topographic sequences. Mapp. Sci. Remote Sens., 38: 79-102.

Dematte, J.A.M. and M.R. Nanni, 2003. Weathering sequence of soils developed from basalt as evaluated by laboratory (IRIS), airborne (AVIRIS) and orbital (TM) sensors. Int. J. Remote Sens., 24: 4715-4738.

Dematte, J.A.M., R.C. Campos, M.C. Alves, P.R. Fiorio and M.R. Nanni, 2004. Visible-NIR reflectance: A new approach on soil evaluation. Geoderma, 121: 95-112.

EMBRAPA-Empresa Brasileira de Pesquisa Agropecuaria, 1999. Manual of chemical analysis of soils, plants and fertilizers. Embrapa Solos/Embrapa Informatica Agropecuaria/Embrapa Comunicacao para Transferencia de Tecnologia, Brasilia, pp: 370.

Goosen, D., 1968. Interpretation of aerial photos and their importance in soil survey. Organizacao das Nacoes Unidas Para a Agricultura e Alimentacao, Boletim Sobre Solos, No. 6, Roma.

INPE, 1999. [Tutorial course-Spring-3.3 (windows version)]. Spring Basico, Instituto Nacional de Pesquisas Espaciais (INPE), Sao Jose dos Campos, Brazil, June 1999, (In Portuguese). http://www.dpi.inpe.br/spring/teoria/aula1.pdf

IPT, 1981. Geomorphological map of the state of Sao Paulo, scale 1:1.000.000. Vol. 2, Instituto de Pesquisas Tecnologicas do Estado de Sao Paulo, Sao Paulo. (Monografias, 5; Publicacao, 1183).

Nanni, M.R. and J.A.M. Dematte, 2006. Spectral reflectance methodology in comparison to traditional soil analysis. Soil Sci. Soc. Am. J., 70: 393-407.

SAS, 1992. SAS/STAT software: Changes and enhancements, release 6.07. Statistical Analysis System Institute, Cary. Chapter 16, The MIXED procedure, SAS Technical Report P-229.

Soil Survey Staff, 1998. Keys to Soil Taxonomy. 8th Edn., USDA Natural Resource Conservation Service, U.S. Government Printing Office, Washington DC., USA.

Thome, K.B., B.L. Markham, J.L. Barker, P. Slater and S. Biggar, 1997. Radiometric calibration of landsat. Photogramm. Eng. Remote Sens., 63: 853-858.

Van Raij, B. and J.A. Quaggio, 1983. Methods of soil analysis for the purposes of fertility. Instituto Agronomico, Campinas, IAC. Boletim Tecnico, 81, pp: 31.