Updating maps of soils through landsat images

G. J. García[1], M. Valerio Filho[2] and S. A. F. Pinto[2]
[1] *Department of Cartography - IGCE/UNESP, Río Claro - SP, Brazil - 13.506 900*
[2] *Remote Sensing Department, INPE/MCT, Sâo José doo Campos - SP, Brazil - 12.227010*

RESUMEN

En Los mapas de suelos son básicos en estudios integrados que tratan del planeamiento de utilización de las tierras. Brasil y otros países en desarrollo tienen muy pocas áreas con mapas en escalas adecuadas y con límites entre suelos bien definidos. El objeto de la investigación es el estudio de la utilidad de las características espectrales de los suelos en la mejora de los mapas existentes. Imágenes Landsat/TM de una zona agrícola en el Estado de Sao Paulo fueron procesadas en términos digital y estadísticos con la finalidad de producir un nuevo mapa de suelos. Este nuevo mapa fue comparado con el mapa existente producido de forma tradicional. La metodología fue utilizada en áreas preparadas para la siembra, por tanto sin cubierta vegetal. Los autores acreditan que la metodología puede ser empleada en muchas otras regiones agrícolas.

PALABRAS CLAVE: Landsat, suelo, características espectrales.

ABSTRACT

Soil maps are basic in integrated studies directed toward land management. Brazil and other developing countries have few areas mapped at adequate scales and definition of soil boundaries. The objective of this research is to analyze the usefulness of spectral characteristics of soils for the improvement of existing maps. Digital processing and statistical analysis of Landsat /TM images in one agricultural region in Sao Paulo state were used to produce a new soil mar which was compared to existing maps. The methodology was successfully utilized in areas without dense vegetative cover (e.g., tilled and prior to major plant growth). The authors believe that the methodology can be applied in many other agricultural regions.

KEY WORDS: Landsat, soils, spectral characteristics.

INTRODUCTION

In the integrated analysis of landscapes, information about soils is essential. Although fundamental, soil maps in Brazil at adequate scales and levels of detail are rafe, even in the most developed regions. The State of Sâo Paulo, Brazil, has an old soil map coverage at 1:250,000 by theSoils Commission, dating from the 1960s. Currently, the Agronomic Institute (IAC) of Sâo Paulo state has conducted mapping at the scale of 1:100,000. By mid-1992, approximately fifteen percent of the state had been mapped. The maps serve well for regional studies, but are generally insufficient for local studies at scales between 1:25,000 and 1:50,000. When using traditional methods to enrich the IAC map information for use at the locallevel, anlyses of geology, topographic relief, drainage network and field work are needed.

For a more rapid, economic and efficient enhancement of Ihe IAC maps, we propose an altemative method. The method uses satistical analysis of the spectral character of exposed soils as seen in satellite images obtained in periods of tillage prior to major plant growth. In this paper we present our methodology and the results from a test afea lo produce a soils map at a scale of 1:50,000.

REVIEW

In their study, Haralick and Shanmugan (1974) found that spectral characteristics, textures and local oontext are the three elements used in visual interpretación of satellite images. In terms of spectral behavior, soils exhibir spectral curves (asignatures) that are much more uniform than those of rocks. Studies by Montgomery and Baumgardner (1974) and Stoner and Baumgardner (1981) show that reflectance of soil is a cumulative property resulting from the heterogeneous contribution of organic matter, iron oxide, moisture, granulometry, and stlruclure. According to Stoner et al (1980), soils can begrouped in five basic spectral curves, as shown in Figure 1. As demonstraled by Pase (1974), the amount of organic matter is inversely correlated with the spectral reflectance. However, Baumgardner et al (1970) comment that levels of organic matter greater than two percent mask the effect of other properties. Furthermore, in the case of iron oxide, levels greater than four percent can mask the effects of high levels of organic matter. Monlgomery et al (1976) state that the significance of iron oxides refectance increases with the increase of the wavelength in the electromagnetic spectrum, especially in the regions of visible light and near-infrared.

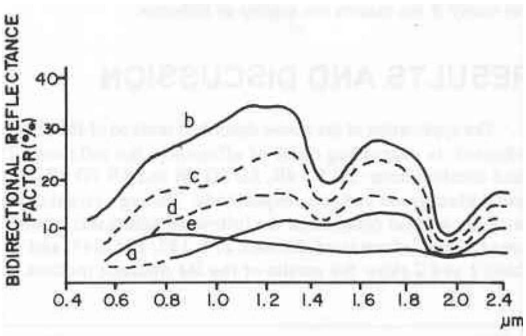

Fig. 1. Five soil reflectance spectra. Dominant factors: a) organic matter (O.M.); b) Iow weathering with low O.M. and medium iron; c) affected by iron; d) affected by O.M.; e) iron.

Cipra et al (1980) compared spectral-radiometer measurements of exposed soils wilh digilal data from Landsatl. Results showed that Landsat 1 radiance and spectroradiometer reflectance values were highly correlated for all wavelength bands.

Lund et al (1980) and Harrison and Johnson (1982) concluded that the use of spectral maps derived from Landsal data improved accuracy and/or quality of map unit delineations. More recently, Coleman and Montgomery (1987) and Everitt et al (1989) studied the same question. The former encountered great interdependence between the moisture content and the refectance of the respective soils. The latter studied the moisture content, organic mater and the level of iron in Alfisols and Vertisols, finfing high correlations between reflectance and the studied variables.

In both cases the soils were separated and accurately mapped on the basis of spectral, physical and chemical properties.Agbu and Nizeyiama (1991) compared soil maps from SPOT spectral data with maps produced in the field. Although the maps based on field work were found to be better than those based on spectral analysis, the differences did not attain statistical significance at the 0.05 level, using the Kappa statistic.

Visual analysis of spectral differences are insufficient for the required studies. Although only a few (4 to 12) bands are selected from the continuum of electromagnetic energy, each band contains a continuum of extremely small variation of the intensity of reflectance in that band. Therefore, the possible number of combinations of bands is extremely large. Consequently, research that deals with such spectral behaviour of targets in images from satellites requires digital analysis. These capabilities exist in image analysis systems such as ERDAS or, in Brazil, SITIM (Sistema de Tratamiento de Imagen) from the Space Research National Institute, INPE.

Spectral image analysis methods of particular note are those that are based on the statistical distance between probability densities that characterize the standard classes. These methods include divergence, transformed divergence, Bhattacharyias distance and Jeffreys-Matusita (JM) distance (Swain and King, 1973;Richards, 1986).

METHODS

Description of the study area

The study area is approximately 10 x 10 minutes of latitude and longitude (220 square kilometers) on the Araras quadrangle in the state of São Paulo, Brazil (see Figure 2). The area is tropical, located 130 kilometers north of the Tropic of Capricorn. The minimum and maximum elevations are respectively 560 and m above mean sea level. The topography is a slightly rolling landscape. Only ten percent of the area has limitations that prevent mechanized agriculture. According to the maps of the Instituto Geográfico e Cartográfico-IGC (1982). the geology of the afea includes rocks from the Tubarâo Group, the Irarti and Curumbataf formations (siltstone and shales) of the Passa-Dois Group, basic intrusions, sandstones and Cenozoic deposits.In the Köppen system of climatic classification, the climate of the afea is mesothermic with dry winter, type Ewa. The winter dryness extends from April to September; the summer rains occur from October to March. June and July temperatures average 18 ºC (64 ºF), rising to 22 ºC (72 ºF) in January and February. Frosts do not occur.

The natural vcgetation is classified as sub tropical forest. The area is used for sugar cane, citrus, cotton and foud agriculture. Pastures and reforestation are found in the steeper areas. Keeping in mind the methodological considerations of the research, we selected an area predominately ocupied with annual crops and obtained images from the period prior to planting. The major part (85%) of the afea was free of vegetation.The soils of the area, according to Oliveira et al (1982), area listed below, in order of highest to lowest occurrences. Their approximate distribution, according ta the pre-existing 1:100,000 scale map, is shown in Figure 2.

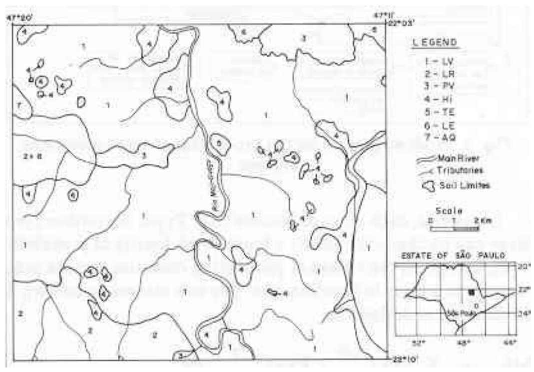

Fig. 2. Study area as mapped In 1982 by fleld work 01 the Instituto Agronómico de Campinas. (IAC) published at 1:100,000 scale.

- LV- Latossolo Vennelho Amarelo
  (USA)- Quartzipsammentic Haplorthox

- LR- Latossolo Roxo- eutrófio
  (USA)- Typic Eutrorthox
- PV- Podzólico Vennelho Amarelo
  (USA)- Typic Paleudult
- TE- Terra Roxa &tructurada- eutrófica e distrófica
  (USA)- Thodic Paleudalf + Rhodic Paleudult
- AQ- Areias Quartzosas
  (USA)- Typic Quartzipsamment
- Hi- Solos Hidromórficos
  (USA)- Hydromorphic soils
- LE- Latossolo Vennelho Escuro
  (USA)- Typic Haplorthox

Characteristics ofthe images and equipment used

Analogue (1:100,00) and digital images from Landsat Thematic Mapper (TM) were obtained from six visible and reflected infrared bands. The images were at path 220, row 75 (WRS) for the month of December. The Instituto Brasileiro de Geografía e Estatística- IBGE topographic quadrangle at the scale 1:50,000 was used as cartographic base for plotting information.

The digital images were processed with the SITIM-150 system on a microcomputer. A PROCON projector/enlarger was also used. The work sequence is presented in Figure 3.

Image Analysis

For selecting the subgroups of bands for generation of the color composites, the Jeffreys-Matusita distance method was used, as discussed by Swain and King (1973). The JM distance is an appropriate technique to measure the average separability between spectral classes, calculated as functions of probability density. The following researchers, among others, implemented or applied thelM method: Bendat and Piersol (1986), Paradella (1984) and Andrade (1985). This technique is a convenient alternative for selecting the best color composite images. The series of interband statistical measurements of the JM method results in a reduction of the dimensionality. processing and redundance of data.

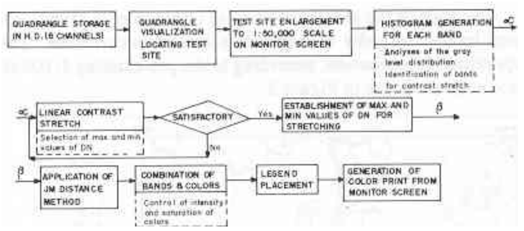

Fig. 3.- Work sequence for the production of color composite images

In general, each class, of interest (e.g. Typic Eutrorthox) in an image can be characterized by a function of density of probability, Pi (x), that givex the values of probability, densities that the pixels x belong to a class in function of x. For two classes w_i and w_j, the JM distance is defined as:

$$JM_{ij} = X \ Pi(x)^{1/2} - Pj(x)^{1/2 \ 2} dx$$

Where:

JM_{ij} = JM distance between classes w_i and w_j
Pi(x) = probability density of the pixels belonging to class w_i
Pj(x) = probability density of the pixels belonging to class w_j
X = range of interest for the x values

The algorthm implemented on the SITIM system calculates the JM distances between classes selected by the user for all possible combinations of bands. The output include, subsets that maximize the JM average and minimum distance criteria.

A multi-variate analysis was applied to classify thescene. The method offers the advantage of working with both parametricand non-parametric data. Cluster analysis was adopted in order to work with a group of units characterized by diverse variables. The result is the separation of existing groups characterized by homogeneity between the elements within the group and by the heterogeneity beween elements in different groups (Curi, 1982). The specific analysis called ISOMIX (Prelat, 1981) was used because of its great discrimination power, with the advantage of being interactive.

The degree of differentiation between the groups is measured by the similarity of the "centers of groups". If the distance between two groups is less than a specified limit, the two centers of groups are joined and have the average value of the two original groups. The process is cyclically repeated until the standard deviation of each group center is less than thespecified level, or until tbe maximum number of permined groups is attained. The control parameters specified by the analyst are: a) standard deviation-controls the number of classes; b) minimum groupcenters and maximum group centers-controls the category level to be attained; c) minimum number of pixels per group- below which it is not possible to form a new group; and d) separation threshold - to verify if the classes are similar or different.

RESULTS AND DISCUSSION

The application of the above described method of JM distance indicated, in decreasing order of efficiency, the following TM band combinations: 2 B 5G 4R, 3B 5G 4R and 5B 7G 4R, in the colors blue, green and red, respectively. Through visual examinations, we also considered the following additional combinations to have informative content: 274, 157, 174, 247, and 154. Table 1 and 2 show the results of the 1M distance method.

The classification of spectral information from the cluster analysis (ISOMIX) permit tbe union of the soil units, whether homogeneous or not, as represented in Figure 4. Table 3 presents the control parameters for tbe test application.

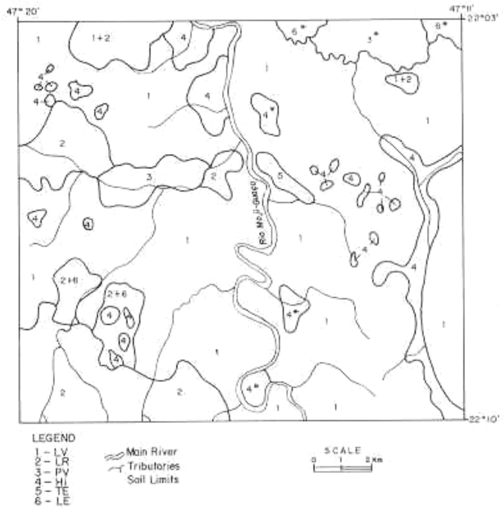

Fig 4. Field work map of the study area and map of soils produced from interpretation of spectral data

Table 1- Rank of best original TM bands

Bands	Results
4	1.4325
5	1.2604
2	1.1288
3	1.0936
7	1.0850
5	1.0682

Table 2- Rank of the six best subsets of TM bands

Bands	Results
4	1.4325
45	1.2604
245	1.1288
2345	1.0936
23457	1.0850
123457	1.0682

N.B.: Rectangles indicate the best subsets of three or four TM bands.

Table 3- Control parameters for Isomix

Parameters	Values
STANDARD DEVIATION	2.00
MIN GROUPCNTRS	4
MAX GROUPCNTRS	6
MIN PIX/GROUP	50
SEPARATION THRESHOLD	2.50

The delimitations of the soils in the study afea based on the composition 2R 5G 4R are shown in Figure 4. Comparing this mar with theone in Figure 2 reveals that much ofthe information coincides, especially for the langest parches of soils. Nevertheless, the new mar presents a greater richness of detail, has better definition between the soil boundaries, and reveals important transitions between soils.

A comparison between the two soils maps was made with a 2 x 2 mm grid sample (5425 grid cells, each representing 200 x 200 meters on the earth surface). The fieldwork map is used as the reference. Comparing the homolugous squares, the percentage of coincidence (86.9%) was calculated with the following formula:

$$\text{Percent Correct} = \frac{CP}{TN} \times 100$$

where:
CP= Number of correct predictions of map units
TN= Total number of map units in the sample

Figures 2 and 4 indicate that the main discrepancies appear in the spectral-data map in patches of homogeneous or associated soils that are absent from the map based on field work. Subsequent field checks have verified the existence of the patches. Of the total 13.1 % error in coincidence, 7.8 % resulted from deficiencies in the mar based on field work, where as 5.3 % were from insufficiencies of the spectral mar. Of the 5.3 %, 1.7 % derived from patches of hydromorphic soils whose reflectances are masked by dense natural vegetation. We note that both types of errors are from omission of detail, not from excessive detail that was incorrect.

The results of the study match well the existing literature. The sepectral differences between soil types are derived mainly from the different percentages of organic maner and iron oxide (Montgomery and Baumgardner, 1974, and Stoner and Baumgardner, 1981). In this case, the soils in the afea are distinct between themselves, especially in relation to iron oxide.

When the best spectral combinations are analyzed, the TM4 and TM5 bands were found to be present in the composites considered to be the most informative. The spectral curves shown in Figure 1 confirm that the greatest differentiations occur precisely in the intervals that correspond to bands 4 and 5. Because the soils of the study area have quite similar concentrations of organic maner (C/N relation from 9 to 12), the spectral difference more dependent on the quality and quantity of iron oxides present. The average percentages of iron oxides in the soil types are: LR=34%, TE=26%, LE=22%, PV=10%, LV=5%, AQ=2.0%, and Hi=0.5%. In a consistent way and as expected, the spectral response decreased from the higher to lower levels of iron oxide. Tbe results were darker ton es for LR and lighter tones for AQ.

In the case of Hi, the dominant factor was the level of moisture for the absorption of the infrared radiation. In terms of our purely visual interpretations of the images, we were able to distinguished with confidence the LR, LE, and LV soils. The AQ soils were confused with the more sandy areas of LV soils. PV soils could not be distinguished, possibly because of their low representation in the study area.

These results are comparable to those of other authors who compared soil maps from field work and spectral data: Cipra et al (1980), Lund et alii (1980), Harrison and Johnson (1982) and Agbu and Nizeyiama (1991). Of note, however, is that this current study is conducted with completely different soils and conditions, being tropical soils in Brazil.

CONCLUSIONS

Por the study area, the methodology permits us to make the following conclusions:

1. The employed mathematical models of JM distances and ISOMIX were sensitive and effective for the data analyses of these tropical soils.
2. Por areas of exposed soils, their spectral character was of extreme usefulness for the improvement of the quality and precision of the final map.
3. The methodology shows that it is not only possible to redefine the limits of the soil units, but also the detection and delimitation of associated soil units.
4. The authors believe that the high degree of discrirnination obtained permitid thesuggestion that the metholodoly is valid for application in areas with soils that are more similar to each other than are those in the study area.

BIBLIOGRAPHY

AGBU, P. A. and NIZEYAMA, E. 1991. Comparisons between spectral mapping units derived from SPOT image texture and field soil map units. *Photogrammetric Engineering andRemote Sensing,* 57:397-405.

ANDRADE, L. A. 1985. Critérios de seleçâo de atributos visando a escolha dos quatro canais significativos do Thematic Mapper. *Proc. 12º Congresso Brasileiro de Cartografía,* Brasília- DP, vol 1,205-226.

BAUMGARDNER. M. P. KRISTOP, S. J. JOHANSEN, A. L and ZACHAR y, A. L 1970. Effects of organic matter on the multispectral properties of *soils.lndiana Academy olSciences,* 79:413-422.

BENDA T, J. S. and PIERSOL, A. G. 1986. *Random dota analysis and measurement procedures.* N. York, John Wiley, 304 p.

CIPRA, J. E. PRANZMEIER, D. P: BRAUER, M. E. and BOYD, R. K. 1980. Comparison of multispectral measurements from some nonvegetated soils using Landsat digital data. and a spectroradiometer. *Soil Sci. Soco Am. J.,* 44:80-84.

COLEMAN, T. L. and MONTGOMERY, O. L 1987. Soil moisture, organic matter and iron content effect on the spectral characteristcs of selected and Alfisols in Alabama. *Photogrammetric Engineering and Remate Sensing,.53:1659-1663.*

CURI, P. 1982. Análise Multivariada. Botucatu-SP, Int. Biociência-UNESP, 64 p

EVERITT, J. H. ESCOBAR, D. E. ALANIZ, M. A. and DAVIS, M. 1989. Using multispectral video imagery for detecting soil surface conditions. *Photogrammetric Engineering and Remote Sensing,* 55:467-471

HARAUCK, R. M. and SHANMUGAN, K. S. 1974. Combined spectraJ and spatial processing of ERTS imagery data. *Remote Sensing of Environmet,* 3:3-13.

HARRISON, W. D. and JOHSON, M. E. 1982. Improving mapping unir delineation accuracy using Landsat MSS spectral maps. *Proc. Western Region Tech. Work Plannig Con! Nat. Coop. Soil Survey,* SCS, Washington, D. C., 112-128.

INSTITUTO GEOGRAFICO E CARTOGRAFICO - IGC. 1982. Mapa Geológico de Estado de Sao Paulo. Sao Paulo, SEPLAN.

LUND, L. l., WEISMILLER, R. A., KRISTOF, S. l., KIRSCHNER, F. R. and HARRISON, N. D. 1980. Development of spectral maps for soil-vegetation mapping in the Big Desert area, Idaho. *Proc. Sixth Ann. Symp. on Machine Processing of Remotely Sensed Data.* Lab. for Application of Remote Sensing. Purdue Univ., West Lafayette, Indiana, 84-96.

MONTGOMERY, O. L. and BAUMGARDNER, M.F.1974. The effects of the physical and chemical properties of soils on the spectral reflectance of soils. *LARS lnformation Note.* West Lafayette- USA, Purdue University, 36 p.

MONTGOMERY,O. L BAUMGARDNER, M.F. and WEISMI- LLER, R. A. 1976. An investigation of the relationship between spectral reflectance and chemical, physical, and genetic characteristic of soils. *LAR lnfonnation Note.* West Lafayette- USA, Purdue University, 147 p.

OLIVEIRA, l. B. MENK. l. R. F., BARBIERI, J. L, ROTTA, C. L. and TREMOCLDI, W. 1982. *Levanamiento pedol6gico* semidetalhado do Estado de Sâo Paulo- Quadrícula de araras. Campinas-SP, IAC, 180p.

PAGE,N. R.1974. Estimation oforganic matter in Atlanticcoastal plain ooils with color-difference meter.Agronomy Jornal 66:652-653.

PARADELlA, W. R. 1984. Avaliaçâo de critérios de seleçao de atributos espectrais de imagens digitais MSS-Landsat em discriminçao litológica no baixo vale do río Curuça, BA. Sâo José dos Campos- SP, INPE-SCT. Bol. Tec. 3248-PRE/591. 28 p.

PRELAT, A. E. 1981. ISOMIX. An interactive clustering programo Stanford, Ca, Stanford Univ., 20 p.

RICHARDS, J. A. 1986. Remote Sensing digital image anaiysis: An introduction. Berlin, Springer-Verlag, 284 p.

STONER, E. R. and BAUMGARDNER, M. F. 1981. Charac- tersitic variation in reflectnce of surface. Soil Science Soc. 01 Am.!., 45:1161-1165.

STONER, E.R. BAUMGARDNER, M. F. BIEHI, L L and ROBINSON, B. F.1980. Atlas of soil reflectance-properties.Research Bulletin 962. West Lafayette-USA, Purdue University. 75 p.

SWAIN, P. H. and KING, R. G. 1973. Two effective featore selection criteria for multispectral remote sensing. West Lafayette- USA, LARS Information Note. Purdue University, 24 p