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Spectral Mapping of Soil Organic Matter

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by

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Abstract

Multispectral remote sensing data were examined for use in the mapping of soil organic matter content. Computer-implemented pattern recognition techniques were used to analyze data collected in May 1969 and May 1970 by an airborne multispectral scanner over a 40-km flightline. Two fields within the flightline were selected for intensive study. Approximately 400 surface soil samples from these fields were obtained for organic matter analysis. The analytical data were used as training sets for computer-implemented analysis of the spectral data.

It was found that within the geographical limitations included in this study, multispectral data and automatic data processing techniques could be used very effectively to delineate and map surface soils areas containing different levels of soil organic matter.

Introduction

Organic matter is one of the most important constituents of mineral soils in determining soil color. Under natural conditions

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the organic matter content of surface soils may range from less than one percent in severely eroded soils to more than fifteen percent in mineral soils where conditions favor an accumulation of organic matter. Many physical, chemical, and microbiological phenomena in soils change with an increase or decrease in organic matter, and the quantity of organic matter in cultivated soils influences to a great extent the kind of cultural practices applied. The quantity and quality of organic matter in soils also has an important bearing on the determination of soil type (10).

Through the years many methods have been used to determine or estimate the organic content of soils (1, 6). Recently studies have been made to relate various soil properties to the amount and kind of energy radiating from soils (2, 7, 8). Research results from numerous laboratories have shown striking differences in the spectral reflectance curves of different soils and geologic materials (4, 5, 9). Condit (3), studying soils reflectance with a laboratory spectrophotometer over the spectral range from 0.32 to 1.0 μm, found evidence that the spectral reflectance of a wide range of soils can be predicted with sufficient accuracy from measurements made at only five wavelengths.

Kristof (7) has demonstrated that multispectral data obtained with an airborne optical-mechanical scanner can be analyzed by computer-implemented pattern recognition techniques to identify and map surface soils having different spectral properties. Baumgardner et al. (2) have studied the correlation between multispectral reflectance and organic matter content of surface soils.

The objective of the research reported in this paper was to test the hypothesis that multispectral reflectance data can be analyzed by computer to delineate and map different levels of soil organic matter for different soil associations and types. It was further hypothesized that (1) the spectral properties of cultivated soils do not change significantly from one year to the next and that (2) soil sample training sets (ground measurements and observations) from a small area could be used for the analysis of spectral data from a much larger area.

Description of Test Areas

A north-south flightline extending 40 km in Tippecanoe County, Indiana, USA, was selected for this study. Two specific test fields 15 km apart were designated for detailed investigations: Soil Test Area 4 (STA 4), a 25-ha field located in the SE 1/4 Sec. 6, T21N, R3W; Soil Test Area 5 (STA 5), a 40-ha field located in the W 1/2 Sec. 30, T23N, R3W.

The soils of STA 4 were derived under native deciduous hardwood forest vegetation and have surface soil patterns typical of the Hapludalfs. Soils in this area are within the region of the Alfisols but include some wet Mollisols. These soils were developed in 45 to 90 cm of loess over glacial till. The topography is level to sloping.

Soil Test Area 5 is also within the Alfisol region but includes some wet Mollisols. The topography is nearly level. The soils in the southern half of STA 5 were developed in glacial till with less than 40 cm of loess at the surface, whereas the soils of the northern half were developed in deeper loess.

Procedures

Multispectral reflectance and photographic data were obtained over the designated flightline between the hours of 1100 and 1300 on 27 May 1969 at an altitude of approximately 1300 meters, and between the hours of 1400 and 1600 on 6 May 1970 at an altitude of approximately 1500 meters. The aircraft scanner missions were flown by the University of Michigan.

Following the data collection flight in May 1969, a sampling grid pattern was followed in obtaining 1-kg surface soil samples from STA 4. A total of 197 samples were taken at 32-m intervals to a maximum depth of 2 cm. An additional 80 surface soil samples were obtained from this area in May 1970.

For Soil Test Area 5 no sampling plan was initiated until May 1970, at which time 200 samples of surface soil were obtained to a maximum depth of 2 cm on a grid pattern of 46-m intervals.

Organic matter content was determined on all samples by the Walkley and Black (11) procedure. To study the correlation between organic matter content and spectral reflectance, it was necessary to obtain a quantitative spectral value in each wavelength band which was representative of the area from which each soil sample had been obtained. On a gray scale computer printout which depicted the reflectance value or response for a specific wavelength band, four resolution elements were selected to represent each soil sample location. A resolution element is the smallest area on the ground which is resolved by the optics of the scanner system. This area may also be referred to as the instantaneous field of view.

The average reflectance value of the four resolution elements for each surface sample in each of twelve wavelength bands was used to plot against the organic matter content.

Following this procedure, the samples were divided into the five categories established by Alexander (1) for estimating organic matter by soil color (Table 1).

TABLE 1.

Levels of soil organic matter content.

Average (%)	Range (%)
5.0	3.5-7.0
3.5	2.5-4.0
2.5	2.0-3.0
2.0	1.5-2.5
1.5	1.0-2.0

The computer was instructed to classify each of the data points from the test area. A pattern recognition technique, described in detail by other researchers (4, 8, 9), was used where the unknown data were compared to the known sample response signatures. Appropriate computer symbols were assigned to each organic matter category. Symbols on the computer printouts were colored to enhance the groupings.

To check the ability to duplicate these results from one year to another, scanner data obtained in 1970 were classified using training sets from the 1969 soil sample data. In a like manner 1970 soil sample data were used as training sets for the classification of 1969 scanner data.

Further, the training set of organic matter values from STA 4 was used in the classification of scanner data from STA 5. Likewise, the training set for STA 5 was used in the classification of scanner data from STA 4.

The validity of using localized training sets for classifying scanner data over a large area was tested further. The training set from STA 4 was used in the classification of all fields of soils without surface cover over the entire length of the 40-km flightline. A limited number of soil samples was obtained from randomly selected test fields in the flightline. Location of each sampling site was recorded on a computer-produced gray scale printout of each field. The organic matter content was determined for each of these samples. The computer-generated organic matter classification was examined to determine if the sites from which test samples had been obtained and analyzed were correctly classified.

Results and Discussion

The results of this study demonstrate that multispectral data can be used to produce computer maps which delineate boundaries between surface soils having different levels of organic matter content.

For STA 4 a comparison between an aerial panchromatic photograph, a soil map prepared by conventional soil survey techniques, and a computer printout delineating five different levels of organic matter reveals striking visual similarities (Figure 1). The computer printout (Figure 1c) was produced from multispectral data and sample training sets (ground observations) obtained in May 1969. The dark depressional soils, high in organic matter, are clearly definable in each print. These soils which have the lowest organic matter content occupy essentially the same portions of the three illustrations and correspond to the areas in the field with 8-10% slope where severe erosion has occurred.

STA 5 is different from STA 4 in two important features. It has no slopes greater than 2% and therefore has suffered no severe erosion. Second, the average organic matter content of STA 5 is somewhat higher than that of STA 4. A comparison between the aerial photograph, the soil map, and the computer printout for STA 5 shows similar visible results as seen for STA 4 (Figure 2). The computer printout for STA 5 was produced from multispectral data and sample training sets obtained in May 1970.

Data from STA 4 sample sets obtained in 1969 were used with 1970 scanner data to produce a computer-implemented map of organic matter for STA 4 (Figure 3). In cultivated soils under normal conditions the organic matter content would essentially remain constant from year to year. Although the surface conditions of STA 4 were somewhat different at the time of the 1969 and the 1970 flights, there appear to be no significant differences between the organic matter patterns produced from classifications of multispectral data as shown in Figures 1c and 3.

It is recognized that one of the limitations of this study is the relatively small geographical area examined. The utility of these techniques for delineating and mapping levels of soil organic matter content will depend ultimately on the extent to which results can be accurately extrapolated for large land areas. The use of 1969 training sample sets from STA 4 with 1969 multispectral data from STA 5 provides patterns (Figure 4) which compare favorably with the patterns produced when 1970 training sets and spectral data were used for analysis of STA 5 (Figure 2c). Equally good results were obtained when 1970 training sets from STA 5 were used with spectral data from STA 4 to produce an organic map of STA 4.

Finally, the use of 1970 training sets from STA 5 and 1970 spectral data of the entire 40-km flightline provided for each non-vegetated field a map delineating and displaying five levels of organic matter. Computer printouts of two fields located between STA 4 and STA 5 are presented as examples of this study (Figure 5). Although a number of test samples from randomly selected fields in the flightline were analyzed for organic matter content, there was not a sufficient number for adequate statistical treatment. However, an examination of the analytical data revealed that in the majority of cases a sample site anywhere in the 40-km flightline would fall in the correct organic matter class as delineated by computer from multispectral data.

Results from this and related experiments have proved to be valuable in planning soils studies under the Earth Resources Technology Satellite (ERTS) and Skylab experiments. Repetitive coverage by ERTS every 18 days has provided the opportunity to choose satellite-acquired data obtained at the optimum season for mapping or delineating soil patterns. Sets of training samples from one ERTS pass have been used in the analysis of data from an adjacent ERTS pass or from a pass over the same area at a later date.

Summary

Energy radiating from the soil surface was measured and analyzed by computer-aided techniques to produce maps showing soil organic matter content. Airborne multispectral scanner data were obtained over an area approximately 40 km by 1 1/2 km in May 1969 and 1970. Organic matter content was determined for approximately 400 surface soil samples taken on a grid pattern from two fields in the flightline. These ground observation data were used as training sets for computer-implemented analyses of the multispectral data resulting in the delineation and mapping by pattern recognition techniques of areas of soils consisting of different levels of organic matter. Data from training sets obtained in 1969 were used successfully to analyze multispectral data obtained in 1970. Furthermore training set data from one area of the flightline were used successfully to analyze multi-spectral data from another area of the flightline. These results are very important when planning experiments or operational mapping of soil patterns over land areas receiving repetitive coverage.

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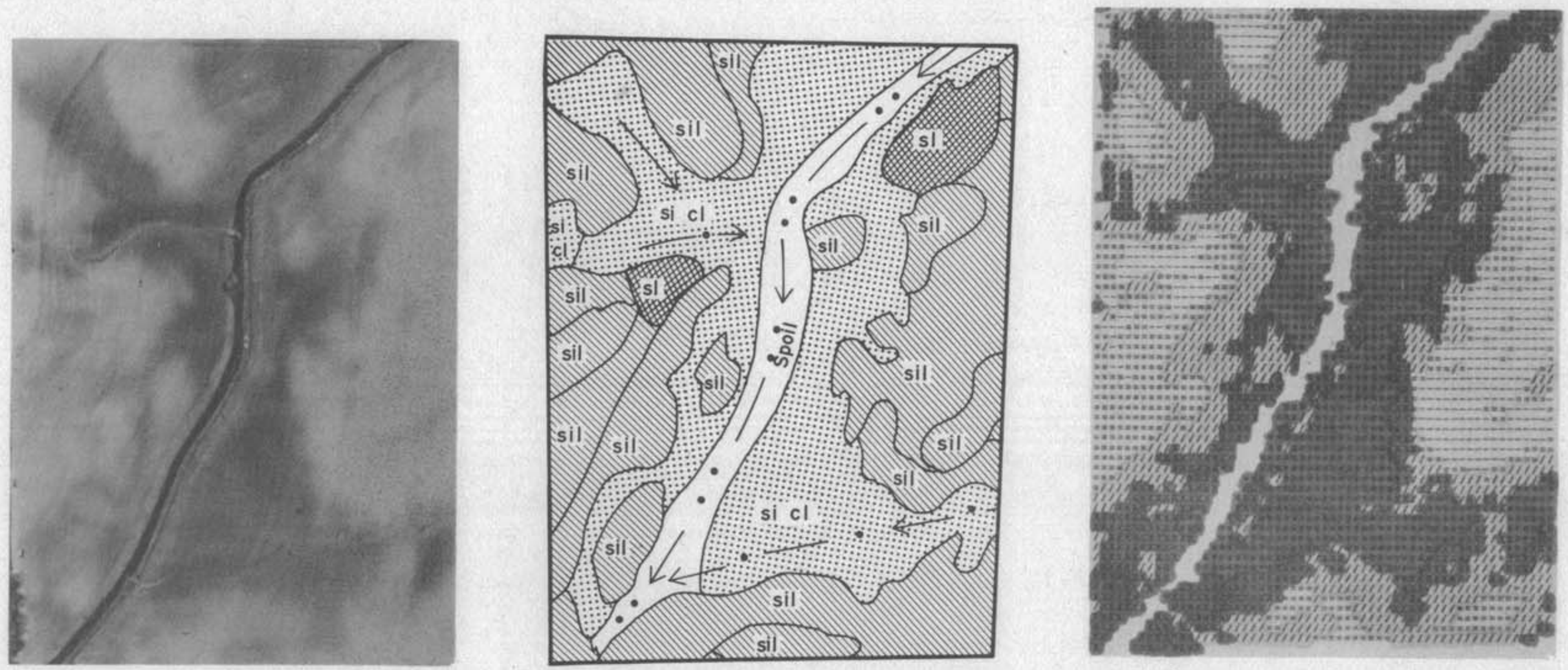

Figure 1. Aerial photograph (a), soil survey map (b), and black and white print of hand-colored computer printout (c) of STA 4 using 1969 data.

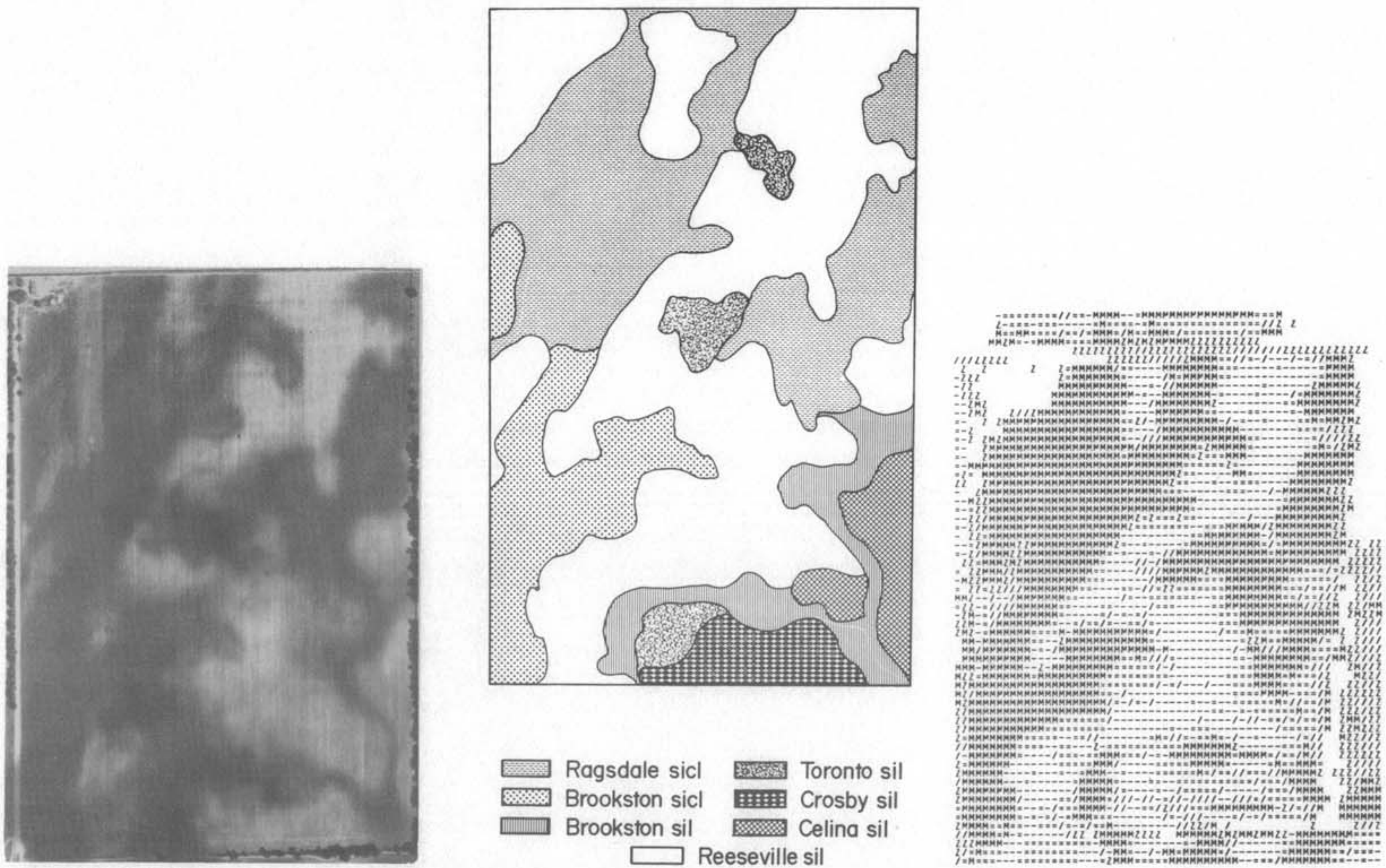

Figure 2. Aerial photograph (a), soil survey map (b), and computer printout (c) of STA 5 using 1970 data.

Figure 3. Computer-implemented map showing organic matter content of soils in STA 4; 1969 sample sets were used in the analysis of 1970 scanner data.

Figure 4. Computer-implemented map showing organic matter content of soils in STA 5; 1969 sample sets from STA 4 were used to analyze 1969 scanner data from STA 5.

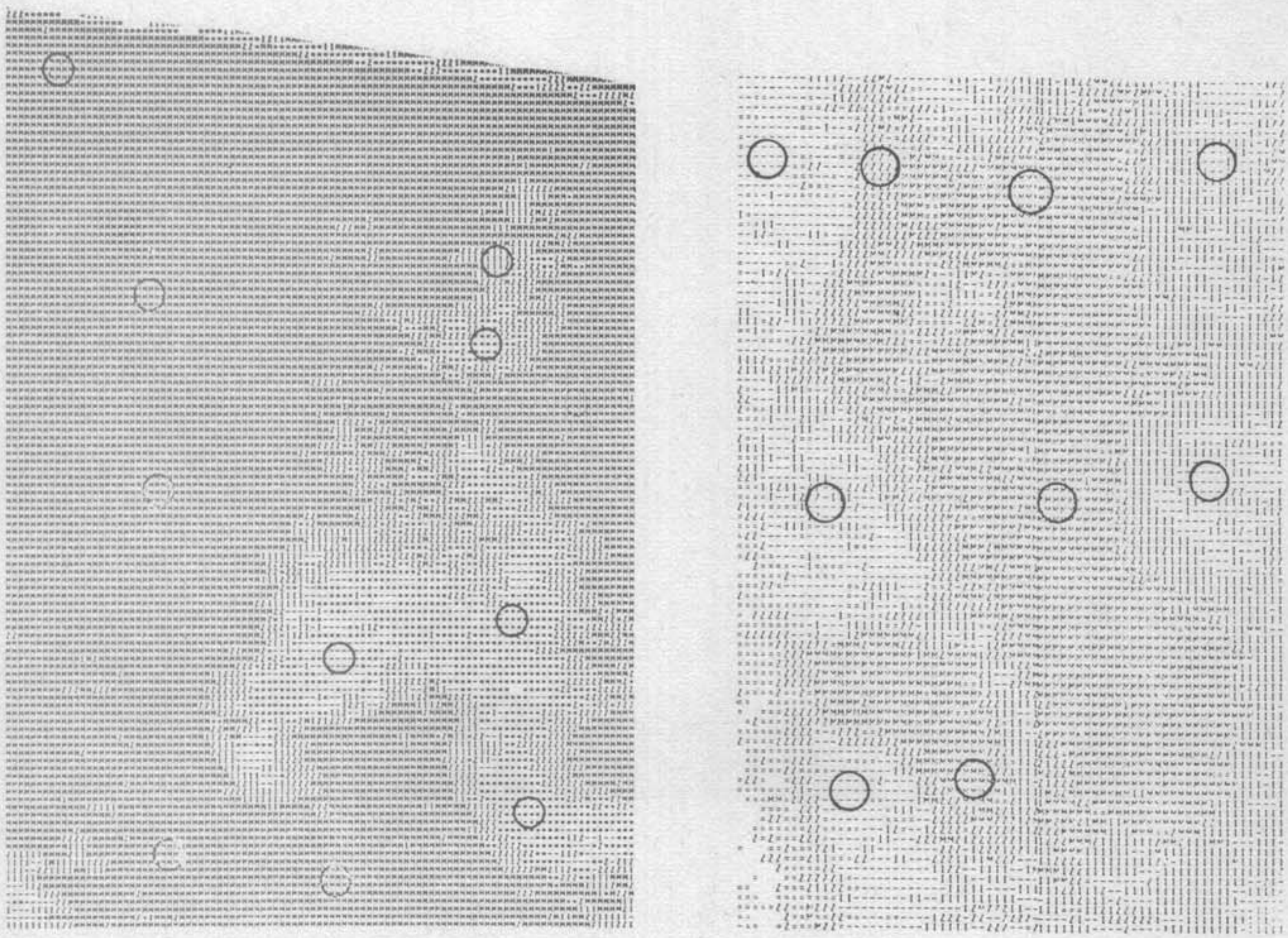

Figure 5. Computer printouts of organic matter content classifications for two fields located between STA 4 and STA 5. Circles indicate areas where soil samples were collected and analyzed for organic matter content; they serve as test areas for the classification.