Effects of Organic Matter on the Multispectral Properties of Soils[1]

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Abstract

The use of data obtained from an airborne optical-mehanical scanner in determining the organic matter content of surface soils is presented. Multispectral data covering the electromagnetic spectrum from 0.32 to 14 microns was recorded on magnetic tape in analog form. After conversion to digital form, the data were analyzed by computer to provide pictorial printouts of soils areas. The computer was trained to recognize the spectral responses of different levels of organic matter of surface soils and produce maps showing the locations of organic matter content. The computer maps were compared with results from approximately 200 surface soil samples analyzed for organic matter. These samples were collected in a 25-hectare field in the center of a flight line in Tippecanoe County, Indiana.

Introduction

For many years the soil scientist has been using a color designation as part of his description of the various horizons of the soil profile. The color designation commonly used in many countries in the world is the Munsell notation system (5).

From a certain color designation the soil scientist can make a number of inferences about other properties of the soil. He relates variability of the soil color to: 1) organic matter content, 2) the presence or absence of oxidized or reduced iron compounds, 3) the internal drainage characteristics of the soil, and even to a certain extent 4) the potential productivity of the soil.

Attempts have been made to quantify the soil color measurements and to relate these measurements quantitatively with other soil properties. Many of these attempts have met with little success because of the difficulties encountered in making quantitative color measurements. Variations of soil color are found when measuring undisturbed soil samples versus disturbed samples. Surface roughness and variations in soil moisture content also affect soil color (2).

During the past 4 years research has been conducted at the Laboratory for Applications of Remote Sensing (LARS) at Purdue University to develop techniques and instrumentation for measuring and characterizing earth surface features with remote sensing devices from aerospace platforms. The use of an airborne optical-mechanical scanner for obtaining earth resources data and the use of computer techniques for reducing the data have been described in numerous papers (2, 3, 6, 7).

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Kristof (4) and Baumgardner *et al.* (2) describe the use of these techniques in the automatic identification, separation, and mapping of soil categories based on the differences of spectral properties of the surface soils.

The initial results of a study of the effects of soil organic matter on the spectral properties of soils are reported in this paper. Data essential to this study were obtained with an airplane containing an optical-mechanical scanner flown by the University of Michigan. The data were analyzed by computer techniques at LARS.

Materials and Methods

General soils studies have been conducted on data obtained from flight lines flown in Tippecanoe County, Indiana, during May, 1969.

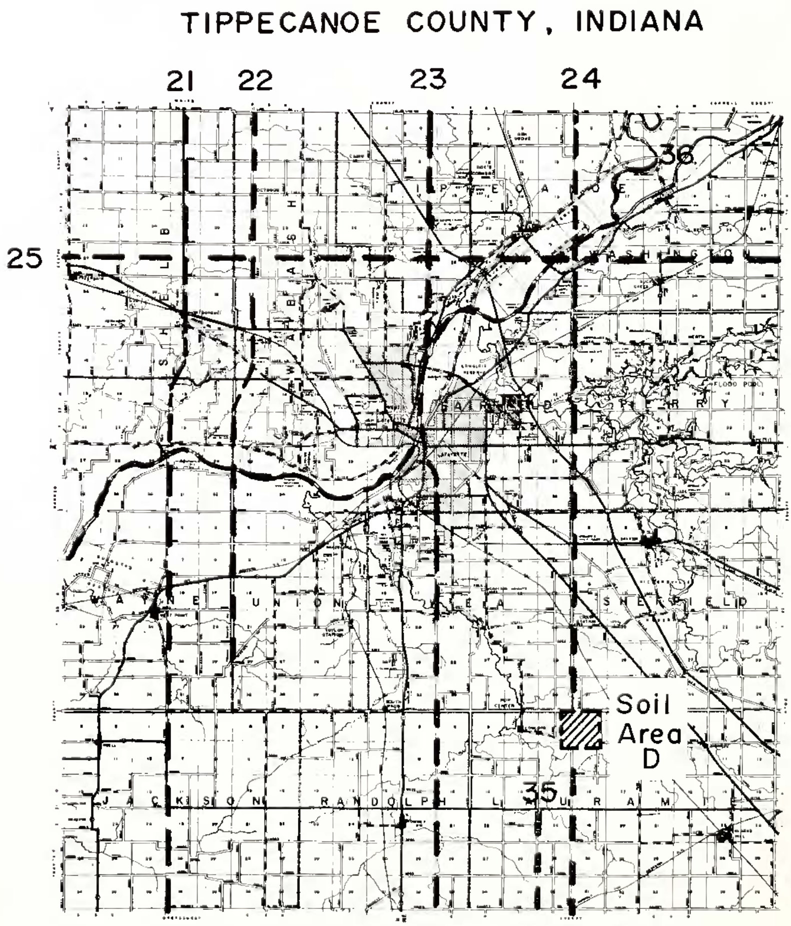

FIGURE 1. *Flightlines flown for scanner data collection and location of Soil Area D.*

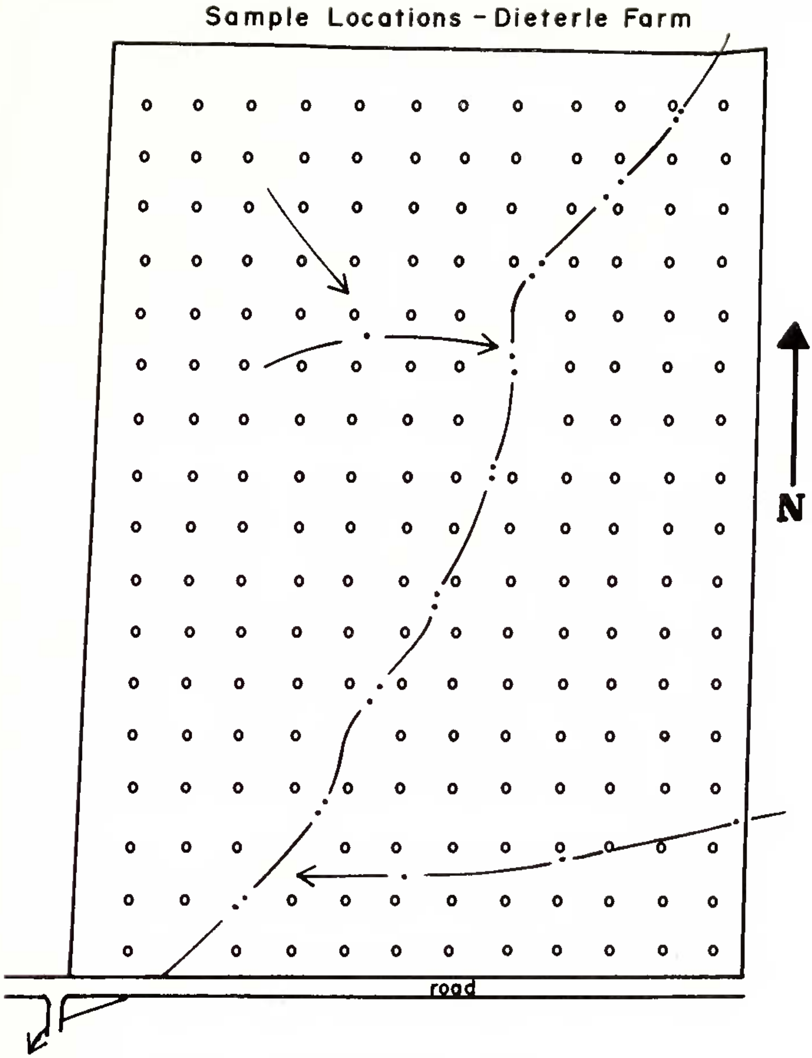

FIGURE 2. *Soil sampling locations on Test Site D.*

Tippecanoe County lies in a transitional zone between prairie and forest soils. In the northwestern part of the County, soils were formed under tall prairie grasses. Soils of the southeastern portion were formed under deciduous hardwood forest.

A 25-hectare field was selected for more intensive soil studies. This field, shown as test site D in Figure 1, is located in the native forest vegetation area and has surface soil patterns typical of the Hapludalfs (gray-brown podzols). The field is a portion of the SE¼, Sec. 6, T21N, R3W, Tippecanoe County, Indiana.

Scanner and photographic data were obtained on the flight lines shown in Figure 1 on May 26, 1969, between 1100 and 1300 hours. Ground truth data showed that test site D had been plowed and disked in preparation for planting corn and soybeans. Since there was no surface vegetative cover, the soil patterns were clearly defined and easily discernible by visual means.

Within a few days after the scanner flight, a sampling grid plan was drawn (Fig. 2) and 1-kg surface soil samples were obtained at 32m intervals. A total of 197 samples was taken from the surface to a maximum depth of 2 cm.

One of the objectives of this research was to study the relationship between the organic matter content of surface soils and the spectral response patterns in the spectral range from 0.40μ to 2.6μ. Accordingly, organic matter determinations were made on each of the 197 samples by the Walkley and Black method (8).

It was theorized that if the correlation between these two variables was good, then the scanner data could be used in the rapid preparation of computer printouts or maps of fields showing different levels of organic matter content in the surface soils.

The scanner data used in this study was obtained at an altitude of approximately 1300 m (4000 feet). The scanner data were digitized at an interval such that each sampling point on one scan line would represent the average energy of a specific area on the ground. At the altitude of 1300 m, each sampling point or resolution element represented approximately 16 to 24 m^2 (150 to 200 ft^2).

To study the correlation between organic matter content and spectral response, it was necessary to obtain a quantitative spectral value in each wavelength channel which was representative of the area from

TABLE 1. *Wavelength ranges in 12 channels of the University of Michigan optical-mechanical scanner.*

Channel Number	Wave length Range (microns)
1	0.40-0.44
2	0.46-0.48
3	0.52-0.55
4	0.55-0.58
5	0.58-0.62
6	0.62-0.66
7	0.66-0.72
8	0.72-0.80
9	0.80-1.00
10	1.00-1.40
11	1.50-1.80
12	2.00-2.60

which each surface sample of soil was obtained. On a gray-scale computer printout of the entire field, four resolution elements were selected to represent each soil sample location. The average radiance values of the 4 resolution elements for each surface sample in each of 12 wavelength channels were used to plot against the organic matter content. Table 1 shows the wavelength frequencies measured in each of the 12 channels used in this study.

Alexander (1) developed a color chart for estimating organic matter in mineral soils in Illinois. Correlations were made of soil colors (Munsell notations) with laboratory analyses for organic matter determined from a large number of Illinois soils.

Table 2 indicates the five levels of organic matter which Alexander uses in his color chart. Soils of the test site, which were used for analysis with the multispectral scanner data, contained similar amounts of organic matter.

TABLE 2. *Levels of soil organic matter content determined in Illinois (1).*

Average (%)	Range (%)
5	3.5-7.0
3.5	2.5-4.0
2.5	2.0-3.0
2	1.5-2.5
1.5	1.0-2.0

In this study the desired task was to obtain a computer printout (or map) of the test site showing the locations of soils having five levels of organic matter similar to the Illinois study (1). The organic matter content and corresponding spectral responses of 12 wavelength bands for each soil sample location were used to train the computer. The samples were divided into five levels of organic matter content (Table 3). The computer classified each resolution element of each scan line in the test site using a pattern recognition technique which used the data provided by the training samples. Less than ¼ of the area in the test site was used to train the computer.

TABLE 3. *Number of samples in each of five levels of soil organic matter used for training the computer.*

Percent Organic Matter	Number of Samples
>3.5	46
2.5-3.5	37
2.0-2.5	18
1.5-2.0	63
0-1.5	46

Results and Discussion

To provide a laboratory model of the soil patterns on the test site area a soil mosaic was constructed with the use of portions of each of the 197 surface soil samples. Figure 3 contains a photograph of this mosaic and provides a good general representation of the soils pattern

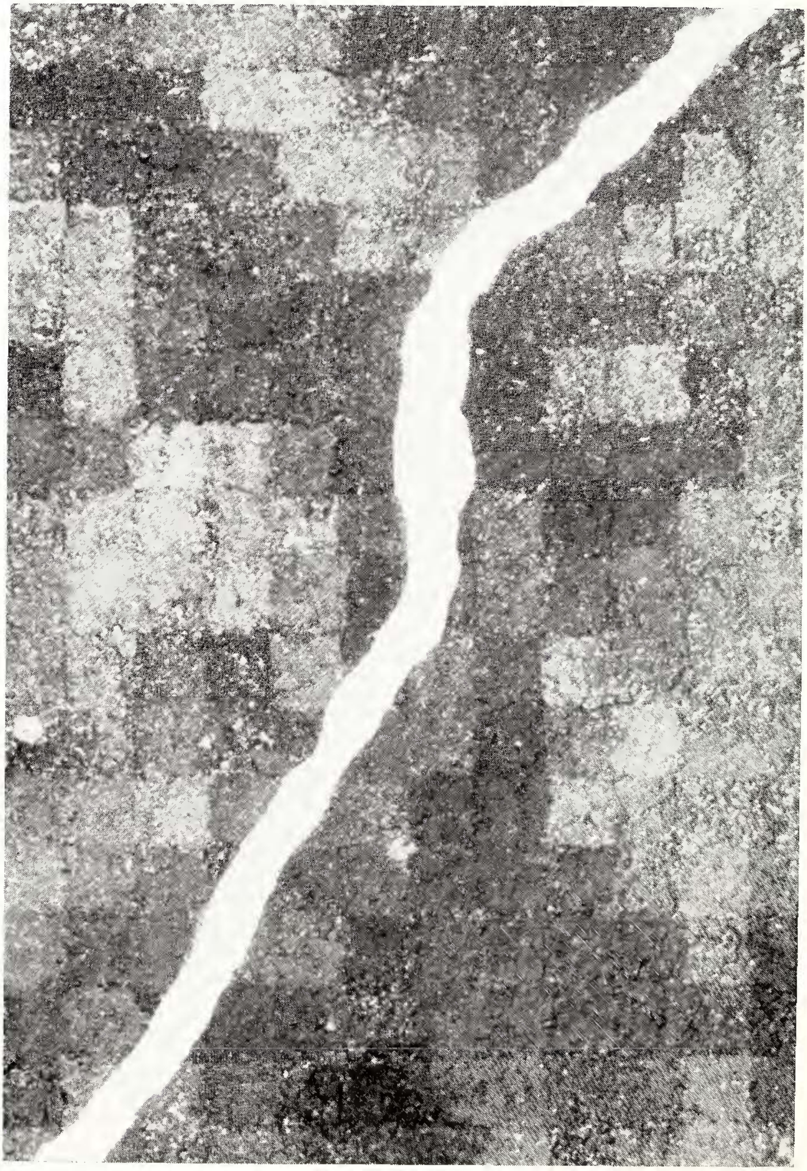

FIGURE 3. *General soil patterns of Test Site D.*

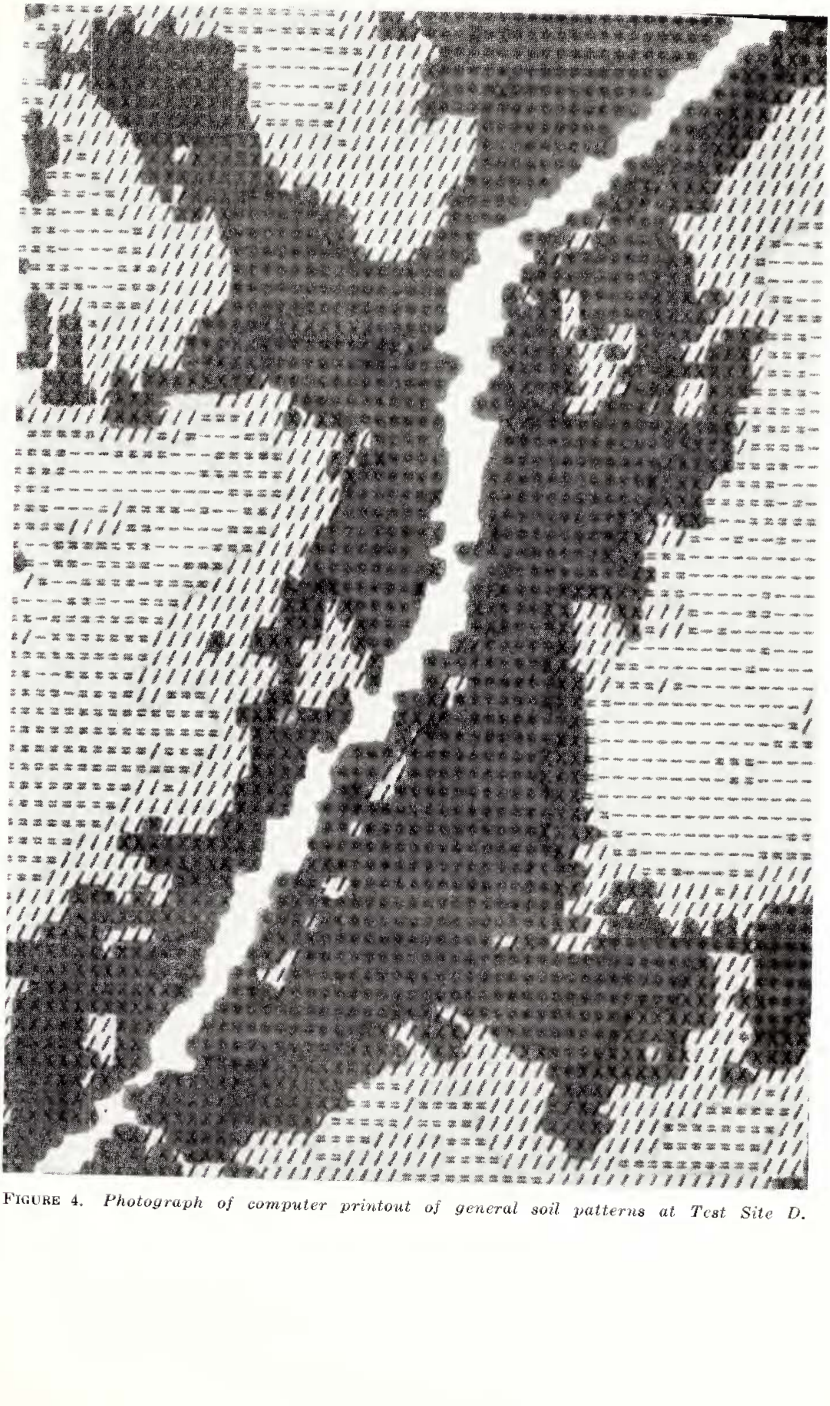

FIGURE 4. *Photograph of computer printout of general soil patterns at Test Site D.*

of the field. A photograph of a computer printout (Fig. 4b) showing five different levels of organic matter in the field is shown for comparison with the soil mosaic. This organic matter map compares very well with the color patterns observed in the soil mosaic. The depressional soils which have the greatest amount of organic matter lie near the broad drainage ditch. In the lower right hand area of the illustration a high organic matter content is also indicated. This is a slight depression and natural drainageway.

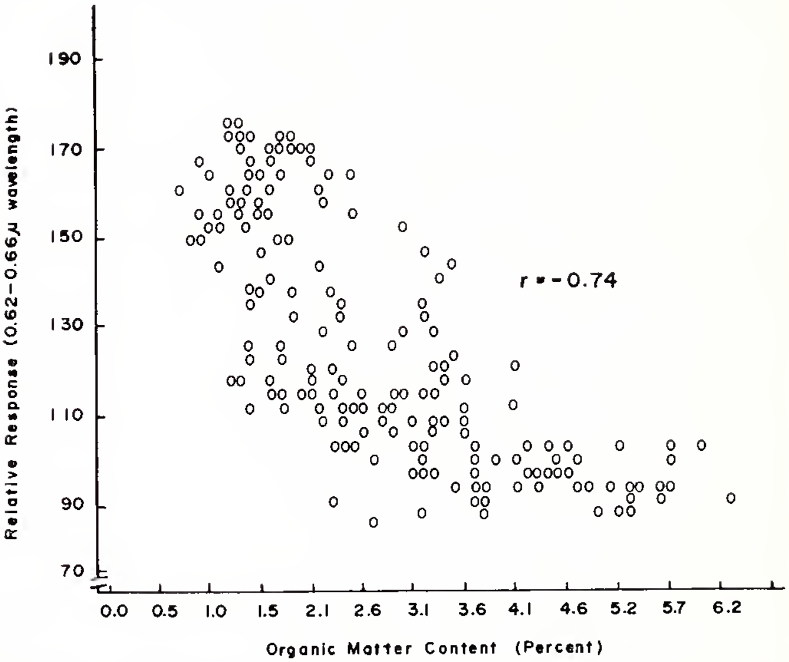

FIGURE 5. *Correlation between average radiance level (relative response) and organic matter content for 197 samples from Test Site D.*

The test site contains undulating land. The lighter areas to the left and right of the center of the illustration represent sloping topography. In some cases, these slopes are as much as 3 to 4 m higher in elevation than the high organic matter soils along the drainageways. It was observed that with more detailed examination of the organic matter classes, severely eroded and moderately eroded spots in the field could be identified on the computer printouts. In these instances, erosion has been sufficiently severe that subsoil was exposed.

Average radiance levels of the 12 wavelength channels were plotted against soil organic matter content of each sample location. Most of the plottings or correlations were quite similar. Figure 5 presents data for channel 6 (0.62-0.66μ). Linear regression analysis gave an r value of —0.74. However, the plotted data seem to indicate that perhaps a linear relationship may not be valid over the range of organic matter used. It appears that above 2.0 or 2.5% organic matter, there may be a linear correlation with a much higher r value. Below 2.0% organic matter, the curve becomes much steeper.

It appears that organic matter plays a dominant role in bestowing spectral properties upon soils when the organic matter content exceeds 2.0%. As the organic matter drops below 2% it becomes less effective in masking out the effects of other soil constitutents such as iron or manganese on spectral response of soils.

Training samples which are used for the test site were also used for obtaining a 5-level organic matter map of the entire north-south flight line across Tippecanoe County. The area covered was approximately 24 miles long and 1 mile wide. The results look very promising. More research is necessary, however, to check the accuracy of the results and to determine the proper methods for determining organic matter levels with the use of the computer. Size of the training samples is also being evaluated.

Summary and Conclusions

Results of this research have well established the feasibility of using multispectral scanner data and computer analysis to prepare maps which outline surface soils with varying levels of organic matter. Surface soil samples were obtained from a test site area and organic matter content was determined. Linear regression of organic matter content and wavelength response gave a r value of —0.74.

More research is needed to define more precisely the effects of and interactions between organic matter, iron, and aluminum compounds, surface roughness, and moisture as these factors affect the spectral properties of soils.

An operational capability to map five or more levels of soil organic matter in a rapid manner would provide a very useful tool to the soil surveyor, the urban and regional planner, the agricultural chemical industry, the drainage engineer, the farm manager, and many others.

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