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ANALYSIS OF REMOTELY SENSED DATA FOR DETECTING SOIL LIMITATIONS[1]

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ABSTRACT

During 1971 and 1972 a detailed study was conducted on a fallow field in the proposed Oahe Irrigation Project to determine the relationship between the tonal variation observed on aerial photographs and the properties of eroded soil. Correlation and regression analysis of digitized, multiemulsion, color infrared film (2443) data and detailed field data revealed a highly significant correlation between film transmittance and several soil properties indicative of the erosion limitation. Computer classification of the multiemulsion film data resulted in maps portraying the eroded soil and the normal soil. Both correlation and computer classification results were best using the reflectance data from the red spectral band. The results showed film transmittance was actually measuring the reflectivity of the soil surface which was increased by the incorporation of the light colored, calcareous parent material exposed by erosion or tillage on soils with thin surface horizons.

INTRODUCTION

Research has been conducted in north central South Dakota to identify the soil limitations in the proposed Oahe Irrigation project area and to develop a method for detecting and mapping them with remote sensing techniques (Benson and Frazee, 1973; Frazee, Heil, and Westin, 1971). The erosion limitation was selected as the subject for a detailed study utilizing machine processing of remotely sensed data. The objectives of the study were:

1. To determine the relationship between the soil properties of eroded soils and the tonal variations observed on photographic film.

2. To determine which band or bands of the photo sensitive spectrum provide the best information for detecting eroded soils.

3. To develop a procedure for the analysis of field data and remotely sensed data that utilizes the analysis and enhancement systems available at the Remote Sensing Institute.

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METHODS

Field data and aerial photography were collected. The field data included soil profile and topographic information obtained by a grid sampling method from a 14 hectare (35 acres) fallow field. The field contained both eroded and non-eroded soils of the Beotia, Great Bend and Zell soil series (Westin, 1970). Soil property data included depth, color, and reaction of the genetic horizons; and organic matter content, reflectivity, and Munsell value (dry) of the surface soil. Slope, position, elevation, and aspect of the sampling site were also recorded.

Aerial photographic data consisted of 70 mm imagery from four Hasselblad cameras exposed at midday on May 14, 1971, from 2440 meters (8000 feet) AGL. The film/filter combinations included black and white (B/W) Plus-X (2402) with green filter (58), B/W Plus-X (2402) with a red filter (25A), B/W infrared film (2424) with an infrared filter (89B), and color infrared film (2443) with yellow and magenta filters (G15/30M).

The first steps in the data analysis were coding and ranking the field data and masking the portions of the frames to be digitized. Each successive film was electronically registered to the previous film and the light level was optimized for the density range of the film prior to digitization. Digitization was accomplished with the Signal Analysis and Dissemination Equipment (SADE) at the Remote Sensing Institute (Figure 3).

The high resolution image dissector of SADE has the capability of dividing the density range of the film into 256 levels at a resolution of 36 lines per millimeter. When on line with the computer the output codes (0-255) from the digitizer are recorded on a tape drive for subsequent retrieval and analysis. SADE also has a color television monitor that displays eight levels of digital data.

Filters were used to separate the spectral bands of the multispectral data recorded on the multiemulsion color infrared film. Trials were run to determine the optimum digitization rate and resolution. In all, seven separate sets of film data were obtained from the three black and white films and the filtered color infrared film.

The next step involved a study of the optimum sample size or matrix size for the film data for subsequent correlation with the field data. Matrix sizes from 3 x 3 to 15 x 15 output codes corresponding to 4 x 4 to 20 x 20 meter (15 x 15 to 75 x 75 feet) squares on the ground were correlated with soil profile data. The matrix data were obtained by initially generating a computer printout and plotting the location of the field data points on it. The coordinates of the points were then determined and a program that would generate matrices around that point was written.

Independent linear correlation and regression was the next analysis method employed. All eleven soil property variables and the seven film variables were correlated using a standard computer program that provided means, standard deviations, correlation coefficients, and regression intercepts.

Multiple linear correlation and regression were conducted on the data to determine if a combination of film variables would improve the relationship. The film variables were considered the independent variables and were used to predict the soil properties of organic matter content, surface reflectivity, Munsell value (dry) and depth of carbonates. The analysis was conducted in two parts using the three black-and-white films for one trial and the four measurements from the color infrared film for the second. The stepwise multiple regression program selected the film variable with the highest correlation coefficient and successively added variables that provided the greatest reduction in the residual sum of squares.

In addition to correlation and regression, pattern recognition techniques were employed to group and classify the data. The pattern recognition technique used included a program utilizing a K-class classifier (Serreyn and Nelson, 1973). Prior to training the classifier, the K-class program required the selection of sample areas for each class to be classified. An indication of the accuracy of the classifier for all 15 feature combinations for the sample areas was provided prior to classifying the entire field. The display from computer classification was compared to a display produced by density slicing to determine if the more efficient density slicing technique could be used for the extrapolation of results.

RESULTS

The results of offline experimentation indicated that the slowest rate and the maximum resolution of digitization provided the best combination of sensitivity and flexibility for the analyses to follow. The digital film data from the unfiltered color infrared film had the greatest range of output codes, and the same film with the addition of a red filter had the lowest range. The digital film data approximated a normal distribution.

The study of the effect of sample or matrix size resulted in the calculation of the means for various sized samples of the unfiltered color infrared film data. Comparison of means for sample sizes ranging from 3 x 3 to 15 x 15 output codes indicated sample size had no significant effect (Table 1). A 5 x 5 sample size was selected for further analysis since it corresponded to a 7.5 x 7.5 meter (25 x 25 feet) square on the ground which approximated the plotting and measuring accuracy.

Independent linear correlation and regression of the soil property variables with the seven film variables provided an insight into the relationship between the physical properties of the soil and photographic tone. Surface reflectivity, organic matter content, Munsell value, and depth to CO_3 were significantly correlated with all seven film variables (Table 2). The correlation coefficients were highest for the color infrared film that was filtered with a green filter to measure the red sensitive layer of the multiemulsion film; however, there was no significant difference between the correlation coefficients of the seven film variables due to the small sample size. Interpretation of the linear regression results for the green-filtered digital data from the color infrared film indicated that as film transmittance increased (lighter tones) there was a corresponding increase in reflectivity and Munsell value and a decrease in organic matter content and depth to CO_3 (Figure 1).

Multiple correlation and regression analysis failed to materially improve the definition of the relationship between the soil and the film (Table 3). The analysis was conducted separately for the four color infrared variables and the three black and white film variables. The four soil property variables having the highest correlation coefficients from independent linear correlation (surface reflectivity, Munsell value, organic matter content, and depth to carbonates) were selected for analysis. The residual sum of squares was not significantly reduced by the addition of more independent variables due to the significant correlation between film variables.

Computer classification of the digital output codes was conducted using a K-class classifier. The K-class program was run on the sample of the two classes in the field using the multiemulsion data from the color infrared film (2443). The sample areas were classified using all 15 combinations of the four features (NRGB). The results revealed the classifier was capable of correctly classifying 90% or more of the data points in the training samples using any one of the features and was 98% correct when all four features were used. Subsequent classification of the field using all four features resulted in a map portraying the field as 13% eroded (Figure 2). A comparison of the soil property means for the two classes revealed a highly significant difference with the exception of elevation (Table 4).

Computer classification of the field was also conducted using the digital data from the black and white film exposed through a green filter (2402-58). Comparison of the outputs from the single feature classification and the four feature classification revealed that both methods classified the 55 data points in the same manner, although a larger percent of the field was classified as eroded using the black and white film. The results indicated that the single feature analysis was adequate for the discrimination of eroded from noneroded soils.

Because computer classification was successful for single feature analysis, density slicing was conducted on the unfiltered color infrared film. The Spatial Data density slicing device is a very flexible machine, and the controls can be adjusted by the operator to produce a wide range of results (Frazee, Myers, and Westin, 1972). To insure consistent results the device must be operated in accordance with standard procedures. Initially, the Spatial Data machine was adjusted to display a two color representation of the field that had the same composition as determined by K-class. The resulting display or map was essentially the same as that from K-class. Secondly, the machine was operated as an enhancement device by an experienced soil scientist who was familiar with the soils and their relationships to the photography. Finally the machine was operated as a measuring device with a minimum of adjustment by the operator. A comparison of the results from the three methods revealed three different compositions were obtained, but all three delineated essentially the same area (Figure 2).

CONCLUSIONS

The results indicated the tonal variation evident on photographs of the field was related to several soil properties characteristic of the erosion limitation. The presence of the erosion limitation resulted in lighter tones on the photography due to the increased reflectivity of the surface soil. The increased reflectivity was primarily due to the lighter color and decreased organic matter content of the surface soils where erosion had exposed the calcareous parent material. The film data from the red spectral band correlated highest with the soil property data.

The analysis approach employed is applicable to a wide range of remote sensing problems. Correlation and regression provide a physical explanation of the spectral relationship, and pattern recognition and/or density slicing permit subsequent extrapolation and rapid map compilation. The density slicing technique was satisfactory for mapping eroded areas in a fallow field although some variation was encountered depending on the procedure used. Problems requiring several features (multispectral) may not find the density slicing technique applicable.

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Table 1. Mean Output Codes for Seven Matrix Sizes

3X3	5X5	7X7	9X9	11X11	13X13	15X15
104.7	105.4	105.7	105.4	105.0	104.4	103.7

Table 2. Independent Linear Correlation Coefficients

Soil Property	EK-IR				B/W		
	N	R	G	B	58	25A	89B
Refl.+	.804**	.742**	.804**	.795**	-.660**	-.655**	-.666**
Organic Matter	-.712**	-.659**	-.729**	-.705**	.623**	.594**	.610**
Munsell Value	.689**	.629**	.699**	.682**	-.600**	-.580**	-.594**
Depth to CO_3	-.589**	-.568**	-.605**	-.587**	.516**	.476**	.483**
Slope (%)	.501**	.395**	.521**	.481**	-.478**	-.478**	-.471**
Depth of A	-.363**	-.394**	-.402**	-.377**	.331*	.235	.206
Elev-ation	.225	.172	.201	.183	-.063	-.335*	-.191

* Significant at .05 level with 54 d.f. (>.246).
** Significant at .01 level with 54 d.f. (>.342).
\+ Reflectivity at .58 μm.

Table 3. Multiple Correlation Coefficients*

Soil Property	EK-IR				B/W		
Refl.+	N .801	N+R .807	N+R+G .824	N+R+G+B .830	89B .668	89B+58 .690	89B+58+25A .691
Organic Matter	G .721	G+B .741	B+B+N .751	G+B+N+R .759	58 .631	58+89B .644	58+89B+25A .644
Munsell Value	G .691	G+R .714	G+R+N .722	G+R+N+B .737	58 .603	58+89B .622	58+89B+25A .623
Depth to CO_3	G .594	G+B .611	G+B+N .620	G+B+N+R .621	58 .506	58+89B .515	58+89B+25A .516

* All coefficients are significant at the .01 level with 54 d.f.
\+ Reflectivity at .58 μm.

Table 4. Relative Significance of Classification to Ground Truth Variables Using Four Features (NRGB)

Soil Property	Class 1 & 2		Class 1		Class 2		F
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	
Refl.+	.081	.018	.069	.010	.098	.012	92.3**
Value	4.24	.84	3.67	.54	5.0	.52	82.5**
Organic Matter	1.96	.42	2.21	.33	1.61	.26	54.6**
Depth to CO_3	10.2	11.7	17.3	10.7	.6	2.0	54.3**
Slope	1.8	.9	1.4	.6	2.5	.8	30.5**
Depth of A	11.9	6.4	14.2	6.5	8.8	5.1	11.0**
Elevation	1288.2	4.9	1287.3	5.7	1289.3	3.5	2.2ns

** Significant at the .01 level with 1 and 52 d.f. (>7.22)
* Significant at the .05 level with 1 and 52 d.f. (>4.05)
ns Nonsignificant at the .05 level.
\+ Reflectivity at .58 μm.

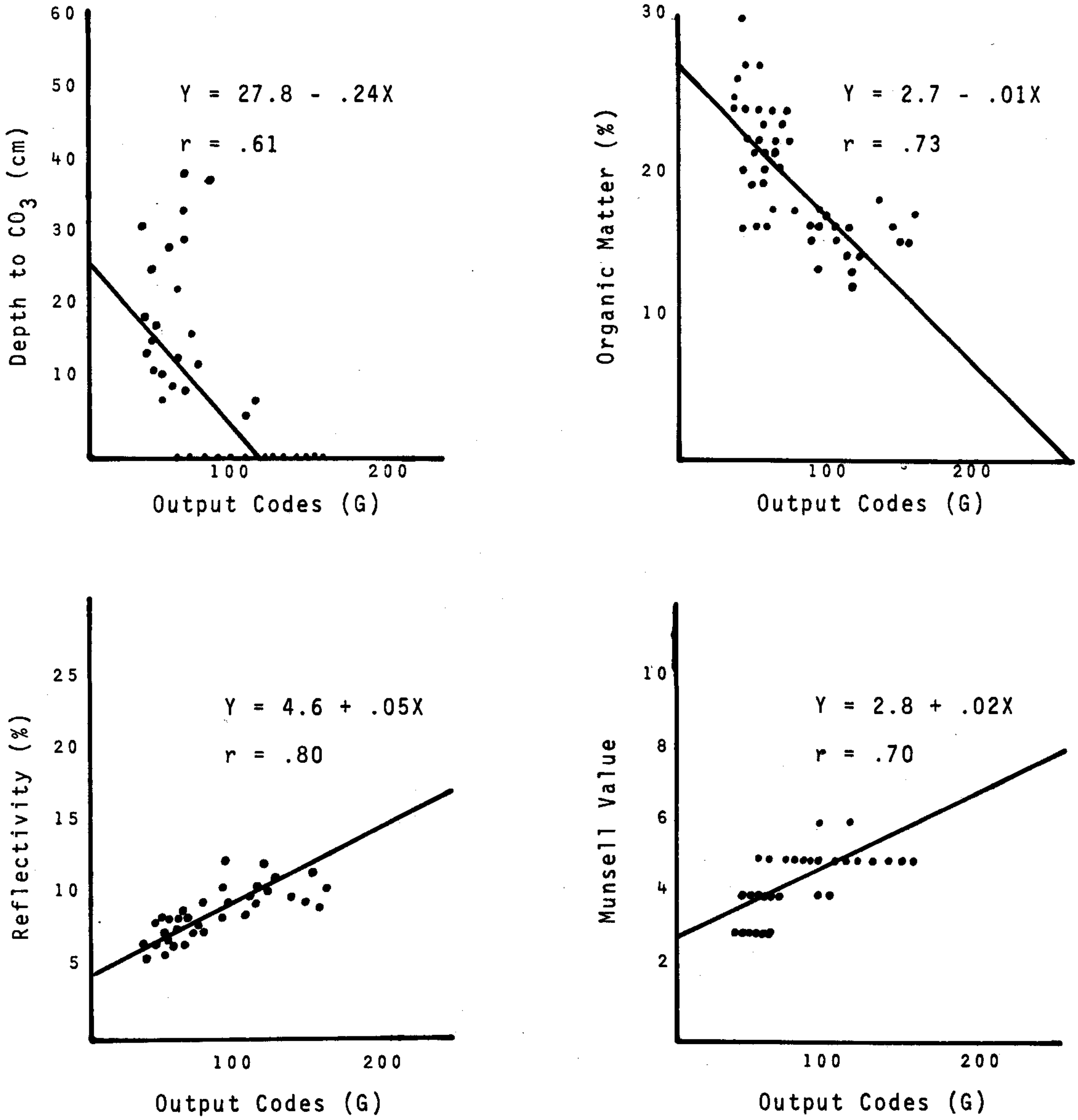
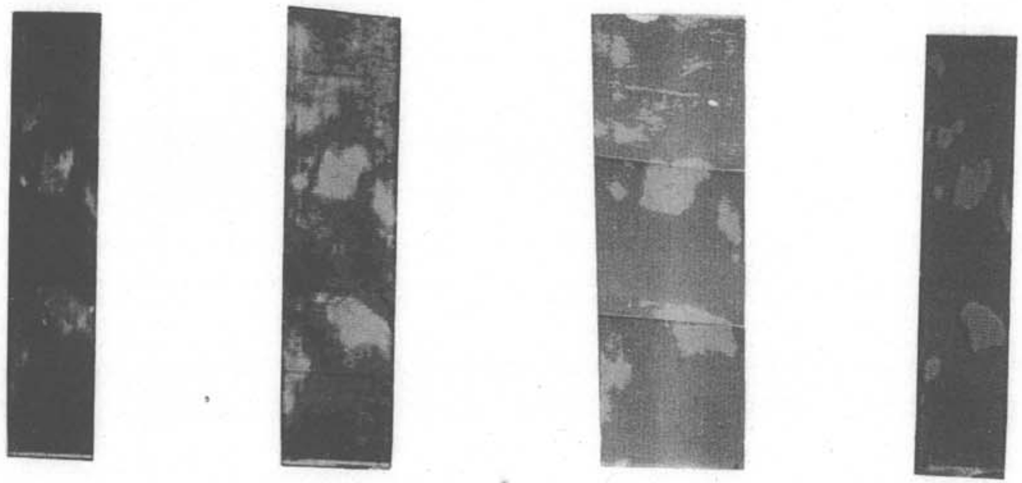
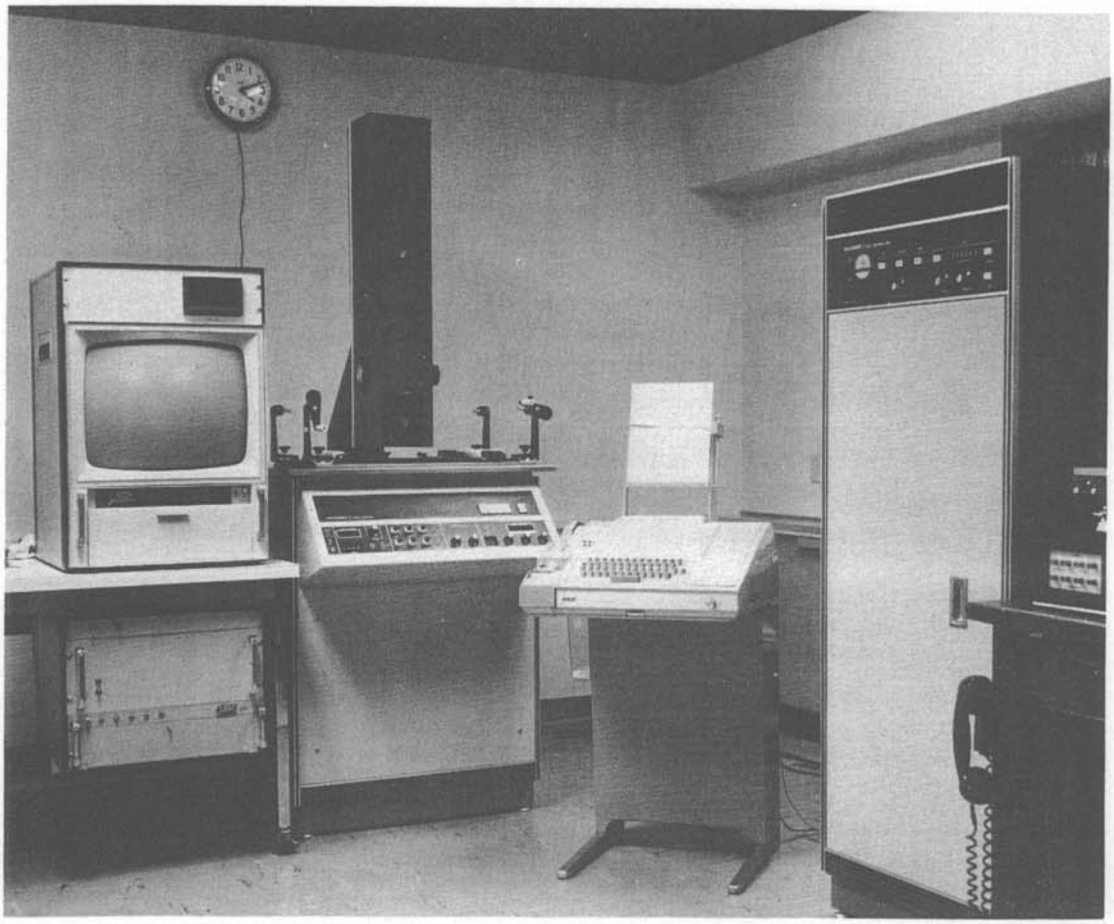


Figure 1. Linear correlation/regression results for color infrared film digitized with a green filter.



Original (2443-G15/30M) | SADE (8-levels) | K-class (13% Eroded) | Spatial Data

Figure 2. Outputs from steps in analysis procedure.



SADE was designed as a state of the art data analysis system with a highly flexible modular design. In the independent off-line mode the system provides monitor display of digital film or analog tape data and transmission of analog information to the film printer. When on line with the computer the system provides transmission of digitized image data and analog tape data to the computer and transmission of data stored or transformed in the computer back to the display monitor or the film printer. The system is composed of the following components:

1. Image digitizer (image dissector tube)
2. Data control and conversion unit
3. Lockheed 417 seven track analog tape recorder
4. Daedalus film printer
5. Band pass filters
   - Red - .59-.70 μm
   - Green - .47-.62 μm
   - Blue - .36-.50 μm

Figure 3. Signal Analysis and Dissemination Equipment (SADE).