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COMPARING SOIL BOUNDARIES DELINEATED BY DIGITAL ANALYSIS OF MULTISPECTRAL SCANNER DATA FROM HIGH AND LOW SPATIAL RESOLUTION SYSTEMS

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ABSTRACT

Aircraft and Landsat data were used with computer-aided techniques to delineate soils patterns of a field of 40 ha in a transition zone between soils developed under deciduous forest and those developed under prairie vegetation. Two computer-aided classification techniques, supervised and nonsupervised, were employed in classifying soils of the study area. The means and covariance matrix statistics were obtained for every cluster or soil class through the statistics algorithm. Each cluster of aircraft and Landsat data was identified and assigned to a specific soil type by correlating the cluster soil patterns with a standard soils map of the test site which was prepared as a part of the ground observation task. A sampling grid plan was used to select a training set for a supervised classification of the aircraft MSS data. The spectral soil patterns revealed in the classifications from aircraft and satellite MSS data resembled the general patterns of the soils of the conventionally prepared soil map. The spatial resolution of the aircraft scanner was adequate to recognize each soil type boundary in the test site. However, the limited spatial resolution of the satellite scanner made it difficult to delineate those soil features with widths less than the spatial resolution of the scanner. On the contrary those soil patterns which were broad enough to exceed the spatial resolution of the Landsat scanner were delineated very well.

I. INTRODUCTION

Previous experience in remote multispectral sensing soil studies indicates that the delineation of soil boundaries could have limited application. Stoner and Horvath demonstrated how cultural practices such as plowing and discing may affect the multispectral response of surface soils.[4] Kristof and Zachary also showed some limitation in a field being mapped by multispectral pattern recognition techniques.[2] Westin and Frazee delineated most of the soil association boundaries very well on Landsat imagery using color composite transparencies at the scale of 1:1,000,000, but areas such as floodplains which were too small were mapped using 1:250,000 enlargement prints.[5]

The general objective of this investigation was to evaluate and compare the use of computer-implemented analysis of multispectral data from aircraft and Landsat scanners to delineate soils patterns of one test area in Tippecanoe County in Indiana.

II. STUDY AREA

A test area of 40 ha was selected in Tippecanoe County, Indiana, in a transition zone between soils developed under deciduous hardwood forests and those developed under prairie grasses. The soils are within the region of the Alfisols but include some wet Mollisols. The soils in the southern half were developed in glacial till with less than 40 cm of silt at the surface; whereas the soils of the northern half were developed in deeper silts. The topography is level to sloping. The following soils are included in the test area:

Reesville silt loam	Aeric Ochraqualf
Celina silt loam	Aquic Hapludalf
Crosby silt loam	Aeric Ochraqualf
Brookston silt loam	Typic Argiaquoll
Brookston silty clay loam	Typic Argiaquoll
Ragsdale silty clay loam	Typic Argiaquoll
Toronto silt loam	Udollic Ochraqualf

III. PROCEDURES

Multispectral aircraft data were collected on May 6, 1970 by an airborne scanning spectrometer mounted in the University of Michigan aircraft at an altitude of 915 m (spatial resolution $43 m^2$ or 0.0043 LANDSAT-2 data (spatial resolution of $4500 m^2$ or 0.45 ha) were obtained on April 6, 1975 at an altitude of 915 km.

A standard soils map was prepared as a part of the ground observation task. A sampling grid plan was used to select a training set for a supervised classification of the aircraft MSS data. Ten wavelength bands were used in the computer analysis of aircraft data. These were 0.40-0.44, 0.46-0.48, 0.50-0.52, 0.52-0.55, 0.55-0.58, 0.58-0.62, 0.62-0.66, 0.66-0.72, 0.72-0.80, and 0.80-1.00 micrometers. Four wavelength bands were used in the analysis of Landsat-2 data. These were 0.50-0.60, 0.60-0.70, 0.70-0.80 and 0.80-1.10 micrometers.

Two methods of computer-aided analysis techniques were used, i.e., supervised and nonsupervised. The supervised was employed for the aircraft data only. The reference samples were selected on the basis of a conventional soil survey map (Figure 1 and 2).

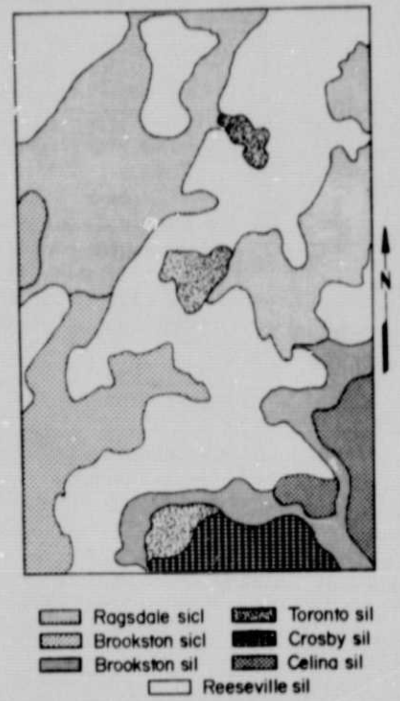

Figure 1. Soil Survey Map of Test Site.

The nonsupervised technique was used in both aircraft and Landsat-2 data analysis. The entire test area of 40 ha from which scanner data were collected by aircraft was subjected to nonsupervised clustering procedures to obtain fourteen spectral or cluster classes using ten wavelength bands. A double number of cluster classes was requested compared to the seven soil types occurring in the standard soil map to avoid later probable incorrect classification by the classify-points algorithm.[2] Since the same test area on the Landsat-2 data is represented by only 88 data points, a much larger area for clustering was used (100 lines by 100 columns).

To make correlation of remotely sensed data with reference easier, the Landsat-2 data were geometrically corrected before they were used.[1] The Landsat-2 data were grouped into 17 clusters using four wavelength bands, in an attempt to represent every type of ground feature. In analysis of both data sources (aircraft and satellite), every second data point from every scan line was grouped into clusters of data having similar spectral characteristics. The means and covariance matrix statistics were obtained for each cluster class.

To enhance observation and to discriminate the different soil boundaries more easily, the statistical data were compressed into a shorter format: magnitude of relative reflected energy and V/IR ratio (the sum of relative reflected energy in the visible portion of the spectrum divided by the sum of relative reflected energy in the reflective IR).

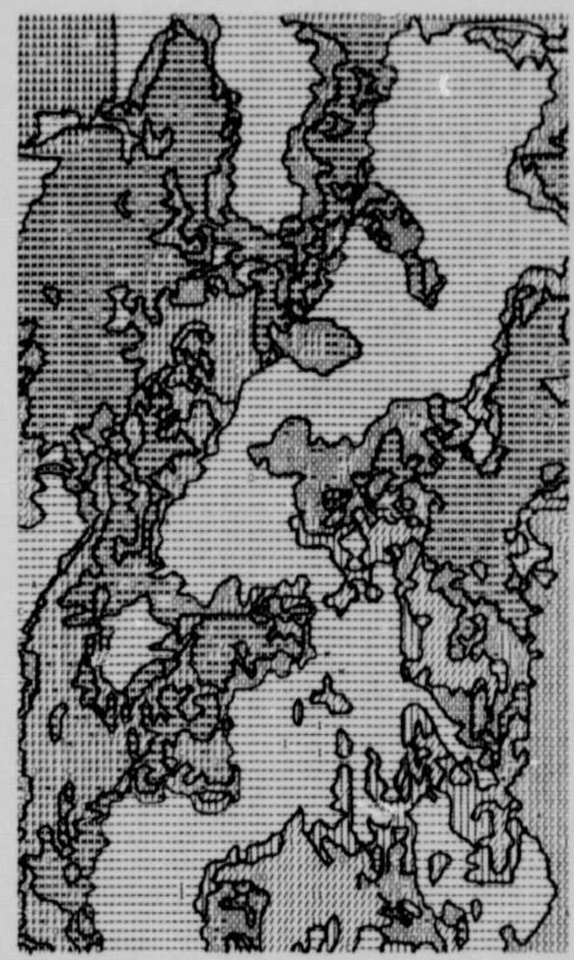

Figure 2. Computer Soil Classification Map of Test Site. Legend: (M) Ragsdale silty clay loam, (F) Brookston silty clay loam, (O) Toronto silt loam, (C) Celina silt loam, (-) Reesville silt loam, (/) Crosby silt loam, (I) Brookston silty loam, (A) vegetation.

Corresponding statistics in the form of magnitude and ratio were assigned to each cluster class. Based on these statistics the

RESULTS and DISCUSSION

The soils were well separated from other non-soil classes of the study site from aircraft and satellite MSS data. The reflectance patterns of soils at various wavelengths are considerably different from all other material on the ground.

Comparing a standard soil survey map of the 40ha test site with a computer-aided supervised map of aircraft MSS data (Figure 2), one can see that the spectral patterns revealed in the computer classification map resembled the general patterns of the soils of the conventionally prepared soil map (Figure 1). Some small areas of Brookston silty clay loam are mapped as Ragsdale soils and vice versa. Light-colored Reeseville soils are mapped very well. Celina and Crosby soils have the same drainage characteristics and similar surface color as Reeseville soils. Toronto and Brookston silt loam mapped by computer-aided techniques are in good agreement with the standard soil survey map. The spatial resolution of the aircraft scanner was adequate to recognize each soil mapping unit in the test site.

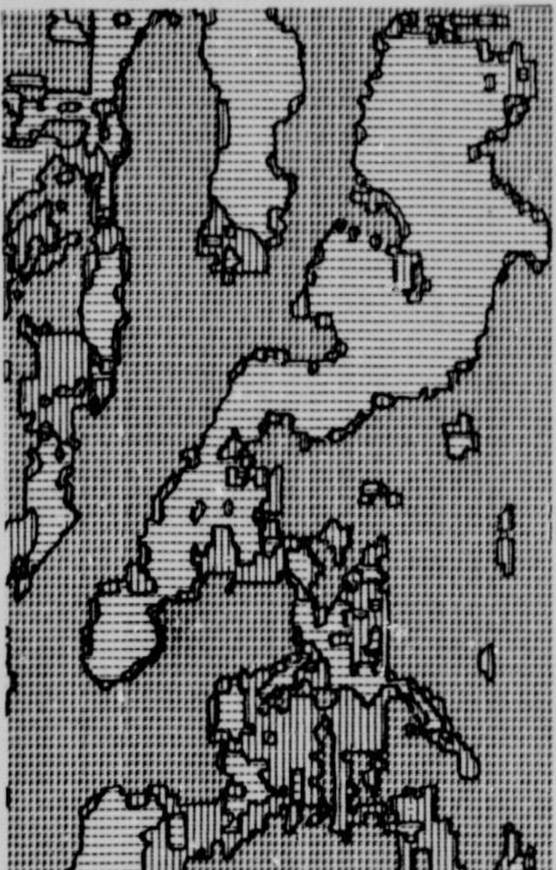

Figure 3. Level 1 computer map of test site from aircraft magnitude data. Legend: - = high magnitude; I = medium magnitude; F = low magnitude.

A hierarchical approach for soil classification was used in both aircraft and LANDSAT data analysis. The general separation of soils in four levels is based only on spectral information, observing the magnitude and ratio between each of the soil cluster classes separately. The soils observed with aircraft scanner data are spectrally divided on Level I into high, medium, and low response soils (Figures 3, 4). Level II is subdivided into high, medium, low, and lowest groups (Figures 5 and 6). Using LANDSAT-2 data, soils of the same area were separated into more levels than with aircraft data. In the first phase, 13 of the 17 cluster classes were identified as bare soil by analysis of Level I statistics. The statistics from the cluster analysis were used in LARSYS merge and clprint processors to produce computer result maps with high, medium, and low soil spectral response (Figures 7 and 8). Fifty of the data points fell into groups of soil with low magnitude and high spectral ratio values. Thirty points were of medium magnitude, and only one data point had high mag-

Figure 4. Level 1 computer map of test site from aircraft ratio data. Legend: - = high ratio; I = medium ratio; F = low ratio.

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hierarchy of soils was established for this investigation (Tables 1,2,3 and 4). Cluster class areas were merged into two levels of aircraft and three levels of Landsat-2 data. Level I is composed of three categories for aircraft and Landsat-2 data. Level II contains seven categories for aircraft and six categories for Landsat-2 data. Level III consists of ten soil categories of Landsat-2 data only.

After clusters were grouped into desired soil categories, the Level I, II and III statistics were used as training statistics for input in the supervised classification approach. An overlaid interpretation technique was used to compare soil categories on photo enlargements made from computer classification maps.

Table 1. Hierarchy Based on Magnitude Developed for Soil Spectral Investigation of Aircraft Data.

	Level I	Level II	Response	NS-Class	Symbols	Code
Non-Vegetated	High 279.87	High A 301.12	323.60	NS-1/14	+	Ha
			278.65	NS-2/14	·	Hb
		High B 258.77	256.04	NS-3/14	-	Hc
			261.50	NS-4/14	=	Hd
	Medium 219.32	Medium A 219.32	218.55	NS-5/14	/	Ma
			220.10	NS-6/14	I	Mb
		Medium B 202.40	198.35	NS-7/14	J	Mc
			206.46	NS-8/14	Z	Md
	Low 173.99	Low A 184.35	191.06	NS-9/14	C	La
			177.65	NS-10/14	O	Lb
		Low B 156.03	164.52	NS-12/14	A	Lc
			147.54	NS-13/14	H	Ld
		Low C 131.15	131.15	NS-14/14	F	Le

Table 2. Hierarchy Based on Ratios Developed for Soil Spectral Investigations of Aircraft Data.

	Level I	Level II	Response	NS-Class	Symbols	Code
Non-Vegetated	High 1.38	High A 1.46	1.46	NS-4/14	+	Ha
		High B 1.36	1.33	NS-1/14	·	Hb
			1.38	NS-5/14	-	Hc
			1.37	NS-7/14	=	Hd
	Medium 1.27	Medium A 1.29	1.30	NS-2/14	/	Ma
			1.29	NS-3/14	I	Mb
		Medium B 1.26	1.26	NS-6/14	J	Mc
			1.26	NS-9/14	Z	Md
			1.27	NS-10/14	C	Me
	Low 1.18	Low A 1.24	1.24	NS-8/14	O	La
			1.25	NS-12/14	A	Lb
		Low B 1.21	1.21	NS-13/14	H	Lc
		Low C 1.03	1.03	NS-14/14	F	Ld

Table 3. Hierarchy Based on Magnitude Developed for Soil Spectral Investigations of Landsat-2 Data.

	Level I	Level II	Level III	Response	NS-Class	Symbols	Code
Non-Vegetated	High 132.86	High A 143.96	High A 143.96	155.03	NS-1/17	+	Ha
				137.72	NS-3/17	·	Hc
		High B 122.92	High B 122.92	122.92	NS-5/17	-	Hb
	Medium 108.30	Medium A 113.46	Medium C 113.46	133.66	NS-7/17	=	Mc
			Medium D 113.13	113.13	NS-8/17	/	Md
		Medium B 104.47	Medium E 105.02	105.02	NS-9/17	I	Me
			Medium F 103.44	103.44	NS-11/17	J	Mf
	Low 88.58	Low A 96.57	Low C 97.11	97.11	NS-14/17	Z	Lc
			Low D 96.03	96.03	NS-12/17	C	Ld
		Low B 83.80	Low E 86.06	89.80	NS-15/17	O	Le
				86.73	NS-13/17	A	Lg
				82.14	NS-16/17	H	Lh
			Low F 71.30	71.30	NS-17/17	F	Lf

Table 4. Hierarchy Based on Ratios Developed for Soil Spectral Investigations of Landsat-2 Data.

	Level 1	Level II	Level III		Response	NS-Class	Symbols	Code
Non-Vegetated	High (1.52)	High A 1.74	High A 1.74	High A	1.74	NS-17/17	-	Ha
		High B 1.45	High B 1.45	High B	1.51	NS-14/17	/	Hb
				High C	1.44	NS-14/17	·	Hc
				High D	1.40	NS-16/17	+	Hd
	Medium (1.30)	Medium A 1.33	Medium C 1.35	Medium C	1.35	NS-7/17	L	Mc
			Medium D 1.33	Medium D	1.33	NS-9/17	[illegible]	Md
			Medium E 1.31	Medium E	1.31	NS-5/17	O	Me
		Medium B 1.26	Medium F 1.28	Medium F	1.27	NS-3/17	J	Mf
			Medium G 1.24	Medium G	1.24	NS-13/17	I	Mg
	Low (1.16)	Low A 1.19	Low C 1.20	Low C	1.20	NS-1/17	8	Lc
			Low D 1.19	Low D	1.19	NS-12/17	A	Ld
		Low B 1.13	Low B 1.13	Low E	1.15	NS-8/17	4	Le
				Low F	1.12	NS-11/17	F	Lf

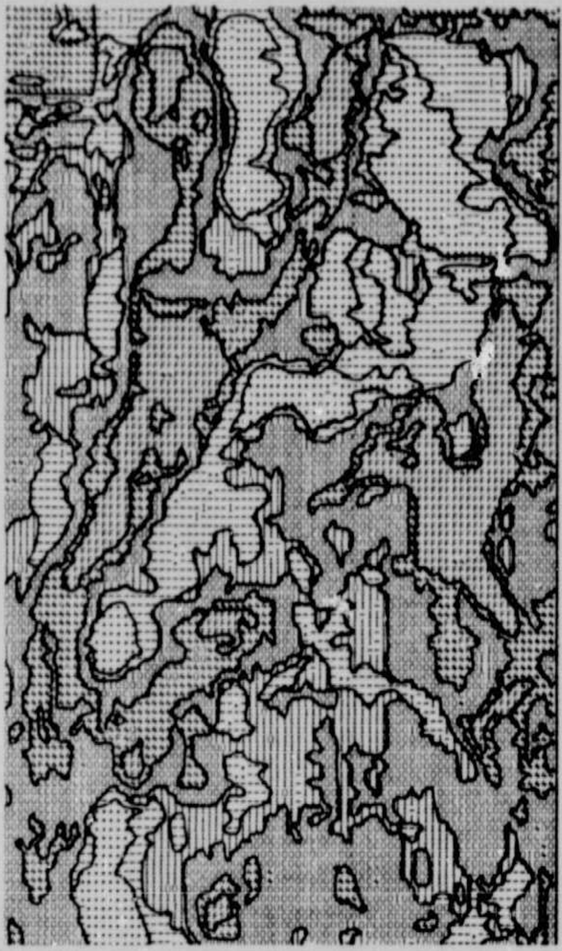

Figure 5. Level 2 computer map of test site from aircraft magnitude data. Legend: · = high magnitude; - = medium magnitude; 0 = low magnitude; 4 = lower magnitude; F = lowest magnitude.

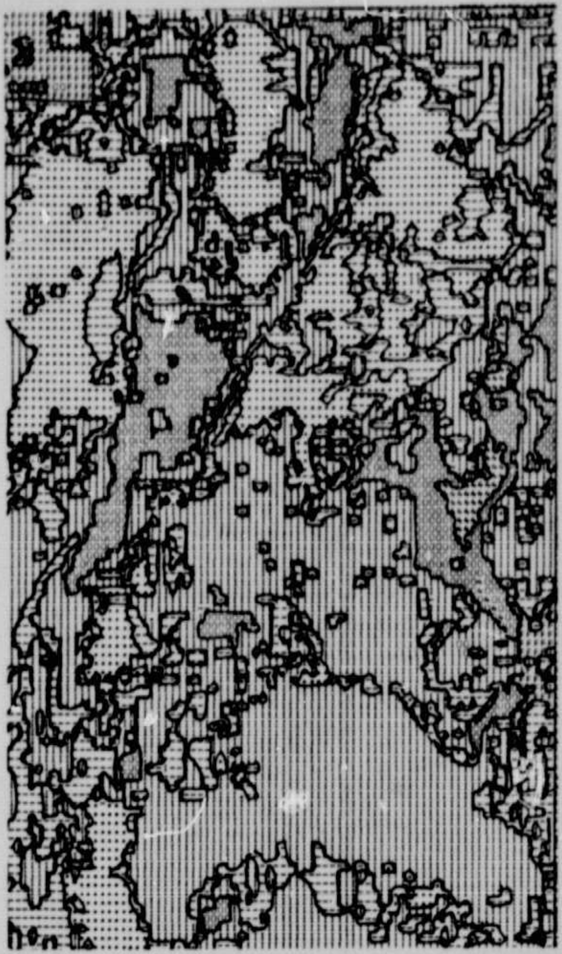

Figure 6. Level 2 computer map of test site from aircraft ratio data. Legend: · = high ratio; I = medium ratio; 0 = low ratio; 4 = lower ratio; F = lowest ratio.

nitude value. Figures 9 and 10 show Level II classifications with five soil sub-groups in which separation is based on spectral response in the form of magnitude and ratio between visible and reflective IR portions of the spectrum. Again, the majority of the data points went into two classes of low, and less into medium and high reflective soils. A more detailed spectral differentiation of the soils is obtained in Level III where the soil test area is broken down into eleven spectral groups (Figures 11 and 12).

In order to achieve greater spectral contrast, the study area was extended and more cluster classes were introduced in the analysis of the Landsat data. This procedure contributed very little in separating the two low reflective soils, namely Ragsdale and Brookston silty clay loams. This may be expected, because the Brookston soil series consists of very poorly drained, nearly level soils with a very dark gray surface, while the Ragsdale soil series consists of deep, dark-colored, poorly drained soils with a black silty clay loam surface layer. To obtain a better separation of the soil series, 21 samples of dark-colored soils were evaluated with two data points per sample and 16 samples of medium and light-colored were evaluated with two data points each. The samples were sorted into an array from lowest to highest spectral response levels. The samples were grouped into eight spectral classes based on magnitude of reflectance and reflectance ratio. These classes were used as reference classes in machine-aided classification. The automated LANDSAT classification map (Figure 13) was compared with an aircraft classification map. This comparison revealed that the large and homogeneous areas of soils could be delineated from LANDSAT-2 data. Small mapping areas are merged together in larger LANDSAT classification areas, or they are added to areas with similar spectral proper-

```
MOFFFOFF
OOFFFOOF
OFFFFOFF
FFFOOOFF
OFOOFFFF
OFFOFFFO
FFFOOFFO
OFFO-OFF
OFOOOFFF
FOFOOOFF
FOOOOOFF
```

Figure 7. Level 1 computer map of test site from Landsat magnitude data. Legend: M = farmstead; - = high magnitude; 0 = medium magnitude; F = low magnitude.

```
MF---O-F
OO---OO-
O--F-O-O
---OOO--
O-OO----
O--O---F
---OO--F
O--OOO--
O-OOO---
-O-OOO--
-OOOOO-F
```

Figure 8. Level 1 computer map of test site from Landsat ratio data. Legend: M = farmstead; - = high ratio; 0 = medium ratio; F - low ratio.

ties. The spatial resolution of the satellite scanner system is such that is is not adequate for delineation of soil mapping units with an extension of only a few hectares.

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MOF44044
0I444I04
I4444I4F
4FFI0IFF
IFII4FFF
04404FFI
4440044I
I4FI/04F
04III444
404I0I4F
4I0III44
```

Figure 9. Level 2 computer map of test site from Landsat magnitude data. Legend: M = farmstead; / = high magnitude; I = medium magnitude; 0 = low magnitude; 4 = lower magnitude; F = lowest magnitude.

```
MF///0/4
00///00/
0//4/0/I
///000//
0/00//-/
0//0///F
///00//F
0//000//
0/000///
/0/000//
/00000/4
```

Figure 10. Level 2 computer map of test site from Landsat ratio data. Legend: M = farmstead; - = high ratio; / = medium ratio; 0 = low ratio; 4 = lower ratio; F = lowest ratio.

```
M/AOO=OZ
=IOOOI=O
IOOZOIOC
OAAI=IAH
IAIIOAFA
=OO=OHAJ
OOO==OOJ
IOAI-=OA
=OIIIOOO
O=OI=IOA
OI=IIIOZ
```

```
M4.//L/A
L7///ZL/
Z//A/Z/I
/..ZLZ.+
Z.ZZ/.-.
L//L/+.F
///LL//F
Z/.ZOL/.
L/ZZZ///
/L/ZLZ/.
/ZLZZZ/A
```

Figure 11. Level 3 computer map of test site from Landsat magnitude data. Legend: M = farmstead; - = highest magnitude; / = high A magnitude; = = high B magnitude; I = medium A magnitude; J = medium B magnitude; O = low A magnitude; Z = low B magnitude; A = low C magnitude; C = low D magnitude; H = low E magnitude; F = low F magnitude.

Figure 12. Level 3 computer map of test site from Landsat ratio data. Legend: M = farmstead; - = highest A ratio; + = highest B ratio; · = high A ratio; / = high B ratio; L = medium A ratio; Z = medium B ratio; O = medium C ratio; I = medium E ratio; A = low B ratio; 4 = low C ratio; F = low D ratio.

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M88ZZ=F8
8I0Z0/Z0
I4000I0Z
4FZI=I44
IFIIZFFF
=F4=88Z/
4Z4==ZZ/
Z80===Z8
Z8IIIFZZ
F=4I=Z88
F==/=I88
```

Figure 13. Computer map of test site from LANDSAT data related to standard soil map. Legend: =,/,I=Reeseville silt loam; 8=Crosby silt loam; 0,F=Ragsdale silty clay loam; 4=Brookston silty clay loam; Z=Brookston silt loam.

CONCLUSIONS

Computer-aided analysis techniques used with aircraft MSS data showed that the spatial resolution was sufficient to recognize each soil mapping unit of the test site. Some difficulties occurred where different soil series were intricately mixed and this mixture showed as a separate spectral mapping unit, or where the difference between two soils depended on the depth of silty surface material.

Analysis of LANDSAT data with computer-aided techniques showed that it was not possible to find spectrally homogeneous soil features of the seven soil series on the 40ha test site on the digital display or on a picture-print map. On the other hand, clustering techniques could be used on an extended test area to group spectrally similar data points into cluster classes. Cluster class statistics in the form of magnitude and ratio serve as a basis for grouping. The level classes are then related to the soil patterns. In some cases the LANDSAT MSS data were not adequate for resolving soil features with widths less than that of the scanner system's spatial resolution (approximately 70m). Those soil patterns which were broad enough to exceed the spatial resolution of the LANDSAT scanner were delineated very well by spectral analysis.

Typically, the total field of view increases as the altitude of the data collection system increases. However, image resolution decreases as altitude increases, so there is less detail available from high altitudes. Advantages and disadvantages of both high and low resolution scanner systems must be taken into account if computer-aided analysis techniques are to be used as a basis for soil survey.

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